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Vulnerability map to hydro-geomorphological processes (Romanian Plain)

Florina GRECU, Cristina GHIȚĂ, Marius BUDILEANU

Abstract. The map of vulnerability to hydrogeomorphological processes occurring in the plain landforms (plain units) is a synthetic map emphasizing the present state of topographic relief evolution, the trend of change of hydrogeomorphological systems and the evolution of man-environment relationships. Being a synthetic cartographic representation, it relies on analytical maps, developed on the base of quantitative indexes. The paper aims to analyze the main factors that determine the vulnerability of the study area (Mostiștea catchment). For the Romanian Plain, where quasi-horizontal interfluvies and shallow channels are widespread, the assessment of vulnerability to hydrogeomorphological hazards relied both on common and on specific criteria for the two major landform units. In order to assess some of the landscape features several morphometric indexes were computed with regard to the almost flat surfaces to the channels of the rivers capable of flooding the adjacent plains, and to the channel processes. Subsequently, analytical maps were prepared based on the obtained values. By employing GIS techniques, we finally came up with two synthetic vulnerability maps, one for the interfluvies and the other one for the river channels.

Keywords: vulnerability, hydrogeomorphological hazard, rivers, flat interfluvies, Romanian Plain.

1. Introduction, objectives and study area

The map of vulnerability to hydrogeomorphological processes of the floodplains emphasizes not only the present state of relief dynamics and the trend of change of hydrogeomorphological systems, but also the evolution of man-environment relationships. Being this a synthetic cartographic representation, it relies on previously developed analytical maps. The detailed working methodology may further be completed based on the results of field investigations and map analysis (Grecu, 1997; Grecu & Cruceru, 2001). The first stage of the investigation consisted in a detailed assessment of the factors influencing relief dynamics, as well as in the analysis of morpho dynamic potential and geomorphological processes. The synthetic approach implies the regionalization of morphodynamic factors and geomorphological processes, followed by the comparison of the results with the mappings done in the field, as a preliminary stage in the preparing of vulnerability map (Grecu 1997 a, b; Armaș, 2006; Driga & Surdeanu, 2007; Furlan et al., 2010; Mukesh & Venerando, 2010; Rusu, 2007).

This method was tested on selected areas in the Romanian Plain, a Quaternary physiographic division, formed within a former sedimentary basin, which long ago was lying inside the Carpathian-Balkan arch (Vîlsan, 1916). These territories are part of the Mostiștea Plain, which is situated in the eastern section of the Romanian Plain, east of the Arges River (Fig. 1). Here, the Upper Pleistocene deposits, which are responsible for the formation and dynamics of micro-landforms, overlie the Mostiștea sands (Grecu et. al., 2009; Grecu, 2010; Geografia României, 2005).

In order to assess some of the landscape features several morphometric indexes were computed with regard to the quasi-horizontal surfaces (vulnerable to compaction, piping, salting, salinization or waterlogging), to the channels of the rivers capable of flooding the adjacent territories, and to the channel processes (lateral erosion, meandering, caving-ins of the riverbanks and sedimentation within the channels) (Grecu et. al., 2010). In the plain regions, the hazards affecting the interfluvies and those affecting the channels have distinct genesis and dynamics, hence the necessity to make the respective vulnerability maps based on specific criteria.

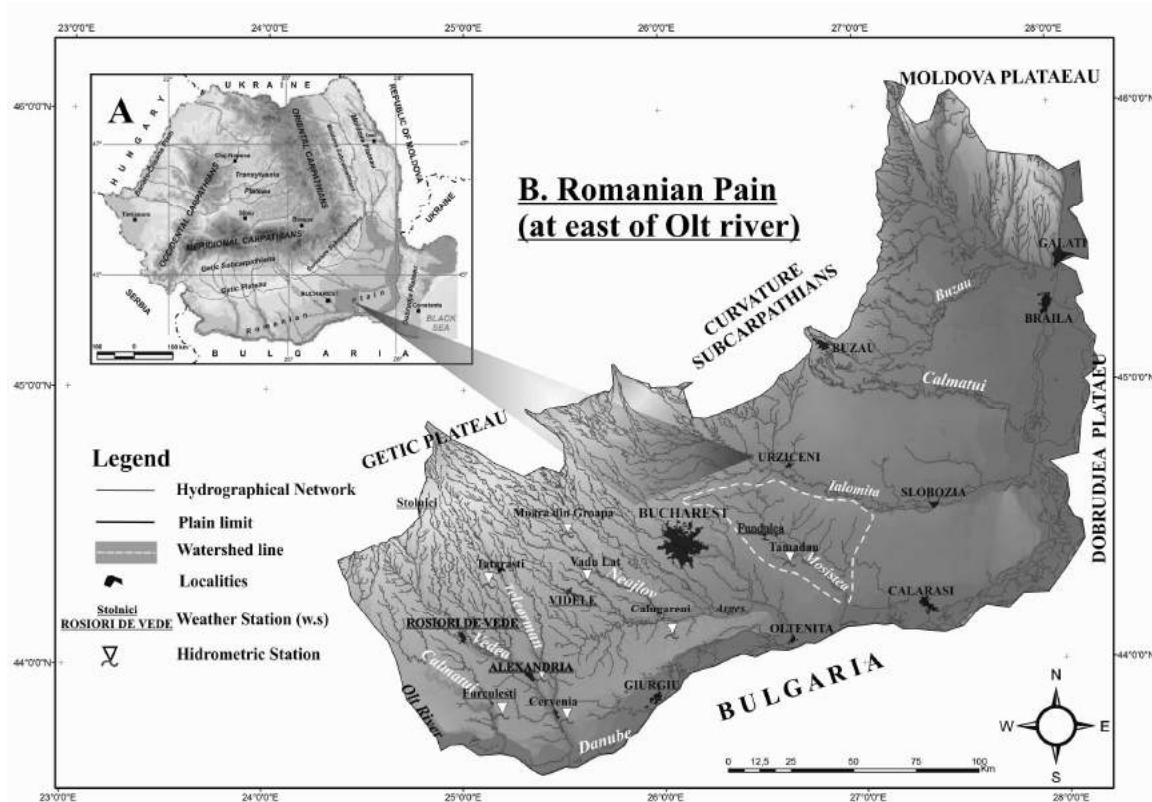


Fig. 1. Location map (Mostiștea catchment/Romanian Plain)

2. Support and data

- Topographic maps of scales 1:50000, 1:25000, and topographic plans of scale 1:5000;
- Thematic maps: geological, climatic, hydrogeological, pedological;
- Satellite imagery LANDSAT ETM+ 2005, natural color image;
- Orthophotos of scale 1:5000 (2005) for channel-mapping processes (step-banks);
- DEM, constructed on the basis of contour lines and elevations by means of kriging interpolation method at 30 m resolution. The digital model of slope gradients is derived from the DEM;
- Normative regarding the foundation of constructions on collapsible grounds sensitive to damping, Technical University of Constructions, Bucharest, 2008;
- SRTM, (Shuttle Radar Topography Mission) and CORINE LAND COVER data (Coordination of information on the environment), used for the analysis of land use.

The maps were georeferenced in Stereo 1970 system, which is based on the Dealu Piscului Datum (EPSG 31700). They served as a base map for the digitization of contours, elevations and perennial and ephemeral streams.

3. Method

There are several methods allowing the developing of vulnerability map, but each of them must necessarily take into account the geographical and geological features of the study area, which derive from the geographical location of the territory. The present study deals with a plain unit quite homogeneous from the geological and climatic points of view.

Unlike the classic method of analyzing land vulnerability (based on the arithmetic mean of the features shown by the thematic maps taken into account), our approach was somehow different. Thus, in order to assess the vulnerability to geomorphological processes of the interfluvial area (IV) we employed the multiplied sum of selected attributes extracted from various types of maps:

$$IV (\text{interfluvial vulnerability}) = (C+S)/\text{km}^2 \times CL$$

where C is the density map of loess sinkholes, S is the map showing the soils specific for subsidence depressions (phreatic wet soils, sinkhole soils, settling depression soils) and CL is the map of collapsible loesses (deposits sagging under self-weight when become wet).

The values of the density of loess sinkholes were reclassified by assigning them points from 1 to 6, while the areas with different types of collapsible rocks were given values from 7 to 9 points. In order

to establish the intervals with different degrees of vulnerability we multiplied the reclassified values and we obtained six categories of vulnerability to field hydrogeomorphological processes (especially sagging and piping), as follows: stable land (less

than 14 points), low vulnerability (14.1 – 16 points), medium vulnerability (16.1 – 21), high vulnerability (21.1 – 32) and very high vulnerability (32.1 – 54). The IV (interfluvial vulnerability) map has a scale of 1:25000 (Table 1).

Table 1. Index classification on categories of vulnerability for the interfluvial areas

Sinkhole density/kmp	After reclassification	Loess	After reclassification	Obtain values
0	1			>14 stable land
0.9-3	2	collapse A ₁ (<5 cm) initial value 2	7	14-16 low vulnerability
3.1-5	3	collapse B ₁ (5-40 cm) >initial value 3	8	16.1 - 21 medium vulnerability
5.1-7	4	collapse B ₂ (>40 cm) initial value 4	9	21.1 - 32 high vulnerability
7.1-9	5			32.1 - 54 very high vulnerability
9.1-12	6			

In order to assess the vulnerability along the river courses (FV) we took into account the multiplied attributes of the following thematic maps:

$$FV (\text{fluvial vulnerability}) = (D \times E) \times (S \times SB)$$

where *D* is the drainage density, *E* is the relative relief, *S* is the slope and *SB* refers to the steep banks.

In order to create the vulnerability map to hydrogeomorphological processes of the areas lying along the river courses the product obtained by

multiplying the attributes of quantitative maps (drainage density map and relative relief map) (Fig. 2) by those of qualitative ones (stretches with steep banks) (Fig. 3) was correlated with the land use map. A particular attention was paid to the position of settlements within the channels and to the distance separating them from the river. Thus, the following five categories of vulnerability to the channel hydrogeomorphological processes were obtained: stable land (less than 6 points), low vulnerability (6.1 – 12), medium vulnerability (12.1 – 21), high vulnerability (21.1 – 32) and very high vulnerability (32.1 – 45) (Table 2).

Table 2. Index classification on categories of fluvial vulnerability

Density value km/kmp	After reclassification	Local relief value (m)	Ater reclassification	density X local relief	Vulnerability classes
0-3	2	0-5	7	14-18	stable courses
3.01-6	3	5.01-12	8	18.01-24	low
6.01-9	4	12.01-19	9	24.01-33	medium
9.01-12	5	19.01-29	10	33.01-45	high
12.01-17	6	29.01-42	11	45.01-60	very high

4. The vulnerability map

4.1. The vulnerability map to interfluvial processes

Judging from the geomorphological processes specific for the flat interfluvies of the Mostitea catchment the most important variables that might influence the occurrence and distribution of loess sinkholes are the following: land morphology and

geomorphological processes, sinkhole morphometry (density, circularity ratio, elongation ratio, shape factor and sinuosity index); soil conditions (soil type); physical, mechanical and chemical properties of the loess formations; thickness of loess deposits; depth of water table (Liteanu, 1969); digital elevation model; digital model of slope gradients, derived from the DEM; land use (Corine Land Cover, 2000).

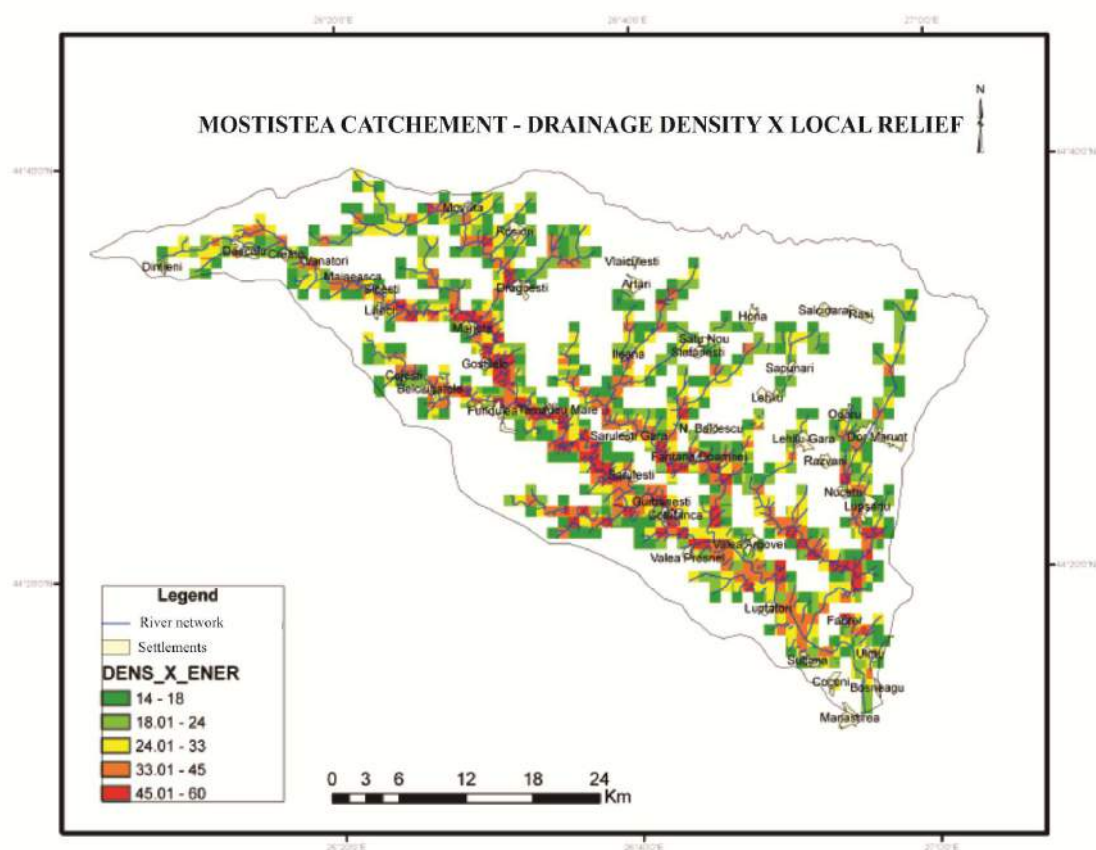


Fig. 2. Drainage density X local relief

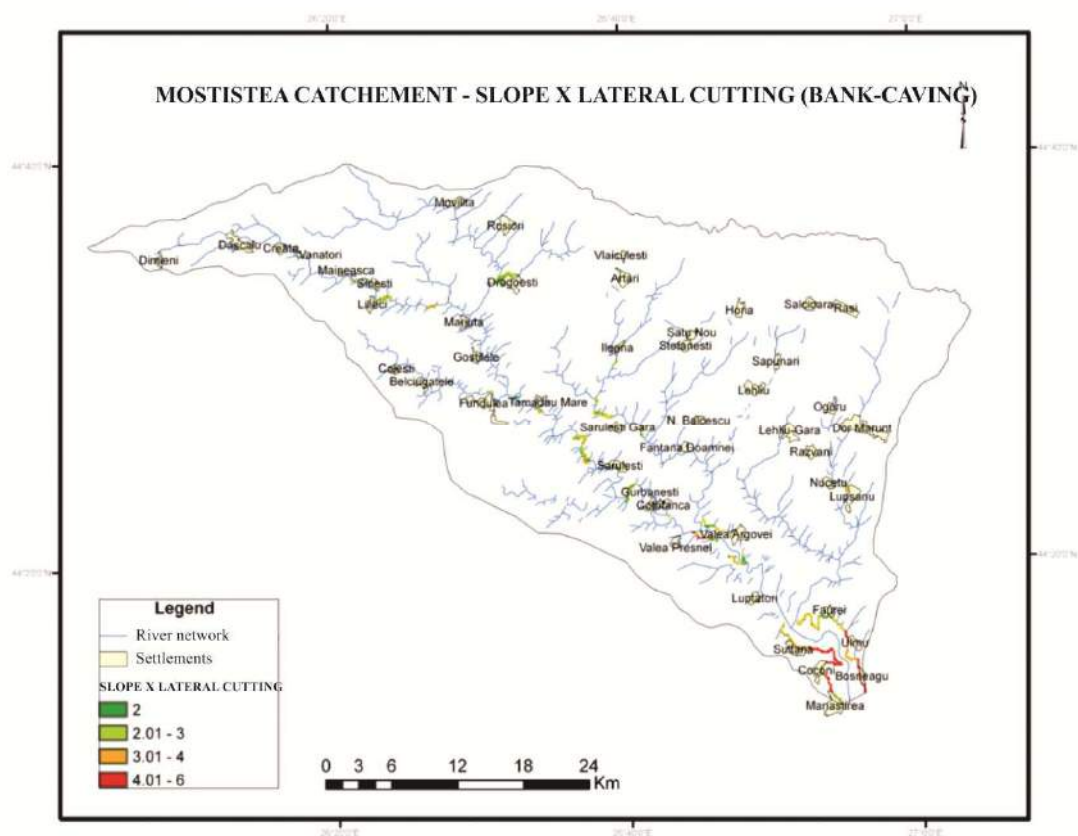


Fig. 3. Slope X lateral cutting

Land morphology and geomorphological processes. The geomorphological processes specific for the interfluvial areas lying within the Mostiștea catchment are sagging and tunnel erosion, which sometimes are accelerated by human impact (Figure 2). Sagging is more active in endorheic and semi-endorheic areas (e.g. the Ciornuleasa flatland), while tunnel erosion is more common near the valleys (Coteț, 1976). The resulted landforms are represented especially by loess sinkholes.

Loess sinkholes have the highest density on the Ciornuleasa flatland and on the third terrace of the Danube, where the high thickness of loessoid deposits and the deep water table have encouraged the appearance of some small (10 m² to 3.3 km²) and rather circular depressions (low sinuosity coefficient) (Grecu et al. 2006). In the northern part of the catchment and on the Ialomița – Mostiștea interfluvium, loess sinkholes have a lower density, but their area is larger and sinuosity coefficient is high.

In order to establish as precisely as possible the vulnerability to hydrogeomorphological processes, the sagging areas identified on topographic maps and orthophotoplans were correlated with the distribution of typical phreatic-wet chernozems, levigated chernozems (weakly eluviated) affected by pseudogleyization phenomena (found in loess sinkholes and sagging areas), phreatic-wet cambic chernozems and phreatic-wet, levigated vertic chernozems, affected by gleyization.

In the Mostiștea catchment, three areas with collapsible loess formations have been identified based on the values of an index that evaluates wet loess compaction under self-weight (I_{mg}) (according to the *Normative regarding the foundation of constructions on collapsible grounds sensitive to damping*, Technical University of Constructions, Bucharest, 2008). In order to assess supplementary sagging, other indexes were taken into account: granulometry, chemical-mineralogical composition, thickness of loessoid deposit, plasticity, shear resistance under natural and flooded conditions, sagging, volumetric weight, skeletal density and so on.

According to how these soils behave when become wet, they can be classified as follows:

- Group A: soils that experience a supplementary sagging (I_{mg}) less than 5 cm;
 - A₁ – with continuous spread (in the Mostiștea Plain);
 - A₂ – with discontinuous spread (in the central section, and especially on the terraces of the Olt and the Danube);
- Group B: soils that experience a supplementary sagging (I_{mg}) equal with or higher than 5 cm.

B₁ – with $I_{mg} = 5 - 40$ cm

B₂ – with $I_{mg} =$ higher than 40 cm

In these areas, loess formations sagging under self-weight when moisture increases have the following indexes: $I_{mg} < 5$ cm (collapse A₁) (value 7- the lowest after reclassification); I_{mg} ranging from 5 to 40 cm – value 8 after reclassification) (**collapse B₁**); and $I_{mg} > 40$ cm (**collapse B₂**) (value 9 after reclassification).

Depending on the compaction rate under self-weight, values were assigned to each soil category so that to obtain results as reliable as possible in the aftermath of their multiplication by the values referring to the density of loess sinkholes. In this way, five classes of values were established, from stable lands to highly vulnerable ones.

The vulnerability map of interfluvial areas lying within the Mostiștea catchment mirrors the existence of some sections with high and very high vulnerability to sagging and tunnel erosion (Fig. 4). All in all, they total about 4% of the catchment's area lying on the Argeș-Mostiștea interfluvium (on the southwest of the basin – plain unit known as Ciornuleasa flat land). The sagging areas have developed on loessoid deposits, 15 – 30 cm thick, which when wet experience supplementary sagging under self-weight, with I_{mg} values higher than 40 cm (collapsible loesses B₁). Here, the bad conditions for surface flow (endorheic and semi-endorheic areas) and the high depth of water table (30 m and even more) have conditioned the appearance and development of underground erosion phenomena. The stable lands and those with low vulnerability to geomorphological processes are found in the north of the catchment and on the Mostiștea – Ialomița interfluvium (accounting for 60% of the area). On these territories, collapsible deposits with supplementary sagging values less than 5 cm (collapse A₁) or less than 40 cm (collapse B₁) prevail. Here, the typical loess is 10 to 15 cm thick and the water table lies between 5 and 10 m deep, which explains the low density of sagging areas.

4.2. Land vulnerability map to fluvial processes

As far as the channels are concerned, their dynamics is strongly influenced by the relative altitude, the drainage density, the presence of stretches with steep banks, the banks' gradients and the distance to the nearest settlement or built-up area.

- Relative altitude – ranges from 90 to 11 m. It encourages the meandering processes, but it also explains the existence of some stretches

where lateral erosion is active and riverbank retreat is a common phenomenon.

- The drainage density – the values were reclassified through raster multiplication (density multiplied by energy) resulting six classes of vulnerability (from stable lands to highly vulnerable areas).
- The presence of stretches with steep banks – stretches of steep-sided valleys were identified and mapped in the field. Subsequently, they were multiplied by the gradients of the river thalwegs. By doing this, we identified the stretches with high and very high vulnerability lying along the middle (Sărulești and Valea Argovei) and lower course (Lake Mostiștea) of the Mostiștea River.
- The banks' gradients – several stretches with steep banks were identified and mapped.
- The distance to the nearest settlement or built-up area.

The mapped valley stretches affected by erosion processes were correlated with the gradient values and thus a vulnerability map to the valley processes came into existence. In order to highlight as accurately as possible the stretches vulnerable to the channel processes these two products were in their turn multiplied and the result was the vulnerability map to river processes (Fig. 5).

From the analysis of vulnerability map, we were able to conclude that stable lands and the areas with low and medium vulnerability are prevalent (92.68%). However, at Sărulești, Gurbănești, Valea Argovei and around Lake Mostiștea, the risk induced by channel processes is high (detachments, collapses and lateral erosion). Consequently, the built-up areas (settlements) and the agricultural lands stretching along the river's middle and lower course are prone to degradation expressed through riverbank retreat.

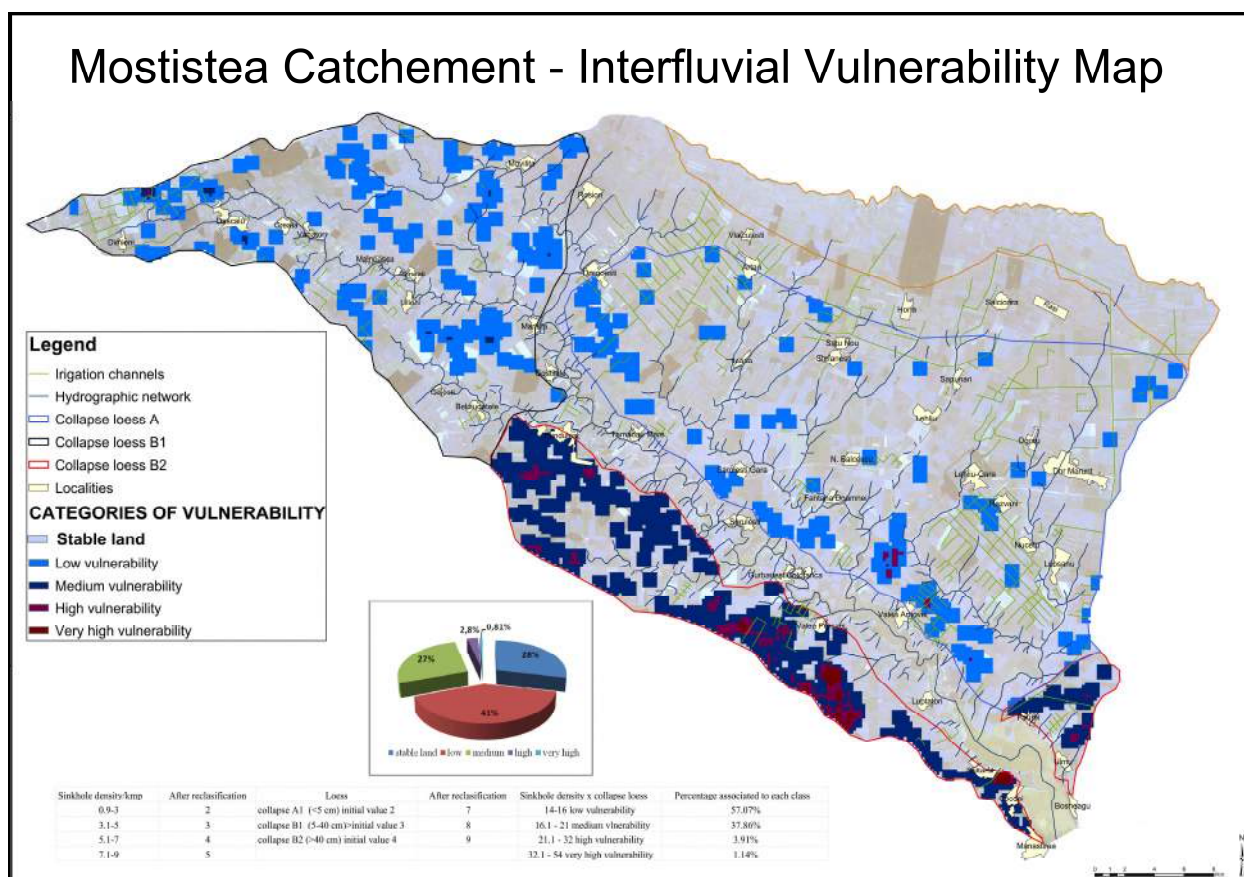


Fig. 4. Interfluvial vulnerability map

Table 3. Categories of vulnerability

Interfluvial vulnerability	Fluvial vulnerability (percentage calculated only to affected area)
>14 stable land = 28.6%	> 6 stable courses
14-16 low = 40.75%	6 - 12 low = 98.28%
16.1 - 21 medium = 27 %	12.1 - 21 medium = 0.40%
21.1 - 32 high = 2.8%	21.1 - 32 high = 0.89%
32.1 - 54 very high = 0.81%	32.1 - 45 very high = 0.46%

Mostistea Catchement - Fluvial Vulnerability Map

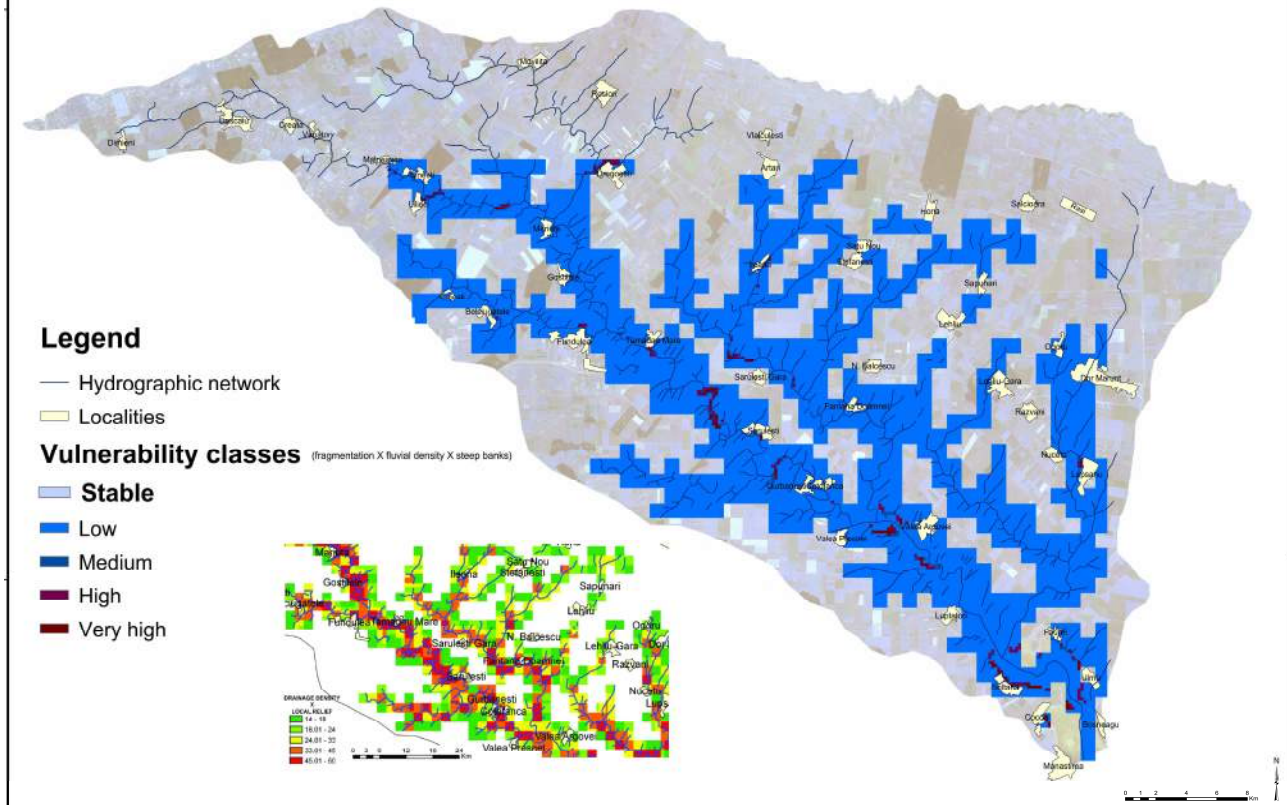


Fig. 5. Fluvial vulnerability map

5. Conclusions

The plain areas in general and the Romanian Plain in particular, are difficult to decipher from the geomorphological point of view. However, field investigations and the employment of proper study methods lead to pertinent conclusions regarding the lowlands hydrogeomorphological dynamics, which are very useful for human society.

The development of the vulnerability map is based on quantitative analysis undertaken at different moments in time. Thus, the outcome is a qualitative map, which allows an easier comparison of the areas exposed to different types of processes. In the Romanian Plain, there have been identified the following vulnerable areas:

- on the interfluvies: the areas affected by piping, compaction and aeolian processes;

- within the channels: areas prone to lateral cutting and bank-caving;
- along the rivers: vulnerability is higher due to the joining of the interfluvial and channel processes, but also to the development of economic activities.

The analysis of vulnerability to hydrogeomorphological processes is important for the proper management of the associated risks.

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Extension urbaine et risque d'inondation autour de l'extrémité septentrionale du Jebel Bou Garnine (Grand Tunis – Tunisie)

Noômène FEHRI

Résumé. Hammam-Lif et Ezzahra, deux parmi les principales communes de la banlieue sud de Tunis, ont connu tout au long de la deuxième moitié du siècle passé jusqu'à nos jours une remarquable extension urbaine qui s'est traduite par la création depuis 1991 de deux communes nouvelles : Hammam-Chatt et Bou M'hal-Bassatine. Mais, cette urbanisation s'est faite dans beaucoup de cas dans des zones inondables. En effet, les grands événements pluviométriques des dernières années (septembre 2003, octobre 2007, avril et septembre 2009) et les débordements plus ou moins gênants qu'ils ont engendrés ont fait surgir les nombreuses erreurs d'aménagement du territoire commises dans ces communes. Et l'on s'est aperçu, une fois de plus, que l'extension urbaine dans bon nombre de nos villes n'a pas toujours respecté les cours d'eau. Outre l'examen du cadre morpho-hydrologique contraignant dans lequel cette extension s'est faite, cette étude essaye de montrer que les erreurs d'aménagement et l'augmentation des enjeux en zones inondables jouent un rôle déterminant en termes d'aggravation du risque hydrologique.

Mots-Clés : Banlieue-sud, extension urbaine, forêt de Bou Garnine, vulnérabilité au risque d'inondation.

1. Introduction

Au pied du Jebel Bou Garnine, qui constitue l'extrémité nord-est de la Dorsale tunisienne, s'étendent quatre parmi les principales communes qui forment la banlieue sud du Grand Tunis (Fig. 1). A l'est et au nord-est de ce jebel, les communes de Hammam-Lif et Hammam-Chatt se sont étalées sur une étroite plaine littorale dont la largeur n'excède guère 1 à 1,5 km. L'habitat y est très dense et se poursuit de façon pratiquement ininterrompue jusqu'à Borj Cedria. Les sols y ont été alors presque totalement imperméabilisés favorisant ainsi le ruissellement. Lors des pluies intenses, une telle situation s'avère d'autant plus gênante que cette frange côtière est également traversée par deux axes de communication, parmi les plus stratégiques du pays. Il s'agit en l'occurrence de la GP1 et de la voie ferrée qui part de Tunis vers le Sud. Les deux font barrage aux écoulements qui drainent les versants est dudit jebel provoquant ainsi des débordements de plus en plus fréquents qui ont, à maintes reprises, paralysé la circulation automobile et piétonne.

Au nord du Bou Garnine, la commune d'Ezzahra (ex-St. Germain) s'est élargie essentiellement vers l'ouest et le nord-ouest sur les terres basses et très

faiblement inclinées du Bas Miliane. Plusieurs quartiers appartenant à cette commune sont actuellement confrontés à de sérieux problèmes de drainage des eaux pluviales.

Forte de son importante réserve foncière, la jeune commune Bou M'hal-Bassatine est en train de s'étaler sur les piémonts nord-ouest de cet ensemble montagneux. Ainsi, entre 1994 et 2004, elle a plus que doublé son parc immobilier puisque le nombre de logements y a augmenté de plus de 127%. Là aussi, l'extension rapide du bâti et le développement du réseau routier sont en train de modifier le comportement hydrologique des cours d'eau comme l'attestent les nombreux débordements qui s'y sont produits au cours des dernières années.

La partie montagneuse de cette zone est caractérisée par un couvert végétal forestier relativement dense. Cependant, ses caractéristiques morpho-lithologiques sont plutôt favorables à la concentration rapide des écoulements. On s'attellera dans ce qui suit à démontrer que, dans un tel contexte, l'urbanisation à outrance des plaines environnantes et les multiples imprudences commises lors des opérations d'aménagement ont incontestablement accru la vulnérabilité de la zone face au risque d'inondation.

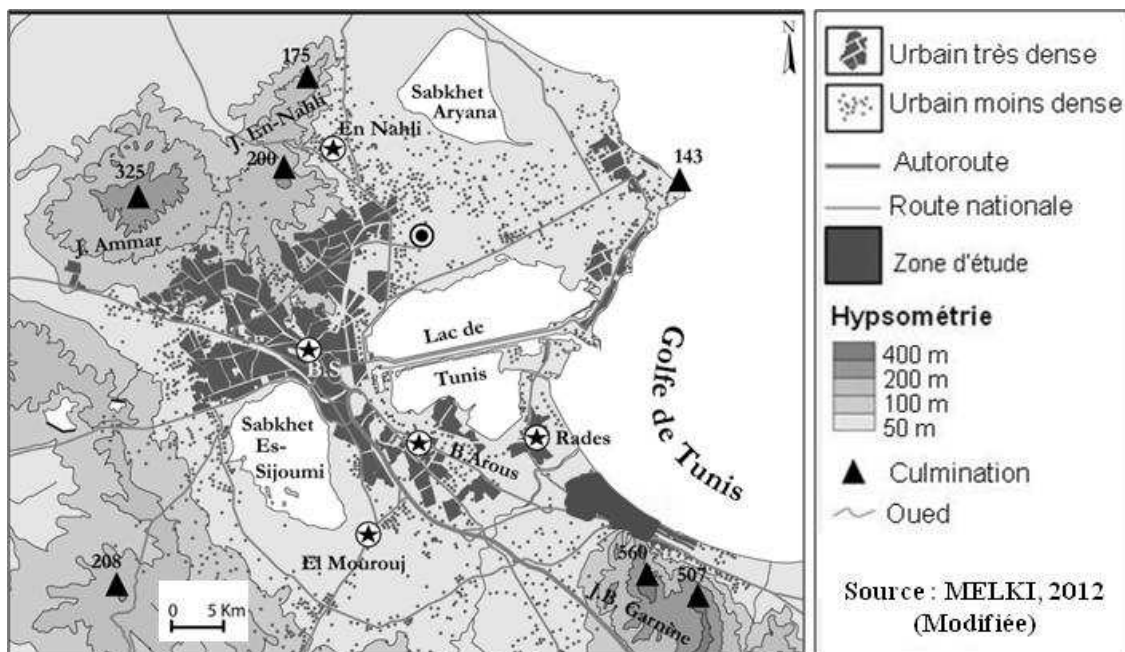


Fig. 1. Localisation de la zone d'étude

2. Contraintes et atouts du milieu biophysique

2.1. Un cadre morphostructural plutôt contraignant

2.1.1. Un secteur dominé par des jebels aux versants raides avec une lithologie favorable au ruissellement

Le secteur étudié est prédominé par un relief montagneux aux pentes assez fortes (Fig. 2 et 3). Le Jebel Bou Garnine culmine à 576 m. Il correspond au dernier pointement résistant du grand anticlinorium El-Messela-Ressas-Bou Garnine (Karray, 1977). Il est formé essentiellement de

calcaires et de dolomies jurassiques qui ont un comportement extrusif car ils sont intercalés entre des couches plus ou moins plastiques : les dépôts gypseux du Trias à la base et les marnes calcaires du Crétacé au sommet. Bou Garnine serait donc un noyau perçant ayant giclé à travers les assises sus-jacentes suite à des mouvements verticaux du socle (Castany, 1955).

A l'ouest du Bou Garnine, des calcaires éocènes très résistants, souvent dressés à la verticale, forment une barre de direction méridienne qui constitue la retombée occidentale de l'anticlinorium. Topographiquement, cette barre correspond à Jebel Ghorof culminant à 225 m (Karray, 1977).

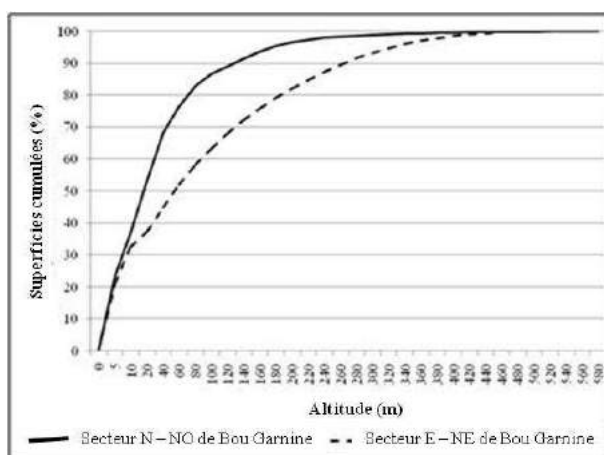


Fig. 2. Caractéristiques hypsométriques autour de l'extrémité nord du Jebel Bou Garnine

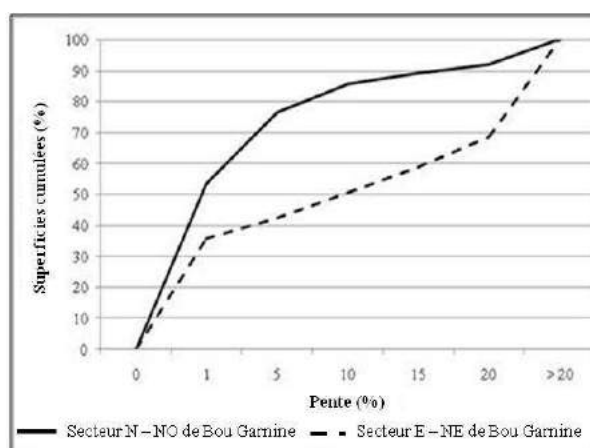


Fig. 3. Répartition fréquentielle des classes de pentes autour de l'extrémité nord du Bou Garnine

A l'est, une importante crête qui culmine à 496 m s'aligne sur plus de 8 kilomètres depuis l'Oued Chouchana au nord (Fig. 4) jusqu'à Khanguet El-Houjaj au sud. D'après M. R. Karray (1977) cet alignement correspond à un crêt majeur regardant vers l'ouest et qui est formé par des calcaires du Turonien-Campanien qui surmontent d'épaisses alternances marno-calcaires d'âge albo-cénomaniens. Le versant est de ce crêt correspond donc à un revers.

En somme, cette unité morphostructurale se distingue par des pentes fortes à très fortes, par des sols somme toute assez minces qui ont une faible capacité de stockage et par des affleurements géologiques à dominante marno-calcaire caractérisés par une faible perméabilité dans l'ensemble. Toutes ces caractéristiques sont à priori favorables à un ruissellement très actif.

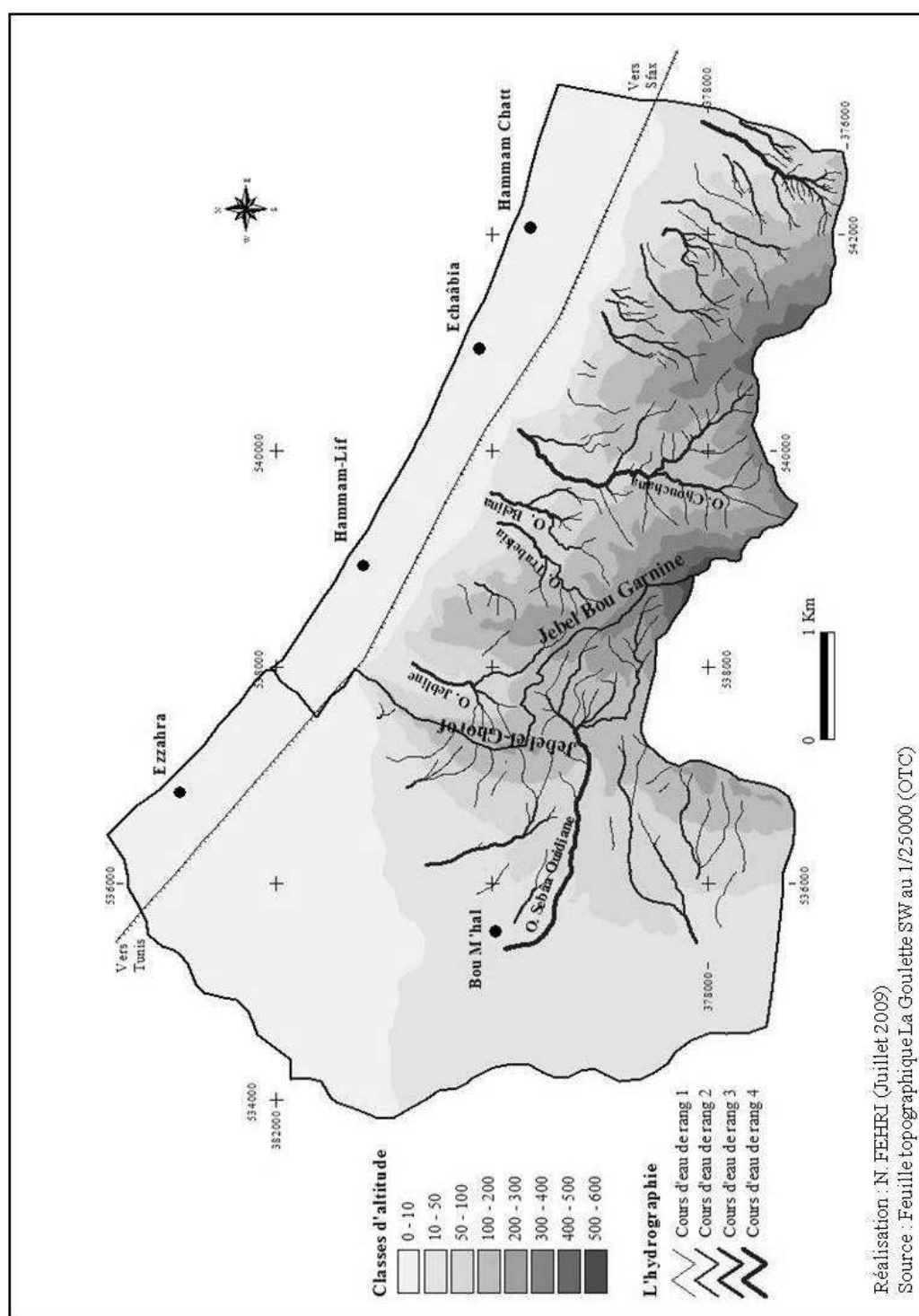


Fig. 4. L'hypsométrie et l'hydrographie autour de l'extrémité septentrionale du Jebel Bou Garnine

2.1.2. Des plaines basses et exiguës raccordées aux versants par des piémonts étroits

Au cours de la dernière glaciation (Würm), les oueds qui descendent les reliefs montagneux ont eu un fonctionnement torrentiel. Ils ont alors édifié des cônes de déjection souvent coalescents. Ces cônes sont constitués d'éléments très hétérométriques issus de la fragmentation de la roche mère, essentiellement marno-calcaire. Ils se caractérisent par un profil légèrement bombé et s'inclinent suivant une pente relativement importante (autour de 5%) en direction des plaines environnantes.

La plaine du Bas Miliane. Des côtés ouest et nord-ouest, le Jebel Bou Garnine se raccorde à une basse plaine sur laquelle s'étendent actuellement les communes d'Ezzahra et Bou M'hal Bassatine (Fig. 5). Il s'agit de la plaine synclinale subsidente du Mornag-Bas Miliane. Celle-ci est limitée à l'est par les jebels Ressass et Bou Garnine et à l'ouest par les collines de Megrine-Radès. Au nord, elle débouche sur le Golfe de Tunis. Les assises tertiaires de cette plaine sont souvent couvertes par

une accumulation sablo-argilo-tuffeuse d'âge Quaternaire pouvant faire 100 mètres d'épaisseur (Karray, 1977).

Ces épaisses accumulations sont pour l'essentiel l'œuvre de l'oued Miliane l'un des principaux cours d'eau de la Tunisie septentrionale. Actuellement, les crues de cet oued sont régularisées grâce à des barrages et des lacs collinaires construits dans son bassin amont (Barrage de Bir M'charga, Barrage El-Hama...).

La plaine littorale d'Hamam-Lif. D'une largeur qui n'excède guère les deux kilomètres, cette étroite plaine constitue le prolongement vers le nord-ouest de la plaine de Soliman-Grombalia. Cette dernière correspond structuralement à un vaste fossé d'effondrement (graben) décollé de la Dorsale par une multitude de flexures et de failles généralement orientées NO-SE (Karray, 1977).

Ces plaines basses et étroites se situent aux débouchés d'une série d'oueds, certes de petite taille, mais qui peuvent avoir un comportement torrentiel car ils descendent les pentes fortes du massif de Bou Garnine.

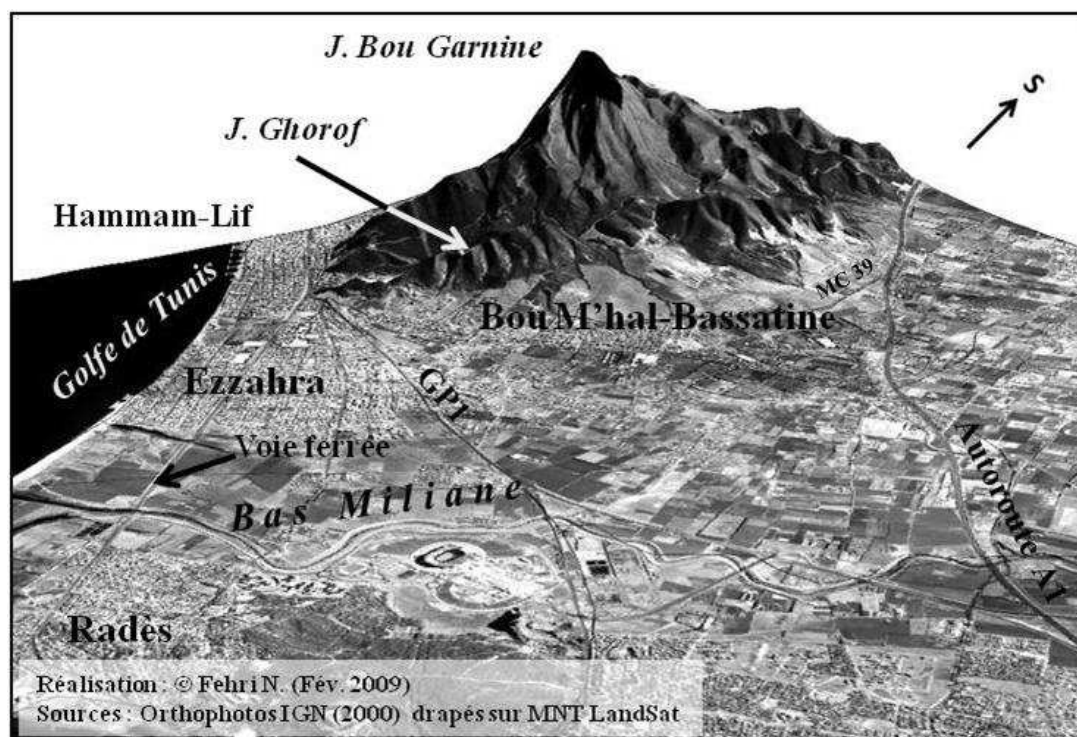


Fig. 5. Principaux éléments du paysage autour de l'extrémité de la Dorsale tunisienne (Jebel Bou Garnine et ses environs)

2.2. Les écoulements : des cours d'eau courts mais pouvant avoir un fonctionnement torrentiel

Autour de l'extrémité septentrionale du Jebel Bou Garnine les écoulements se font suivant deux directions majeures :

- A l'est et au nord du jebel, ils ont une direction sommaire SSO-NNE. Ici, le réseau hydrographique est organisé sous forme de petits cours d'eau souvent et qui sont tous presque parallèles les uns aux autres. Nous en citons surtout Oued Jebline, Oued Trabelsia, Oued Belini, Oued Chouchana... (Fig. 4).

- A l'ouest du Bou Garnine, les oueds coulent en gros d'est en ouest. La plupart d'entre eux prennent source au niveau de la barre calcaire éocène qui correspond au Jebel El-Ghorof. Seul l'oued Sebâa Ouidane présente un bassin-versant un peu plus vaste puisqu'il transperce cette barre et prend sa source directement sur le versant occidental du Bou Garnine (Fig. 4). Du côté aval, ces oueds abordent la plaine du Bas-Miliane et se déversent dans l'oued Fagoussa qui se jette dans le Golfe de Tunis juste au nord de la ville d'Ezzahra.

En somme, cette zone est caractérisée par de petits cours d'eau dont la longueur n'excède guère les 4 à 5 km pour les plus longs. Toutefois, en cas de grandes pluies, le relief assez escarpé, qu'ils entaillent, leur confère un caractère torrentiel matérialisé par les importantes quantités de sédiments qu'ils peuvent charrier jusqu'en aval où s'étendent les quartiers (Photo 1). Ceci est d'autant plus vrai que la zone étudiée (qui appartient à l'étage bio-climatique semi-aride supérieur) se distingue par un régime pluviométrique méditerranéen caractérisé par des précipitations très irrégulières aussi bien à l'échelle interannuelle que saisonnière. Les précipitations automnales, tout particulièrement, se font souvent sous forme d'averses de forte intensité et surviennent après une longue sécheresse estivale au cours de laquelle le sol est ameubli. Elles génèrent ainsi des écoulements importants et fortement chargés.



Photo 1. Laisses de crue de l'oued Chouchana suite aux inondations de septembre 2009 (Echaâbia)
(cliché : N. FEHRI, Septembre 2009)

2.3. Un atout majeur pour la zone : la callitriaie du Jebel Bou Garnine

L'actuel Parc National de Bou Garnine, dominé par une couverture forestière à base de thuya de Berbérie (*Callitris articulata*), constitue un véritable sanctuaire de la nature situé à deux pas d'une zone

très anthropisée. Outre sa grande valeur écologique et récréative, la végétation de ce parc assure une véritable protection des versants contre les méfaits de l'érosion hydrique et contribue aussi à protéger contre le risque d'inondation les installations humaines situées en aval.

Dans le détail, la répartition spatiale ainsi que l'importance des formations végétales de ce jebel (du point de vue densité et hauteur) dépendent du jeu combiné de plusieurs facteurs majeurs dont on cite surtout la position sur les versants, la nature du sol et du substratum, la pente et l'exposition (Gammar, 1975).

D'une manière générale les formations élevées (matorral haut et forêt) s'observent dans la partie centrale du jebel, au bas des versants, ainsi qu'au fond des vallons qui le dissèquent. En effet, par leur position en aval, ces endroits sont périodiquement alimentés en eau, en matière organique et minérale en provenance des parties amont. Ceci leur permet d'avoir un sol relativement épais et assez évolué propice au développement de la végétation. Cette constatation est surtout valable au bas des versants ubacs exposés nord et nord-ouest car ils sont nettement plus arrosés que ceux qui regardent vers l'est, le sud-est et le sud. D'après O.M. Gammar (1975), ces écarts de précipitations dépasseraient les 100 mm/an en moyenne. Ainsi pour la période 1958-1964, l'auteur signale que la moyenne pluviométrique annuelle enregistrée à la station de Crétéville (située à 4 km au SE de Sabbalet Mornag), qui est relativement bien exposée aux vents pluvieux de l'ouest et du nord-ouest, s'élève à 507 mm contre 394 mm/an seulement à la station de Borj Cédria en position d'abri par rapport à ces vents.

Ces formations végétales de bas de versants sont constituées d'une strate supérieure arborescente dominée par des thuyas de Berbérie hauts de 7 à 12 mètres et qui sont assez couvrants (>80%) et une strate arbustive moyenne, haute de 2 à 5 mètres. Cette dernière est nettement moins dense que la strate supérieure et est faite surtout d'arbustes isolés de lentisque, d'oléastre, de jeunes thuyas et de filaire.

En revanche, le haut des versants constitue une zone de départ et de transit des matières minérale et organique car la pente y est généralement très forte et le ruissellement très actif. Les sols y sont alors très squelettiques voire complètement décapés et ne soutiennent, par conséquent, qu'une végétation basse faite d'un matorral bas à moyen avec de nombreuses trouées qui correspondent aux affleurements de la roche mère calcaire ou marneuse. Sur cette partie de la montagne, la

dégradation de la végétation est souvent très rapide notamment sur les versants exposés aux vents dominants forts du NO. Ici la strate ligneuse supérieure est constituée de petits arbustes de thuya de 1 à 2 mètres de hauteur avec un taux de recouvrement de 20 à 30% alors que la strate inférieure se compose de quelques touffes très basses de romarin (*Rosmarinus officinalis*), de globulaire (*Globularia vulgaris*), de cistes (*Cistus*

monspeliensis) et de bruyère (*Erica multiflora*), dont l'élévation n'excède guère les 30 cm avec un taux de recouvrement généralement inférieur à 25%. La strate herbacée se réduit à une pelouse très clairsemée prédominée par le brachypode rameux (*Brachypodium retusum*), quelques touffes d'alfa (*Stipa tenacissima*), le cyclamen (*Cyclamen percicum*)... (Gammar, 1975).

Tableau 1. Evolution surfacique des différents types d'occupation des sols autour de l'extrémité septentrionale du Jebel Bou Garnine (1950-2007)

	Versants et piémonts N – NO						Versants et piémonts E - NE					
	1950		1982		2007		1950		1982		2007	
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Espaces bâtis + routes	100,5	5,3	285,7	15,2	502,4	26,7	85,5	5,1	211,4	12,6	446,4	26,7
Carrière	0	0	4,5	0,2	4,5	0,2	0,0	0,0	8,5	0,5	17,8	1,1
Oliveraie	585,6	31	296,15	15,8	190,5	10,1	49	2,9	44,4	2,7	3,0	0,2
Vergers	69,2	3,7	174,5	9,3	80,375	4,3	19,7	1,2	66,4	4,0	0,0	0,0
Vignoble	259,9	13,8	36,7	2	20,62	1,1	193,7	11,6	5,4	0,3	0,0	0,0
Cultures annuelles ou friches post-culture	873,7	46,3	834,5	44,4	754	40,1	500,2	29,9	476,5	28,5	256,9	15,4
Callitraie	0	0,0	246,6	13,1	326,3	17,4	824,1	49,3	859,5	51,4	947,9	56,7
Total	1888,9	100	1878,7	100	1878,7	100	1672	100	1672	100,0	1672	100

3. Evolution de l'occupation des sols depuis les années 1950 et dynamique récente de la végétation naturelle

Pour retracer l'évolution de l'occupation du sol au cours de la deuxième moitié du XX^{ème} siècle, nous disposons essentiellement de quatre sources d'informations à savoir :

- la feuille topographique au 1/50 000 La Goulette (révisée en 1950) ;
- les feuilles topographiques au 1/25 000 La Goulette SO et La Goulette NO, publiées par l'OTC¹ en 1983 et qui sont réalisées à partir des levés photogrammétriques de 1974 complétés en 1982 ;
- une couverture d'orthophotos de l'IGN² au 1/10 000 datant de 2000 ;
- les données tirées à partir de cette mission de photographies aériennes ont été extraites par simple photo-interprétation et ont été mises à jour grâce à des extraits Google Earth datant de l'an 2007.

L'ensemble de ces données ont été intégrées dans un système d'information géographique (ArcView) ce qui nous a permis d'élaborer des cartes et des tableaux statistiques qui synthétisent les résultats de cette analyse multi-dates de l'occupation du sol (1950, 1982 et 2007).

3.1. Déclin de l'activité agricole face à une urbanisation de plus en plus accélérée

Au bout de 57 ans, la superficie des espaces bâtis autour de l'extrémité nord du Bou Garnine a plus que quintuplé, passant de 186 ha en 1950 à environ 950 ha en 2007 (Tableau 1).

Cette rapide extension urbaine s'explique surtout par l'importante croissance démographique enregistrée dans les communes de la zone (Bounouh, 2008). Elle s'est faite essentiellement à partir de Hammam-Lif vers le sud, c'est-à-dire sur la très étroite bande qui sépare Jebel Bou Garnine de la côte. Elle s'est faite aussi autour de la ville d'Ezzahra (ex-St. Germain) sur les plaines du Bas Miliane et surtout sur le piémont nord-ouest de Jebel El-Ghorof surtout le long de la route MC39 qui bifurque vers Bou M'hal en sortant de Hammam-Lif par la GP1 (Fig. 5).

Parmi les quatre communes de la région, Bou M'hal-Bassatine est celle qui a connu le plus fort taux d'évolution du nombre de logements au cours de la décennie 1994-2004 (127,2%). Vient ensuite la commune de Hammam-Chatt (72.47%), suivie par Ezzahra (37%).

Ayant déjà largement épuisé ses réserves foncières constructibles et ce dès le début des années 1990, la commune de Hammam-Lif arrive en dernière position puisqu'elle n'a augmenté son parc immobilier que de 22,2% entre 1994 et 2004 (Tableau 2).

¹ Office de la Topographie et de la Cartographie (Tunisie).

² Institut Géographique National (France).

Tableau 2. Evolution de la population et de l'habitat dans les communes de Bou M'hal-Bassatine, Ezzahra, Hammam-Lif et Hammam-Chatt (1994-2004)

Commune	Date de création	Population		Nombre de logements		Densité de population (2004)
		1994	2004	1994	2004	
Bou M'hal-Bassatine	31/05/1991	16037	31792	3447	7831	2420.16
Ezzahra	11/09/1909	25940	27977	7143	9783	1887.89
Hammam-Lif	09/03/1899	37494	38401	9449	11549	3077
Hammam-Chatt	31/05/1991	16429	24847	4156	7168	1054.63

Sources : INS – RGPH 1994, 2004

Cet étalement du bâti s'est fait surtout aux dépens des terres agricoles. L'examen des figures 6, 7 et 8 révèle un net rétrécissement des surfaces arboricoles qui s'est échelonné sur toute la deuxième moitié du siècle passé et qui se poursuit jusqu'à nos jours. Cette tendance concerne surtout les surfaces

oléicoles (Fig. 9 et 10). La viticulture a décliné aussi. Aujourd'hui, elle a quasiment disparu. Ceci s'explique, sans doute, par la crise que ce secteur a connue après l'indépendance du pays (Sethom et Kassab, 1981).

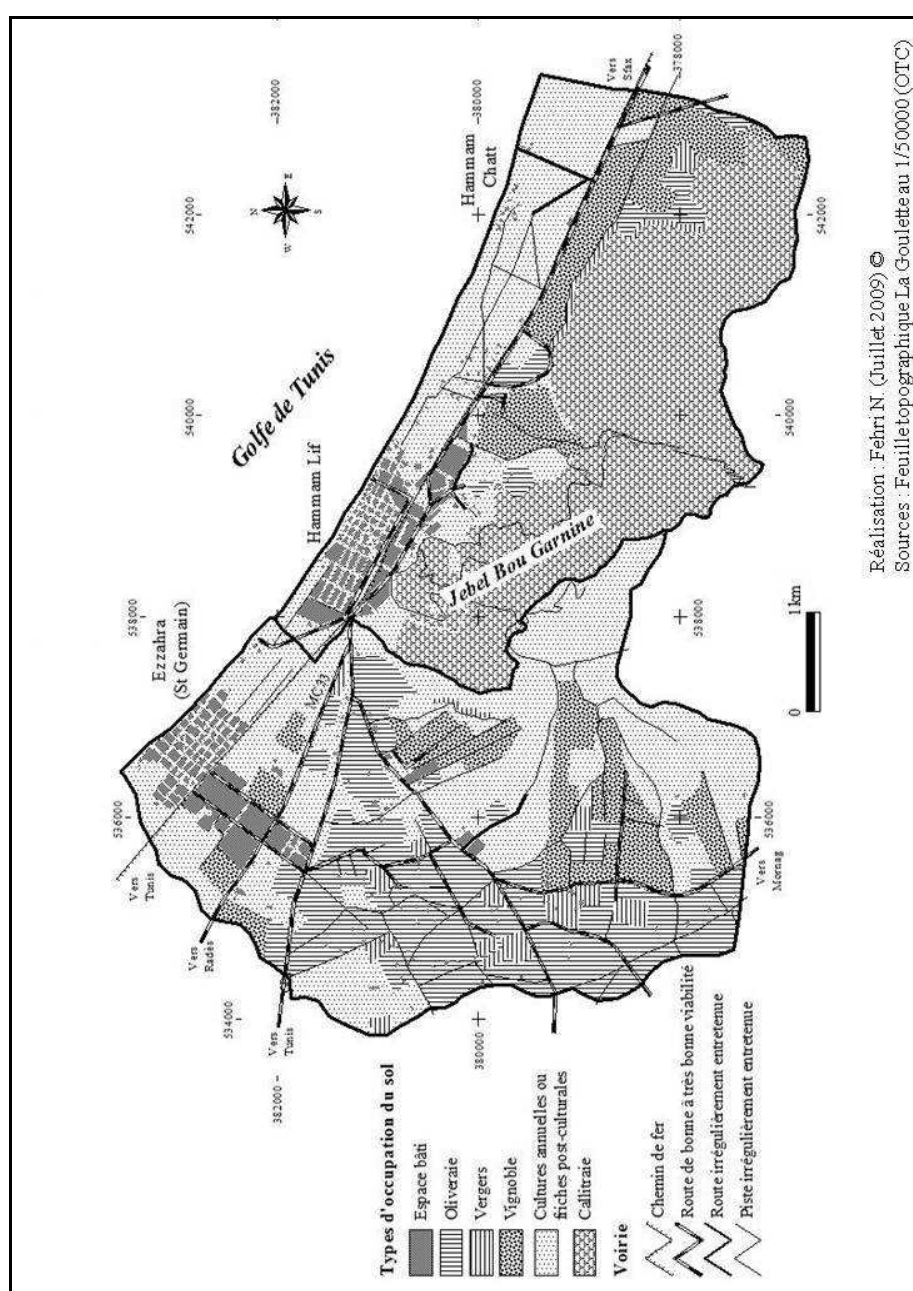


Fig. 6. L'occupation du sol autour de l'extrémité septentrionale du Jebel Bou Garnine : situation en 1950

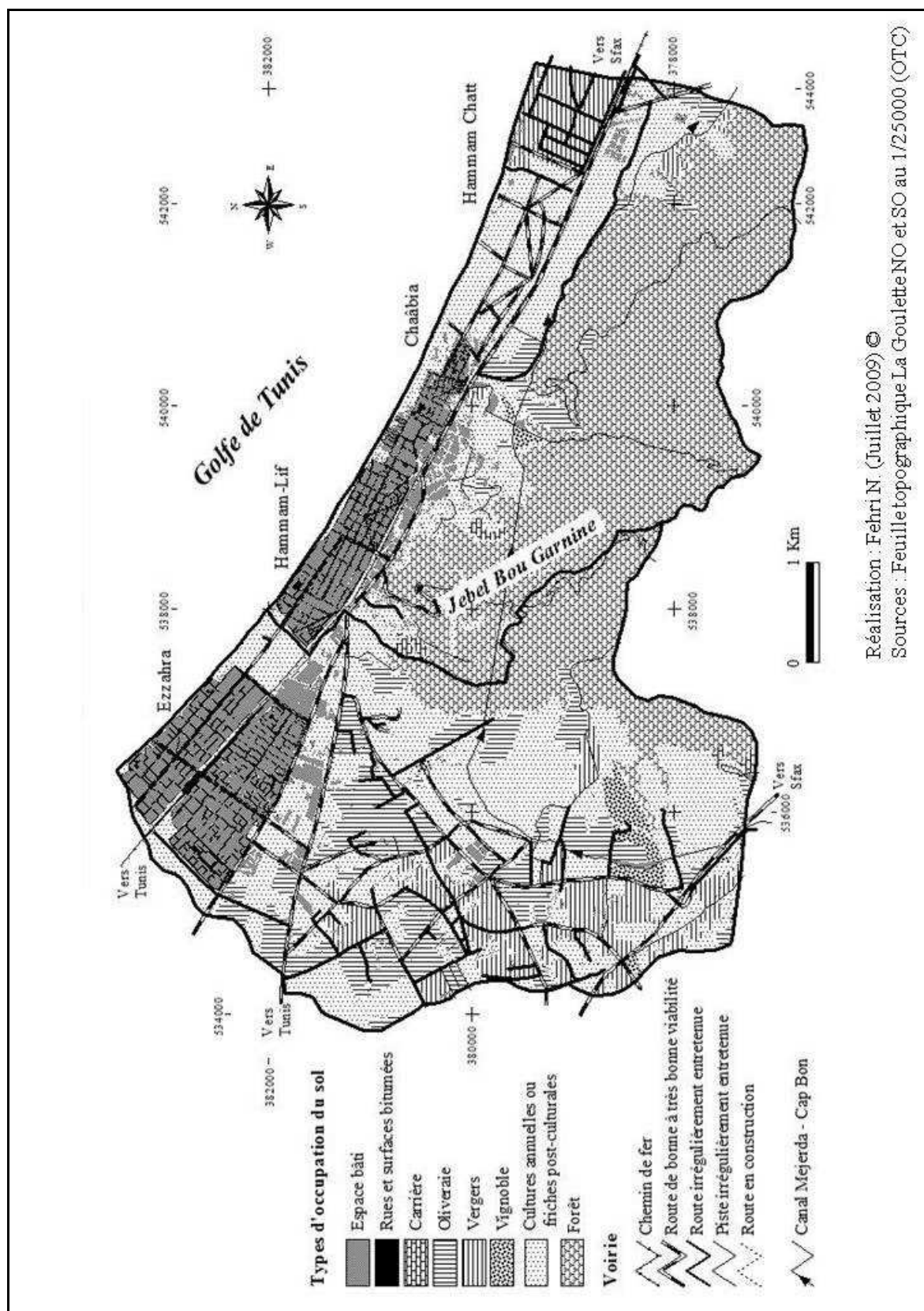


Fig. 7. L'occupation du sol autour de l'extrémité septentrionale du Jebel Bou Garnine : situation en 1982

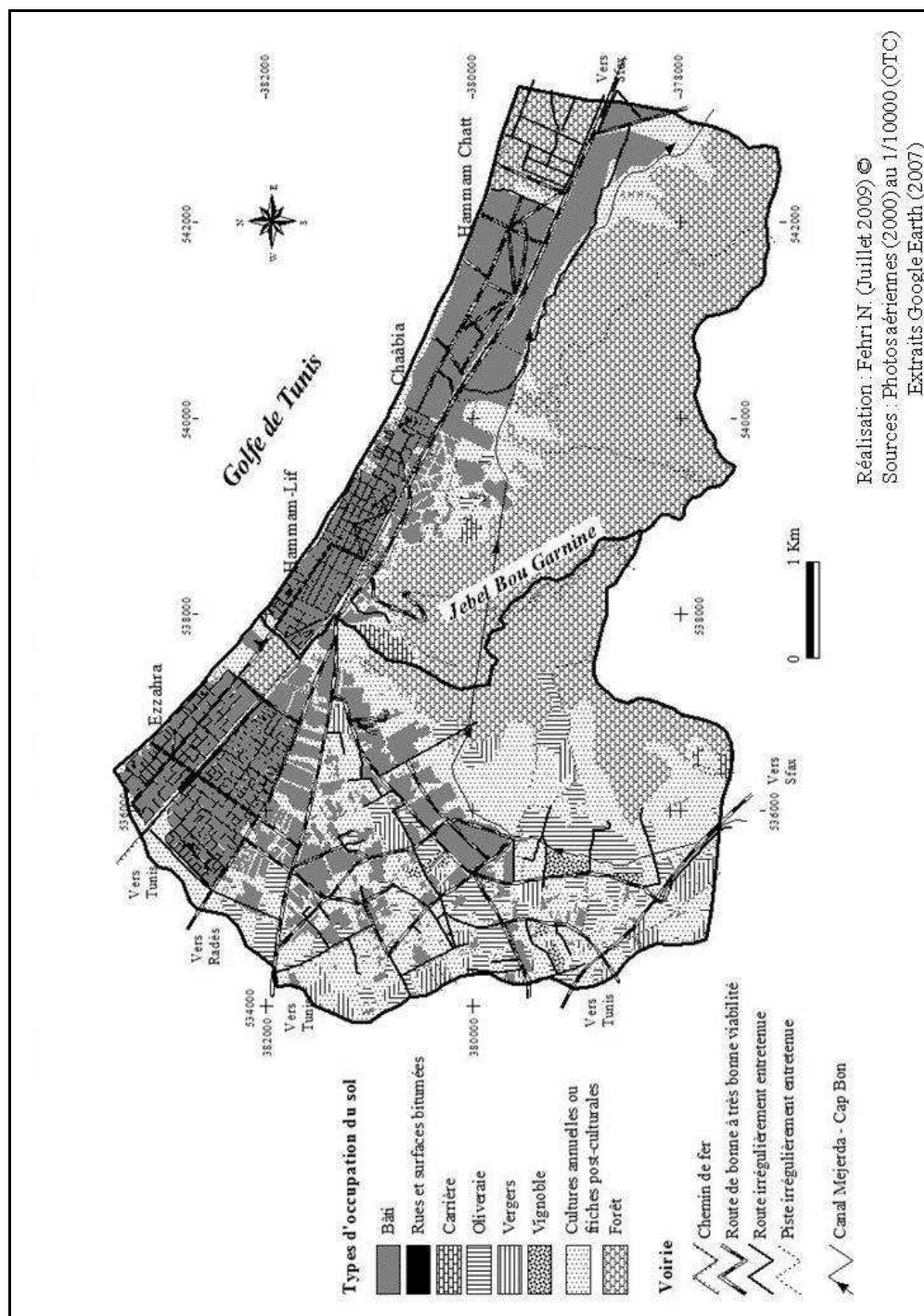


Fig. 8. L'occupation du sol autour de l'extrémité septentrionale du Jebel Bou Garnine : situation en 2007

Entre 1950 et le début des années 1980, une grande partie de l'oliveraie qui s'étendait au nord et au nord-ouest de Jebel Bou Garnine (Bou M'hal) a été transformée en vergers, c'est-à-dire en parcelles de petite taille (généralement moins de 1 ha) clôturées par des haies en brise-vents et où l'on pratiquait essentiellement une arboriculture fruitière. Mais, à vrai dire, il ne s'agissait ici que d'une phase transitoire. Petit-à-petit de nombreuses demeures individuelles ont vu le jour au milieu de ces parcelles dès lors converties en jardins de plus

en plus émiettés annonçant ainsi un processus rapide de « gaspillage » de terres agricoles généralement fertiles au profit de la ville.

Les superficies réservées aux cultures annuelles ont connu également une baisse sensible notamment dans les secteurs est et nord-est du Bou Garnine. N'empêche que sur ses versants et piémonts N – NO en particulier, on leur consacre encore plus de 750 ha soit une vaste réserve foncière alléchante vers laquelle les promoteurs immobiliers ne tarderont pas à se tourner dans les années à venir.

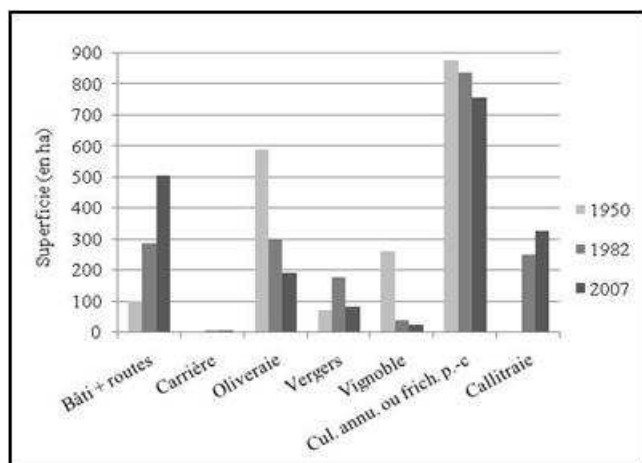


Fig. 9. Evolution de l'occupation du sol sur les versants et les piémonts N – NO de Bou Garnine

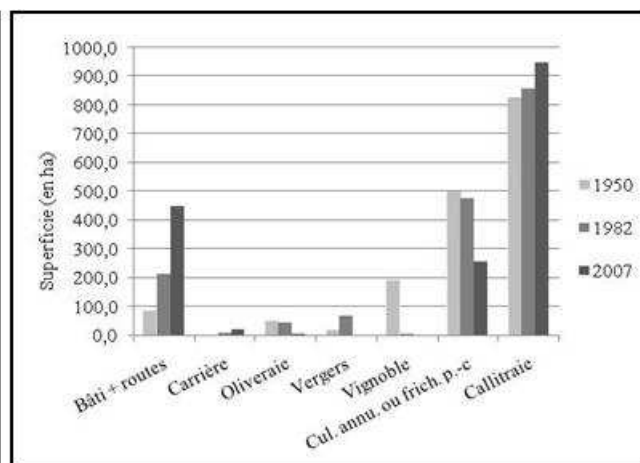


Fig. 10. Evolution de l'occupation du sol sur les versants et les piémonts E - NE de Bou Garnine

3.2. Une dynamique progressive de la callitraie du Jebel Bou Garnine

Depuis la fin du XIX^{ème} siècle, la callitraie du Jebel Bou Garnine connaît une dynamique somme toute progressive et ce grâce à des travaux de reboisement. Ce constat est corroboré par les données du tableau 1 qui laissent voir un net élargissement de l'espace forestier.

Les premiers travaux engagés dans ce jebel ont été effectués au lendemain de la colonisation en 1884. Cependant, ces travaux ont été rapidement bloqués à cause des problèmes fonciers et surtout parce qu'ils étaient en contradiction avec la politique économique coloniale surtout après la découverte des gisements de zinc (mine d'Ain Zarga). C'est à la faveur de la crise économique de 1929 qu'on a commencé les travaux de mise en défens réelle cette montagne notamment après l'abandon total de l'exploitation minière en 1932. En 1947, toute la partie centrale du jebel passe définitivement sous le contrôle direct du Service Forestier.

Le gouvernement de l'indépendance a consolidé ces acquis en généralisant la mise en défens à toute la callitraie du Bou Garnine et en annexant les anciennes terres coloniales à vocation forestière au régime forestier (Gammar, 1975).

De nos jours, les résultats de ces opérations de mise en défens et de reboisement ont entraîné une nette évolution progressive de la callitraie notamment sur les versants ubacs et dans les fonds de vallons. Cela se traduit par une remarquable densification du couvert végétal suite au développement d'un matorral bas fermé qui est constitué de plantes buissonnantes et d'espèces herbacées ligneuses ainsi que par la formation d'une

strate supérieure haute constituée essentiellement de thuyas de Berbérie. On y observe aussi le pin d'Alep, le pin pignon, l'acacia et l'eucalyptus plantés dès l'époque coloniale pour les plus anciens.

Toutefois, sur les versants sud qui sont des adrets, cette évolution progressive est beaucoup moins importante et les années de protection n'ont pas suffi à apporter une nette amélioration de la couverture végétale et ce malgré un faible développement vertical des thuyas (Gammar, 1975). C'est le cas aussi au niveau des affleurements marneux lacérés par le ruissellement concentré. Sur ces affleurements, le couvert végétal se réduit à un matorral bas et clairsemé. Ici, il est clair que la protection passive (par simple mise en défens) ne suffit pas à elle seule à freiner la dégradation alarmante de ces étendues.

Quoiqu'il en soit, nous pouvons dire que d'une manière générale les travaux de mise en défens et de reboisement du Jebel Bou Garnine ont déclenché dans beaucoup de cas une dynamique d'amélioration du couvert végétal. Ajoutons que cette amélioration ne s'est pas réduite à une densification de la couverture végétale ; elle se traduit aussi par une nette augmentation de la superficie forestière. En effet, entre 1950 et 2007 la callitraie de l'ensemble de la zone étudiée s'est élargi d'environ 415 ha.

4. Les conséquences de ces évolutions sur l'inondabilité de la zone

4.1. Impact sur les coefficients de ruissellement

Il s'agit ici d'appréhender l'évolution des coefficients de ruissellement (Kr) en fonction de

l'évolution de l'occupation des sols depuis 1950 jusqu'en 2007 avec une date intermédiaire : 1982. L'approche suivie consiste à appliquer empiriquement des coefficients élémentaires à chaque type d'occupation du sol⁴ (Fehri, 2011). Ces Kr élémentaires sont par la suite pondérés par la part relative de chaque type d'occupation dans la superficie totale du secteur étudié. La somme de ces pondérations nous a permis d'aboutir à un Kr global exprimé en pourcentage (Tableau 3).

La comparaison des résultats obtenus dans la zone étudiée avec ceux observés dans d'autres secteurs du Grand Tunis permet de constater qu'en dépit d'une augmentation sensible des Kr autour de l'extrémité septentrionale du Bou Garnine, celle-ci reste assez modérée si on la compare, par exemple, avec celle enregistrée dans le bassin-versant très densément urbanisé des oueds El-Ghrich et El-Greb⁵ au nord de la ville de Tunis (Fehri et al., 2007 et Fehri, 2011).

Il va sans dire que dans les parties aval lorsque les cours d'eau abordent les secteurs urbanisés, l'imperméabilisation des sols atteint souvent des seuils très élevés et les écoulements s'y font presque à saturation. Lorsque la pente s'annule ou presque, c'est-à-dire dans les parties de la ville construites dans la plaine, le drainage devient difficile. Alors les écoulements venant de l'amont stagnent et inondent les rues, perturbant ainsi la circulation, situation assez fréquente surtout à Ezzahra (Fig. 11).

4.2. Des cours d'eau perturbés par de nombreux obstacles et augmentation des enjeux dans les zones inondables

Le secteur étudié est traversé par deux grandes artères de communication d'envergure nationale. Ces artères relient la capitale au Cap-Bon, au Sahel et au Sud. Il s'agit de la GP1 et de l'axe ferroviaire qui va de Tunis jusqu'à Gabès et Gafsa en passant par Sousse et Sfax. Leur tracé NO-SE est obséquent par rapport à tous les oueds qui drainent les versants est et nord-est du Bou Garnine. Ils sont alors à l'origine de débordements répétés (Nasrallah, 2013). Seulement, au moment où ces axes furent aménagés il y'a plus d'un siècle⁶, l'urbanisation de

la zone étaient assez limitée et le trafic automobile sur la GP1 aussi.

Les inondations observées ces dernières années, ont montré la limite des ouvrages perçant ces deux voies et qui servent à évacuer les eaux pluviales vers la mer. Bien entendu, cela s'explique en grande partie par le caractère assez intense de ces épisodes pluviométriques. Mais il est également opportun de rappeler qu'à pluviométrie égale, les écoulements en ville ont augmenté suite à la modification des coefficients de ruissellement par imperméabilisation des sols. Dans beaucoup de cas, les ouvrages en question sont de nos jours sous-dimensionnés par rapport aux volumes d'eau susceptibles de s'écouler. Ceci est d'autant plus vrai qu'ils sont souvent obstrués et que les travaux de curage tardent à venir à temps, c'est-à-dire avant les premières pluies automnales. Or, de part et d'autre de ces deux artères, les enjeux ont augmenté. Les constructions à vocations diverses sont de plus en plus nombreuses et denses. Il en est de même du trafic routier qui ne cesse de se multiplier comme en témoignent les embouteillages continus à longueur de journée dans le « goulot » de Hammam-Lif. Que l'on soit résident ou bien usager de la route de façon régulière, on est aujourd'hui de plus en plus exposé au risque d'inondation le long d'un tronçon qui va de Hammam-Lif à Hammam-Chatt (Fig. 11 et Photo 2).

Le même constat s'applique aussi au secteur N – NO de Bou Garnine. Ici, la GP1 ainsi que la MC39 barrent également les cours d'eau qui drainent les versants occidentaux de la montagne (Fig. 11). Par ailleurs, l'habitat est ici en train d'empiéter sur les lits des cours d'eau aggravant ainsi le risque d'inondation (Photo 3).

4.3. A propos du rôle protecteur de la forêt : un acquis à préserver

La callitraie de Bou Garnine constitue un écran qui protège efficacement le sol contre l'érosion pluviale et contre l'action du ruissellement. Grâce à leur système racinaire les arbres fixent la terre freinant ainsi la migration des matériaux vers le bas des versants et amorçant, suite à la restitution de la matière organique, une activité pédogénique qui favorise à son tour le développement de la callitraie. Pour étayer l'ensemble de ces constatations, il suffit de faire une simple comparaison entre les états de surface sous couvert végétal et puis juste à côté au niveau des pare-feux ou encore sur les versants exposés au sud (adret) où la végétation est généralement très dégradée notamment si la pente est raide (Photo 7).

⁴ Les coefficients de ruissellement adoptés ici sont ceux utilisés par la Direction de l'Hydraulique Urbaine.

⁵ Dans ce bassin-versant situé au nord de la ville de Tunis, le Kr est passé de 50.7% en 1950 à 69.7% en 1983 puis à 74.2% en 2007.

⁶ A la fin du XIX^{ème} siècle, la Compagnie des Phosphates et des Chemins de Fer de Sfax-Gafsa avait obtenu la concession d'une voie ferrée entre Tunis et Sousse (la section Tunis-Hammam-Lif étant achevée depuis 1882) qu'elle avait construit entre 1895 et 1899.

Tableau 3. Evolution des coefficients de ruissellement autour de l'extrémité septentrionale de Bou Garnine

Occupation du sol	Kr élémentaires	Kr pondérés (en %) dans le secteur N – NO du jebel			Kr pondérés (en %) dans le secteur E du jebel		
		1950	1982	2007	1950	1982	2007
Espaces bâtis + routes	0,8	4,3	12,2	21,4	4,1	10,1	21,4
Carrière	0,6	0,0	0,1	0,1	0,0	0,3	0,6
Oliveraie	0,5	15,5	7,9	5,1	1,5	1,3	0,1
Vergers	0,4	1,5	3,7	1,7	0,5	1,6	0,0
Vignoble	0,4	5,5	0,8	0,4	4,6	0,1	0,0
Cultures annuelles ou friches post-culturelles	0,5	23,1	22,2	20,1	15,0	14,2	7,7
Callitraie	0,3	0,0	3,9	5,2	14,8	15,4	17,0
Σ des Kr pondérés (%)	-	49,9	50,8	54,0	40,4	43,1	46,8



Photo 2. Les écoulements qui descendent les versants et les quartiers construits sur les piémonts sont barrés par la clôture qui longe la voie ferrée inondant ainsi la GP1 (Hammam-Chatt)



Photo 3. Oued Sebâa Ouidiane inondant une route qui le barre. A remarquer aussi la prolifération des constructions en zones inondables (Bou M'hal)

Comme on vient de le signaler, dans le premier cas on a affaire à une dynamique de piégeage et de fixation des matériaux en transit sur le versant. Ceci est attesté par l'accumulation d'une couche d'éléments fins qui ensevelissent une matière grossière assez abondante. Si squelettique soit-elle, cette couche témoigne d'une relative amélioration des conditions édaphiques qui ne peut être que bénéfique pour la végétation. De son côté, cette végétation recouvre le sol par une litière souvent assez abondante qui le protège contre l'érosion pluviale et hydrique (Photo 4). En revanche, au niveau des pare-feux, larges couloirs qui sont régulièrement débroussaillés afin d'éviter la propagation du feu en cas d'incendie, ou encore sur les versants nus, le « sol » est directement exposé à l'action de la pluie et du ruissellement diffus. La matière fine étant transportée, il ne reste en surface qu'un pavage grossier issu du démantèlement de la roche mère calcaire (Photo 5).

A cause de leur forte imperméabilité, ces espaces constituent des aires fortement contributives au ruissellement. Lorsque celui-ci arrive à se

concentrer, il y cisèle des ravins parfois assez profonds. Au fil du temps, ces ravins peuvent dans certains cas prendre des dimensions alarmantes notamment si les écoulements viennent, au passage, ébrécher une banquette de conservation des eaux et des sols (CES) qui n'aura pas été réparée (Photo 6). Ces entailles constituent une menace pour les infrastructures et les équipements situés en aval car elles réduisent le temps de concentration des eaux de ruissellement et les drainent rapidement vers le bas des versants où elles risquent d'inonder.

De toute évidence, la callitraie de Bou Garnine joue un rôle majeur en termes de protection des versants contre l'érosion hydrique. Elle contribue aussi à protéger la ville contre les inondations. En effet, et par rapport à d'autres secteurs du Grand Tunis, l'augmentation des coefficients de ruissellement dans cette zone a été, comme déjà signalé, assez modérée. Cela s'expliquerait par l'amélioration de la couverture forestière qui aurait, en quelques sorte, contrebalancé la forte augmentation des Kr due à l'extension du bâti.

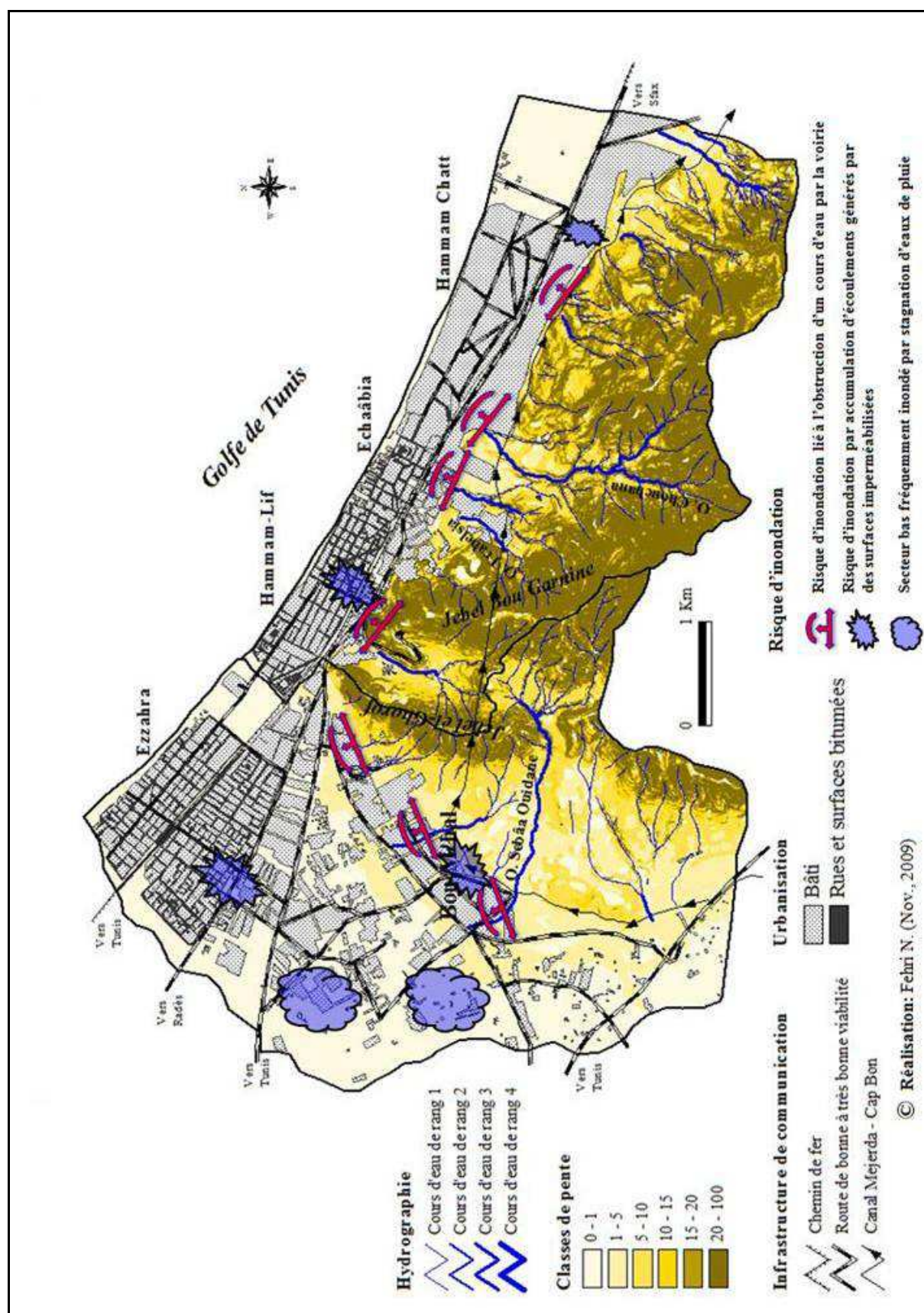


Fig. 11. Vulnérabilité au risque inondation autour de l'extrémité septentrionale du Jebel Bou Garnine



Photos 4 (à gauche) et 5 (à droite). Détail des états de surface observés sous la callitraie (sol protégé par une litière à gauche) et sur les versants dénudés (pavage grossier hétérométrique à droite)
(clichés N. FEHRI, Octobre 2009)



Photo 6. Ravin formé parallèlement à une bande aménagée en pare-feu (versant de la montagne à la hauteur de Hammam-Chatt)
(cliché N. FEHRI, Octobre 2009)



Photo 7. Etat de la couverture végétale sur un versant adret et en pente raide (versant de la montagne à la hauteur de Hammam-Chatt)
(cliché N. FEHRI, Octobre 2009)

5. Conclusion

Les plaines qui bordent l'extrémité nord du Jebel Bou Garnine constituent presque le seul passage facile d'accès entre la capitale Tunis et les autres villes du littoral oriental tunisien. Dès la fin du XIX^{ème} siècle, on y a aménagé le plus important axe ferroviaire de la Tunisie. Ces plaines sont aussi traversées par la GP1, principal axe routier du pays dont le nombre d'utilisateurs n'a cessé d'augmenter tout au long du siècle passé. Toutefois, ces infrastructures barrent les petits cours d'eau qui drainent les versants raides de la montagne et qui peuvent avoir un comportement torrentiel en cas de grandes pluies. Entre Hammam-Lif et Hammam-Chatt les eaux pluviales s'accumulent alors derrière le mur qui longe le chemin de fer inondant la GP1 et les équipements riverains.

Depuis plus d'un demi-siècle, ces plaines sont aussi le siège d'une extension urbaine effrénée qui

s'est faite au détriment des terres agricoles. La généralisation des surfaces bitumées est alors de règle dans les quatre communes de la zone. Cette imperméabilisation des sols a provoqué une sensible augmentation des coefficients de ruissellement et par voie de conséquence une aggravation du risque d'inondation.

Mais cette zone présente un atout majeur : la callitraie de Bou Garnine. Située à l'amont de ces espaces urbains, elle constitue un énorme écran protecteur qui augmente le temps de concentration des écoulements et améliore la capacité de stockage des sols si minces soient-ils. La maîtrise du risque d'inondation passe donc d'abord par la protection de cette forêt notamment contre le risque d'incendie (Chabaane-Lili et al., 2005). Toujours en amont, il faudrait prévoir des cordons en pierre sèche notamment à l'intérieur des bandes de pare-feu et penser à entretenir les banquettes présentant des brèches car elles provoquent une suralimentation des écoulements.

Outre ce volet de protection douce, il serait judicieux d'envisager des études en vue d'examiner la possibilité d'aménager des lacs collinaires sur les principaux cours d'eau qui drainent ce relief montagneux en particulier sur les oueds Chaâbia, Jebline et Sabâa Ouidane.

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Impact of Land use/Land cover change on Runoff Regime of the Upper Jhelum Catchment

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Abstract. The factors which govern the response of hydrological processes to a rainfall storm are interrelated across a river basin. There is a close relation between water resource management, river management and land use management. This paper aims at assessing the impact of land use/land cover change on the hydrological regime of the Upper Jhelum Catchment. Land use/land cover has drastically changed in the study area and as a result the annual peak discharges from 1991 to 2010 with different recurrence intervals have been more intensive in magnitude than the peak discharges from 1971 to 1990. During 1991 to 2010 the rainfall, recorded from the various meteorological stations located within the study area, has shown a decreasing trend. This increase in various hydrological events from 1991 to 2010 clearly reflects the role of the land use/land cover as a determinant of hydrological response of a watershed to a given amount of rainfall.

Keywords: land use/land cover, runoff, peak discharge, recurrence interval

1. Introduction

Hydrology of a watershed shows an intimate relationship with the prevalent land use. Land cover plays a key role in controlling the hydrologic response of watersheds in a number of important ways (Schilling et al., 2008; Mao & Cherkauer 2009; Elfert & Bormann, 2010 and Ghaffari et al., 2010). As the watershed becomes more developed, it also becomes hydrologically more active, changing the flood volume, runoff components as well as the origin of stream flow. In turn, floods that once occurred infrequently during predevelopment periods have now become more frequent and more severe due to the transformation of watershed from one land use to another. Changes in land cover can lead to significant changes in leaf area index, evapotranspiration (Mao & Cherkauer 2009), soil moisture content and infiltration capacity (Fu et al., 2000; Costa et al., 2003). Furthermore, land use modifications can also affect flood frequency and magnitude (Ward et al., 2008; Remo et al., 2009; Benito et al., 2010; Qiu et al., 2010).

In the upper Jhelum Catchment, floods are causing enormous damage to life and property very often. The flood problem in the study area arises primarily from the inadequate carrying capacity of the Jhelum in its length from Sangam to Wular Lake. The safe carrying capacity of the Jhelum from Sangam to Wular Lake ranges from 40 000 to 50 000 cusecs (cusec = cubic feet per second =

= 0.028316847 m³s⁻¹) and through the Srinagar city only about 35 000 cusecs. Compared to this, the flood discharge at Sangam rose to as much as 90 000 cusecs in 1957 and over 100 000 in 1959. The inadequate discharge carrying capacity of the Jhelum results in different type of flood problems in various reaches of the study area.

2. Study area

The study area spatially lies between 33° 21' 54" N and 34° 27' 52" N latitude and between 74° 24' 08" E and 75° 35' 36" E longitude with a total area of 8600.78 sq.km² (Fig. 1).

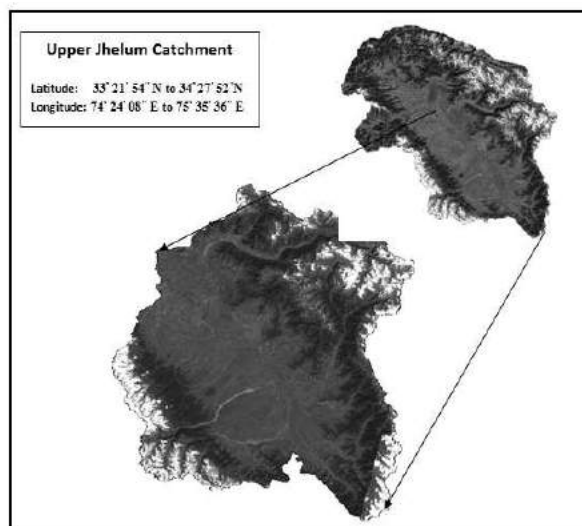


Fig. 1. Study area map

It covers almost all the physiographic divisions of the Kashmir Valley and is drained by the most important tributaries of the river Jhelum. The Jhelum and its associated streams that drain the bordering mountain slopes together constitute the drainage network of the study area. They include the fairly developed systems of the Sind, Rembiara, Vishaw and Lidder rivers as well as tiny rivulets such as the Sandran, Bringi and Arapat Kol. Adjusted to the varying nature of the geomorphic and geological setting, the fluvial systems in the study area have peculiar characteristics of their own. Four meteorological stations are situated within the study area namely Pahalgam, Srinagar, Qazigund and Kokarnag. Kokarnag is a high altitude meteorological station like Pahalgam, situated in the south bordering mountain chain of Pir Panjal. The monthly mean minimum rainfall recorded at this station from 1971 to 2010 is 25.8 mm

while as the monthly mean maximum is 208.2 mm. Qazigund meteorological station is no exception to this variability. The monthly mean minimum and the monthly mean maximum rainfall figures recorded at this station during the above mentioned period are 73.3 mm and 234 mm respectively.

3. Material and methods

The methods and materials involved in the study are different for different parameters but guided to solve the main problem. In order to assess the impact of land use/land cover change on the hydrologic regime of the Jhelum basin, the methodology has been divided into various steps. The methodological set up employed during the current study can be grouped into three categories: remote sensing and GIS, field work and statistical methods.

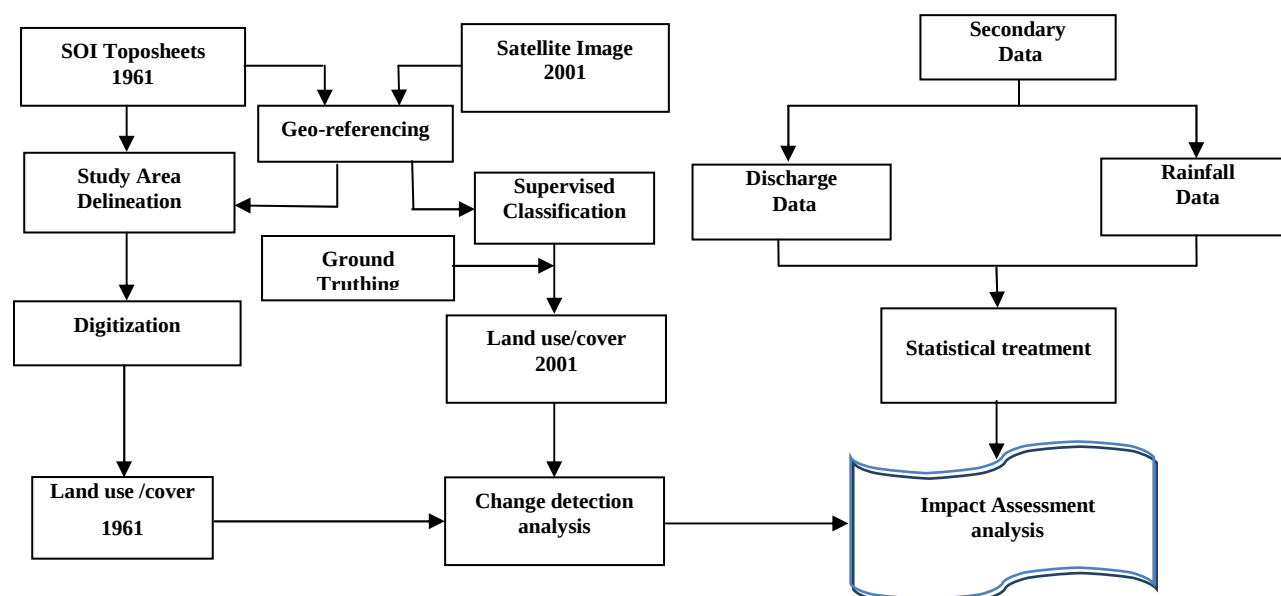


Fig. 2. Flow chart showing methodological framework of the study

The present study has been carried out utilizing both primary as well as secondary data sets. Fig. 2 shows the general methodological scheme that has been applied in order to accomplish the present study. Primary data includes Survey of India toposheets on 1:50000 scale and satellite imagery of IRS-1C LISS III of the year 2001.

4. Results

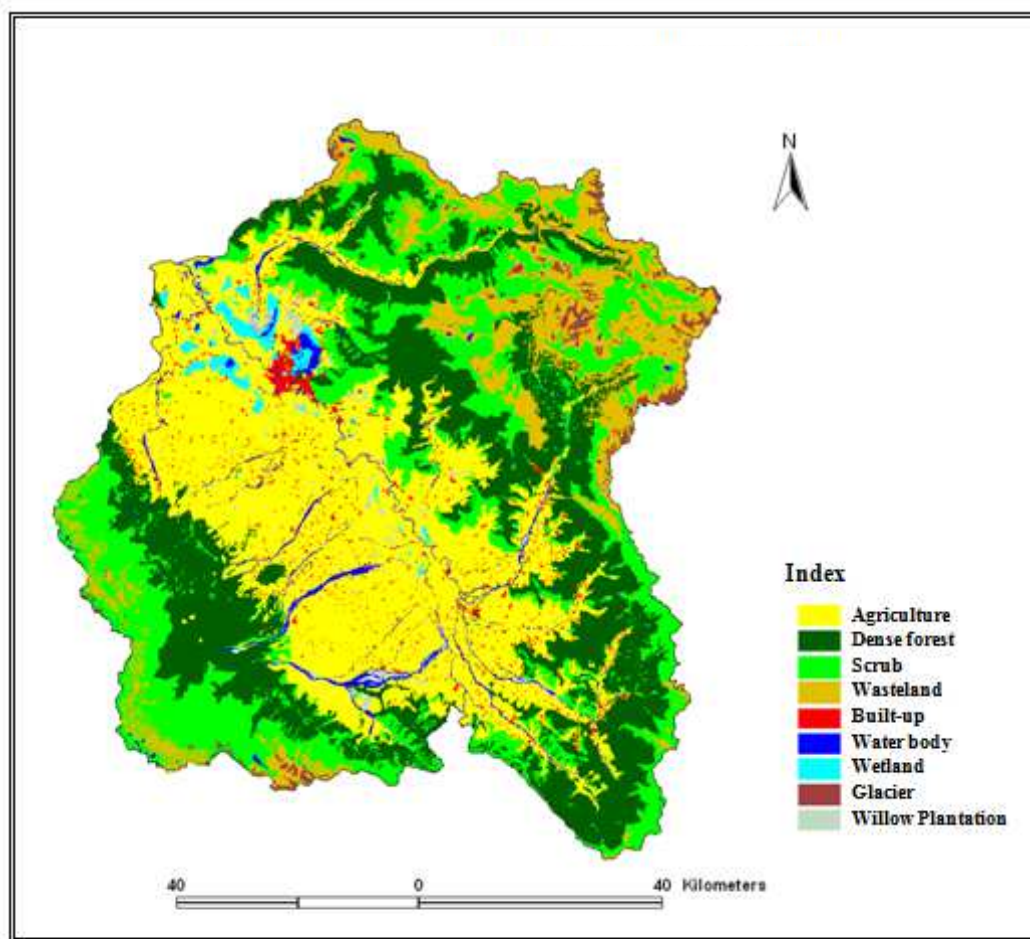
4.1. Land use/ Land cover of the Upper Jhelum Catchment (1961)

Agriculture was the dominant land use category in the Upper Jhelum catchment in 1961 followed by the Forest cover. Agriculture being practised almost

throughout the Valley floor was the dominant land use with an area of 2909.89 km². It comprised 33.83 % of the study area. Dense Forest and Scrub were the other major land cover classes comprising of 26.36 % with a total area of 2266.89 km² and 20.18 % with an area of 1735.47 km² of the study area respectively. Wasteland is spread throughout the study area along the periphery. It occupied 1059.83 km² and constituted 12.32 % of the Upper Jhelum Catchment. Willow plantation, mostly spread around the wetlands and close to the banks of the river Jhelum covered an area of 73.69 km² which was only 0.85 % of the study area. Water bodies occupied 174.04 km² which constitute 2.02 % of the study area.

Glaciers are mainly found along the higher reaches of Pir Panjal towards the south-west and Greater Himalayas but most of them are present in the lidder valley. Glaciers were extended over an

area of 99.69 km² followed by wetlands with total area of 95.28 km². Glaciers and wetlands constituted 1.16 % and 1.12 % of the study area respectively.



Source: Generated from SOI toposheets on 1: 50000 scale, 1961.

Fig. 3. Land use/Land cover (1961) in the Upper Jhelum Catchment

The land use/land cover statistics of 1961 in the Upper Jhelum catchment is given in the table 1.

4.2. Land use/ Land cover of the Upper Jhelum Catchment (2001)

The land use/land cover map of 2001 has been generated from satellite data and is given below (Fig 1.2). Table 1.1 reveals that agriculture is the dominant land use with a total area of 3283 km² which constitutes 38.2 % of the study area followed by scrub that occupies 2018.5 km² which is 23.5 % of the total area. Forest is the next major land cover category spread over an area 1305.2 km² occupying 15.2 % of the study area. Wetlands have the least coverage of the area in the Upper Jhelum Catchment. Total area under this category is 46.3 km² which is only 0.5 % of the study area.

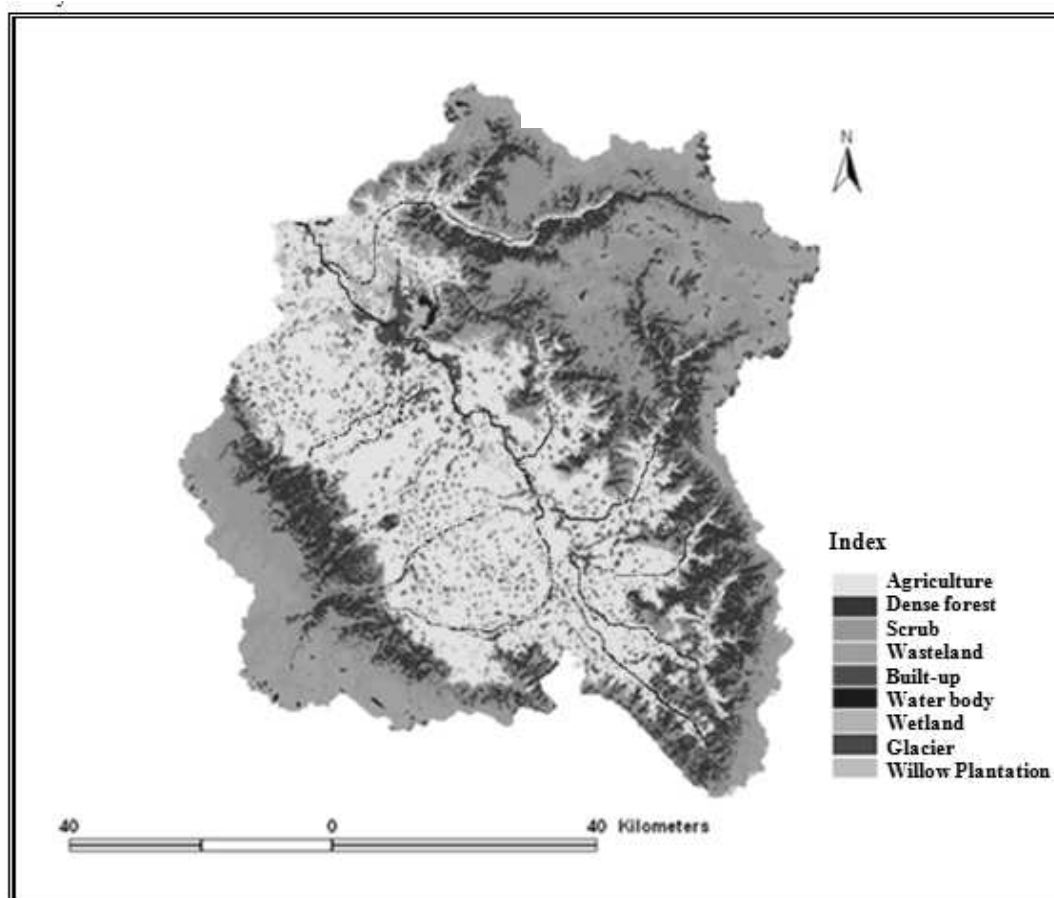
Wasteland is one of the dominant land cover categories in the study area. It occupies an area of 1253.2 km² and constitutes 14.6 % of the study area. The built-up area, which is mostly spread on the Valley floor covers 370.85 km² followed by plantation with an area of 146.43 km² constituting 4.3 and 1.7 % of the study area respectively. A total area of 122.3 km² is occupied by the water bodies which is only 1.4 % of the study area. Area under glaciers is 55 km², a little bit higher than the wetlands. They occupy on 0.6 % of the study area.

4.3. Land use/Land cover status and Change in the Upper Jhelum Catchment, 1961-2001

The land use land cover change that has occurred in the study area from 1961 to 2001 is shown in Table 1. The figures given in the table reveal that the

highest change has occurred in the forest cover. It has declined from the total area of 2266.89 km² in 1961 to 1305.2 km² in 2001 thus, registering a

decrease of 961.69 km² within a period of forty years with an average annual rate of decrease of 24 km².



Source: IRS-1C LISS III satellite image, 2001.

Fig. 4. Land use/Land cover (2001) in the Upper Jhelum Catchment

Table 1. Land use/Land cover status and Change in the Upper Jhelum Catchment, 1961-2001

Land use/land cover category	Area in km ² (%) 1961	Area in km ² (%) 2001	Change in area (%)
Agriculture	2909.89 (33.8)	3283 (38.2)	+373.11 (4.4)
Dense Forest	2266.89 (26.4)	1305.2 (15.2)	-961.69 (-11.2)
Scrub	1735.47 (20.2)	2018.5 (23.5)	283.03 (3.3)
wasteland	1059.83 (12.3)	1253.2 (14.6)	193.37 (2.3)
Built-up	186 (2.2)	370.85 (4.3)	184.85 (2.1)
Water body	174.04 (2)	122.3 (1.4)	-51.74 (-0.6)
Wetland	95.28 (1)	46.3 (0.5)	-48.98 (-0.5)
Glacier	99.69 (1.2)	55 (0.6)	-44.69 (-0.6)
Willow Plantation	73.69 (0.9)	146.43 (1.7)	72.74 (0.8)
Total	8600.78 (100)	8600.78 (100)	2214.2 (25.8)

Source: Computed from SOI toposheets, 1961 and satellite data, 2001

Scrub being one of the dominant land cover categories in the study area recorded a net increase of 283.03 km² with an average annual increase of 7.1 km². Total area under the scrub in 1961 was 1735.47 km² which has increased up to 2018.5 km² by 2001. Scrub has recorded a total increase of 2.3 % followed by wasteland that has registered an increase of 193.37 km² to its total area. Wasteland was spread over an area of 1059.83 km² in 1961 and this figure has gone up to 1253.2 km² in 2001. Net increase was of 2.3 %. On an average wasteland has increased by 4.8 km² per year. Built-up land in the study area has increased from 186 km² in 1961 to 370.85 km² in 2001, thus, registering a net increase of 184.85 km². Built-up has recorded an average annual increase of 4.6 km².

A net decrease of 51.74 km² has occurred in the water bodies located in the study area. Water bodies have decreased from 174.04 km² in 1961 to 122.3 km² in 2001 with an average annual decrease of 1.3 km². Wetlands have shown a reduction in their areal

coverage from 95.28 km² in 1961 to 46.3 km² in 2001. The total decrease in the area under wetlands has been of 48.98 km² which is a decrease of 0.6 %. Glaciers all over the world are showing a fast decreasing trend and so is the case with the glaciers situated in the Upper Jhelum Catchment. The figures related to the area of glaciers in the study area have gone down from 99.69 km² to 55 km² between 1961 and 2001 respectively, which is a total decrease of 44.69 km². 0.6 % decrease was recorded by glaciers with an average annual decrease of 1.2 km². Willow plantation has increased from 73.69 km² in 1961 to 146.43 km² in 2001 with a total increase of 72.74 km². Plantation witnessed an increase of 0.8 % in its total area coverage with an average annual increase of 1.8 km².

Various hydrometeorological parameters are shown in Table 2. Average annual discharge in the river from 1971 to 1990 is showing a decreasing trend while as the total annual rainfall is depicting an increasing trend (Fig. 5a).

Table 2. Various hydrometeorological parameters of the Upper Jhelum Catchment, 1971-1990

Year	Avg annual discharge (Cusecs)	Total annual rainfall (mm)	Discharge to rainfall ratio
1971	3095	863	3.6
1972	14878	1252	11.9
1973	24224	1158	20.9
1974	12260	816	15.0
1975	21021	1318	15.9
1976	23826	1038	23.0
1977	5113	721	7.1
1978	8910	923	9.7
1979	7957	1170	6.8
1980	9672	1019	9.5
1981	6616	964	6.9
1982	5128	1102	4.7
1983	10675	1271	8.4
1984	6483	1034	6.3
1985	15062	823	18.3
1986	12743	1342	9.5
1987	18558	1178	15.8
1988	24348	1172	20.8
1989	10860	1084	10.0
1990	8770	1126	7.8

Source: Department of Flood Control (P & D Division) and Regional Meteorological Centre, Sgr.

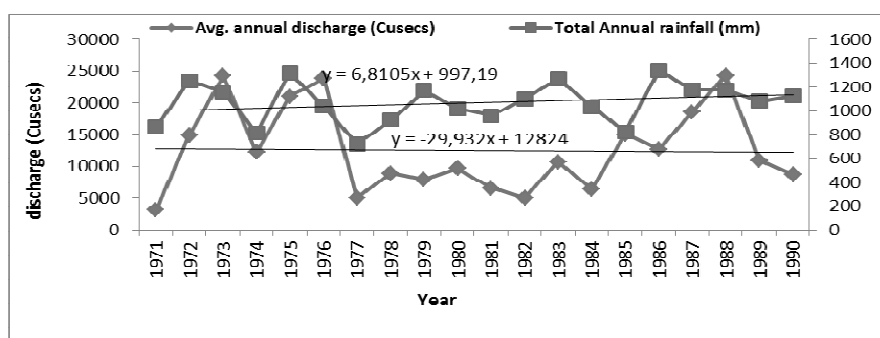


Fig. 5a. Discharge-rainfall relation, 1971-1990

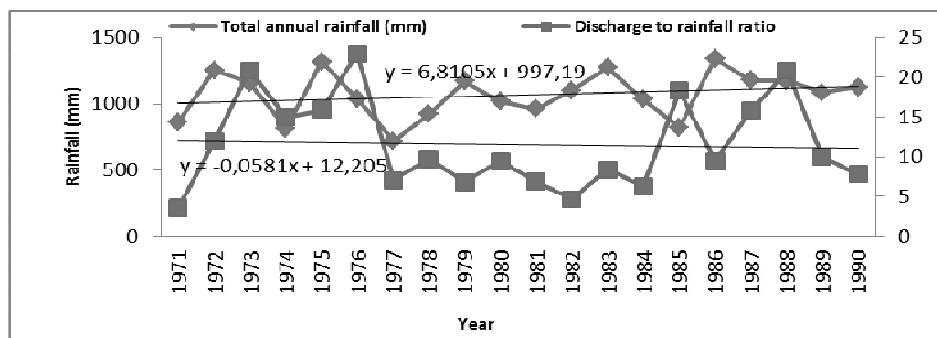


Fig. 5b. Average annual discharge and discharge to rainfall ratio 1971-1990

Table 3. Various hydrometeorological parameters of the Upper Jhelum Catchment, 1991-2010

Year	Avg. annual discharge	Total annual rainfall (mm)	Discharge to rainfall ratio
1991	10468	1039	10.1
1992	22335	1261	17.7
1993	20775	1114	18.6
1994	10401	1057	9.8
1995	27683	884	31.3
1996	26279	1090	24.1
1997	24098	967	24.9
1998	7591	982	7.7
1999	4994	828	6.0
2000	8830	905	9.8
2001	8007	897	8.9
2002	9826	802	12.3
2003	19228	1054	18.2
2004	15737	1029	15.3
2005	24098	1174	20.5
2006	27034	1194	22.6
2007	14098	754	18.7
2008	15310	845	18.1
2009	16498	766	21.5
2010	25870	1180	21.9

Source: Department of Flood Control (P & D Division) and Regional Meteorological Centre, Sgr.

Discharge to rainfall ratio has also decreased during the same time period (Fig. 5b). The decreasing nature of average annual discharge and the increasing trend of total annual rainfall are evident from figures 6a and 6b.

Since 1990 onwards, the general trend of various hydrometeorological parameters of the Jhelum

basin has changed significantly as shown in Table 3. Total annual rainfall in the study area from 1991 to 2010 is showing a decreasing trend where as the average annual discharge is manifesting an increasing trend along with the discharge to rainfall ratio (Fig. 6a and b).

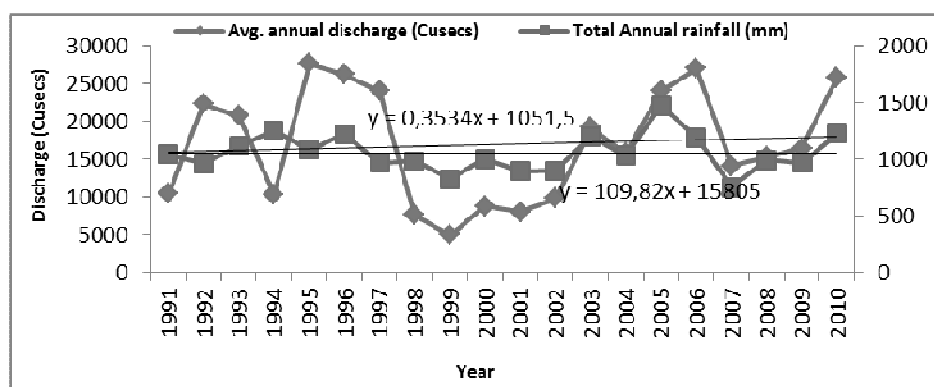


Fig. 6a. Discharge-rainfall relation, 1991-2010

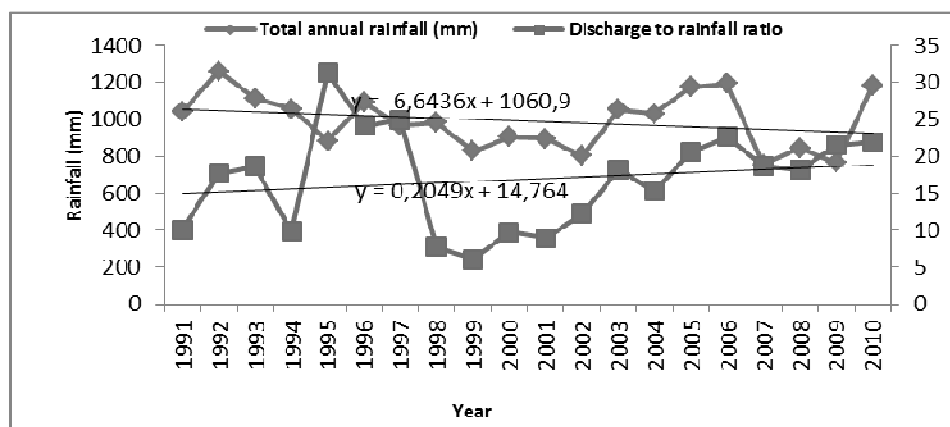


Fig. 6b. Average annual discharge and discharge to rainfall ratio, 1991-2010

Table 4. Annual peak discharge with recurrence interval and exceedence probability, 1971-1990

Peak discharge (Descending order)	Rank	Recurrence Interval	Exceedence Probability (%)
41310*	1	21.0	4.8
41100*	2	10.5	9.5
40425*	3	7.0	14.3
30665*	4	5.3	19.0
21621	5	4.2	23.8
20425	6	3.5	28.6
19801	7	3.0	33.3
18487	8	2.6	38.1
18243	9	2.3	42.9
18111	10	2.1	47.6
16410	11	1.9	52.4
15555	12	1.8	57.1
15117	13	1.6	61.9
14880	14	1.5	66.7
13501	15	1.4	71.4
11225	16	1.3	76.2
11000	17	1.2	81.0
8700	18	1.2	85.7
8674	19	1.1	90.5
4552	20	1.1	95.2

Source: Department of Flood Control (P & D Division), Srinagar. *Secondary Floods

FigureS 6a and 6b clearly show that average annual discharge from 1991 to 2010 has remained above the average discharge line for most of the years. Total annual rainfall depicts a slight decreasing trend with respect to its average rainfall line.

Recurrence interval of various annual peak discharges from 1971 to 1990 has been shown in Table 4. The annual peak discharge with recurrence interval of one year is having an average magnitude of 9609 cusecs. Similarly the value of two year recurrence interval annual peak is calculated at 16386 cusecs with an exceedence probability of 54.76% which means that an annual peak discharge with magnitude of 16386 cusecs has a probability of 54.76% to be equaled or exceeded every two years on an average. The value of annual peak discharge with five year recurrence interval is 30665 cusecs.

An annual peak with the calculated value of 41100 cusecs may be expected every ten years. The twenty year recurrence interval peak may come with a magnitude of 41310 cusecs, but the exceedence probability is only 4.8%.

It is inferred from Table 1.5 that the magnitude of annual peak discharge with different recurrence intervals has increased from 1991 to 2010. The magnitude of one year recurrence interval annual peak is 15397 cusecs and the two year recurrence interval annual peak has a magnitude of 19467 cusecs. The figures with asterisk sign show the secondary floods i.e. the floods that have over spilled the banks of the river due to the discharge beyond the retaining capacity of the channel or due to breaches caused in the banks.

Table 5. Annual peak discharge with recurrence interval and Exceedence probability, 1991-2010

Peak discharge (Descending order)	Rank	Recurrence Interval	Exceedence Probability (% age)
51638*	1	21.0	4.8
50361*	2	10.5	9.5
49677*	3	7.0	14.3
43731*	4	5.3	19.0
40886*	5	4.2	23.8
36867*	6	3.5	28.6
27728*	7	3.0	33.3
27534*	8	2.6	38.1
25697*	9	2.3	42.9
21913*	10	2.1	47.6
18281	11	1.9	52.4
17760	12	1.8	57.1
16721	13	1.6	61.9
16428	14	1.5	66.7
14740	15	1.4	71.4
14343	16	1.3	76.2
13404	17	1.2	81.0
12880	18	1.2	85.7
9285	19	1.1	90.5
27728	20	1.1	95.2

Source: Department of Flood Control (P & D Division), Srinagar. *Secondary Floods

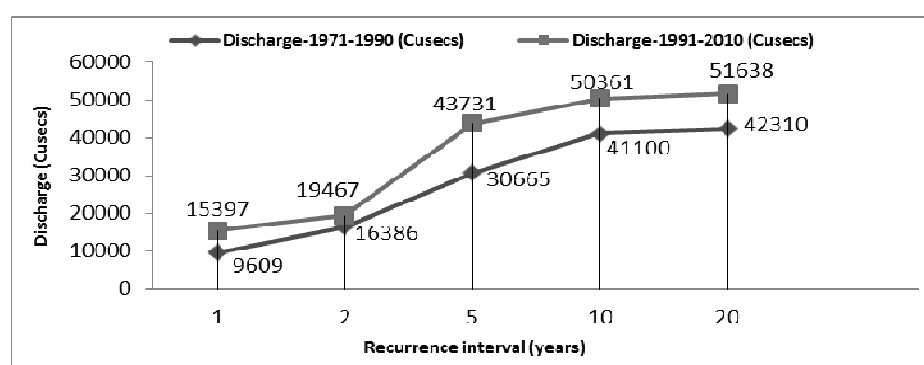


Fig. 7. Comparative analysis of peak discharges between 1971-1990 and 1991-2010

An annual peak discharge of 43731 cusecs, 50361 cusecs and 51638 cusecs may be expected every five, ten and twenty years with the exceedence probability of 19%, 9.5% and 4.8% respectively. It is clear from Figure 7 that the volume of discharge associated with the annual peak discharges has been substantial from 1991 to 2010 as compared to the period 1971-1990.

5. Conclusion

The results revealed that the detected land use changes have increased peak discharges and flood runoff volumes within the catchment. This effect was more severe within the upstream areas where higher rates of deforestation and agricultural expansion were rampant. However, the relative increases in the peak discharges were noted to diminish with increasing rainfall amounts. This portended that the detected land cover changes did

not have a strong influence during large storm events. The results of the analysis have highlighted the remarkable sensitivity of the flood flow regime in response to the occurred land use changes, which implies an increase in the magnitude of peak discharges of a given frequency. Precipitation is a major factor controlling the hydrology of a region. For this purpose total annual rainfall and runoff data from 1971 to 2010 were plotted to analyze the rainfall-runoff relationship in the study area. The investigations show that changes in land use has produced significant change in the peak flow and the average discharge. From 1971 to 1990 there have been only four floods while as the river Jhelum has flooded ten times from 1991 to 2010. From 1991 onwards the study area witnessed good number of dry years. Despite this fact, five floods have been recorded from 2001 to 2010 as discharge to rainfall ratio increased due to the changing land use pattern in the upper catchments.

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Land degradation in the lower catchment of the Crasna river (Central Moldavian Plateau)

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Abstract. Land degradation has been recognized as an important environmental threat in the Moldavian Plateau of eastern Romania. The cumulated action of natural factors, especially the coupling of the Kersonian sandy-clayey facies and the hilly fragmentation as well as anthropogenic ones resulted in triggering degradation processes, especially soil erosion, gully and landslides. In addition, another issue of interest is the reservoir sedimentation.

Land with slopes over 5% is subjected to soil erosion with different intensities and it represents the process with the highest extension. Landslides represent the most relevant geomorphological process, affecting particularly the cuesta fronts and amounting up to 34.6 % of the study area. Locally, where in the bedrock appear loose sandy and sandy-loamy layers, numerous valley-bottom gullies and valley-side gullies have developed, some with an impressive growth.

Even if through soil erosion, gully and landslides are carrying significant quantities of solid material to the base of slopes, the average rate of sedimentation in reservoirs remains relatively low.

Keywords: landslides, soil erosion, gully, sedimentation.

1. Introduction

Land degradation is defined as “*the total or partial removal of an area from the economic circuit through various geomorphic processes (soil erosion, landslides, sedimentation etc.)*” or as “*the gradual reduction in relief height through the destructive action carried out by external geomorphic agents*” (Băcăuanu et al., 1974).

Among land degradation processes, for the lower catchment of Crasna, of most interest, both in terms of damage and affected areas, are soil erosion, gully erosion, landslides and sedimentation. Since 1960, these processes have attracted the attention of many experts in agronomy, forestry, land improvement, soil science, geography, etc. As a result of the many deployed efforts by the end of 1980s, it was possible to implement different soil conservation practices on half of the land with degradation potential within the study area.

Since 1990, new Land Reforms have been implemented in Romania. The impact of implementing two major provisions of Act No. 18/1991 was very severe on soil conservation and crop yields. One of these stipulates that land re-appropriation has *to be usually applied on the old locations*. In most cases, this means that the layout of plots is orientated up-and-down slope. The second provision refers to ‘*successors*’ rights up to the 4th degree of kinship. Consequently, the rate of land division has sharply increased and today there

are over 46 million small individual plots. An added Act (No. 1/2000) focuses on forestland division for private ownership. The major effect of these Acts is the revival of traditional agricultural systems, especially the up-and-down hill farming. Another major problem over the recent decades is that the State ceased the funding of conservation practices and such an investment is not a high priority for landowners. However, the merging of some agricultural land through the establishment of free associations or by taking on leasing can be noticed over the last few years in the study area, and *there* contour farming can be performed again.

Located in the eastern part of Central Moldavian Plateau, the lower catchment of the Crasna river, upstream of the junction with the Lohan river, has 16 491 ha, which represents 31% of the total catchment (Fig. 1). From a territorial-administrative point of view, it is stretching entirely within the Vaslui County, partially overlapping the territories of the Albești, Boțești, Crețești, Munteni de Sus, Munteni de Jos, Olteneste, Solești, Tanacu, Tătărăni villages and Vaslui municipalities.

Erosion revealed sedimentary loose, Kersonian, Meotian and Quaternary formations, namely clay, sand and weakly cemented cineritic sandstones.

Altitudes vary between 84 m at the junction with the Lohan river and 412 m in the northern part of the basin, in the Popești Hill. Slopes record average angles of 19.7%, the lowest characterizing the main floodplains and the highest ones the main cuesta fronts.

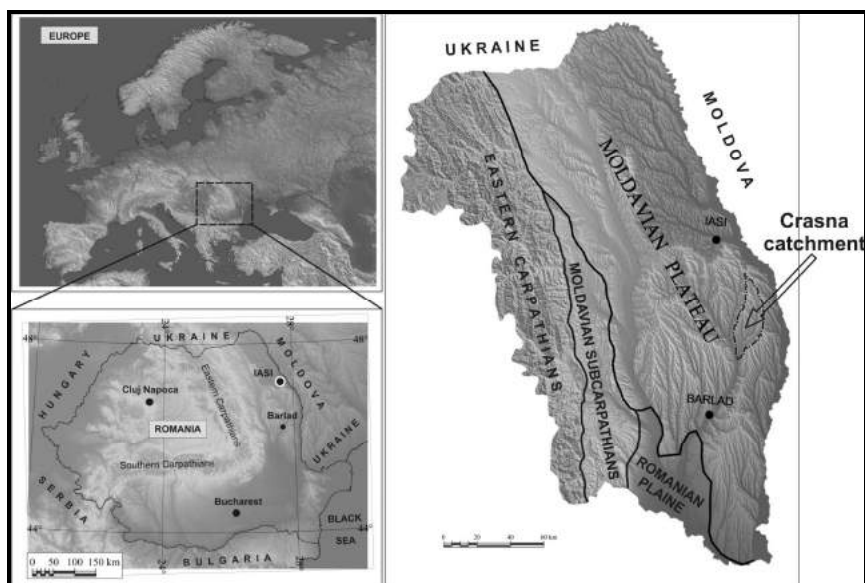


Fig. 1. Location of the Crasna catchment in the Moldavian Plateau of eastern Romania

All the specific landforms developed in a hilly-rolling/hilly region developed on a homocline have been identified in the Crasna catchment. The highest extension is represented by the sculptural relief (fluvio-denudational landforms) within a general homoclinal structure (80%), followed by depositional (17%) and structural-lithological landforms (3%).

Taking into account the ENE-WSW orientation of the lower Crasna valley, one of the most representative examples of cuesta landforms occur associated to its subsequent position. Thus, the left valley-side is a vast cuesta front (antidip slope) facing NNW, almost uniform, while the right valley-side exhibits a very broad cuesta backslope (dip slope) looking SSE and deeply incised by resequent tributaries. At their turn, the valleys of those tributaries display the structural asymmetry by second degree, where typical are a westward looking cuesta front on the left valley-side and an eastward facing cuesta backslope on the right valley-side (Fig. 2). Those two systems of cuestas are associated with the double dipping of the underlying strata to the south and to the east, and from their combination the general homocline structure is resulting (Ionita, 1998, 2000a).

The study area has a temperate continental climate with shades of excessivity, underlined by high values of thermic amplitude and by a frequency of heavy rainfalls. The average precipitation amounts to 534 mm yr⁻¹ and the average annual temperature is 9.7° C at the Vaslui weather station over the period 1961-2008.

In terms of water discharge regime, flash floods triggered by snow-melt and overlapping with

certain rains during late winter and early spring are distinguished. Floods induced by heavy rainfall during the warm season are more frequent in May and June, followed by shallow flows over autumn-winter.

The natural vegetation includes species belonging to the silvo-steppe and broadleaf forests but over large areas it was replaced by agricultural crops that fail to provide the same protection to the soil.



Fig. 2. Cuesta landforms along the resequent Burghina Valley. Eastern looking cuesta backslope in the foreground and western looking cuesta front in the background (October 1st 2011).

By processing information from the soil surveys deployed in the lower catchment of the Crasna, 7 soil classes and 11 soil types could be counted. Widespread surfaces, covering almost half of the area (7 742 ha), belong to the cernisol class. The increased weight of eroded anthrosols and regosols (26%) emphasizes the development and the intensity of the degradation processes.

The human impact is a first-order controlling factor in triggering recent land degradation processes, through deforestation, overgrazing, improper farming etc.

2. Materials and methods

In order to reach the proposed objectives, both traditional research methods (analysis, synthesis, mathematical-statistical processing, field observations and mapping) and modern methods based on the GIS softwares were used. The cartographic material was obtained by using TNTmips v.6.9 software and statistical processing was done using Microsoft Office Excel 2007.

A very important step in the spatial modelling of land degradation consisted in achieving the Digital Elevation Model by vectorizing contour lines on 1:5 000 scale topographic plans. Then, different thematic maps have been released for the complex analysis of land degradation processes, such as the hypsometric, slope angle and slope aspect maps. Also, the following data were of interest:

- The geological map of Central Moldavia between the Prut and the Siret rivers (Jeanrenaud, 1971);
- Climatic data from the Vaslui and Huși weather stations;
- Hydrologic measurements recorded at the Mânjești hydrometric station;
- Soil surveys for the Albești, Boțești, Crețești, Munteni de Sus, Munteni de Jos, Oltenești, Solești, Tanacu, Tătărași villages and Vaslui municipalities, carried out by O.J.S.P.A. Vaslui since 1980.
- Corine Land Cover maps (2000) and aerial orthophotos from 2005 to identify some features of the geomorphological processes and highlight land use.

The map of soil erosion intensity was made by processing information obtained from soil surveys at a scale of 1:10 000. The distribution of gullies

and landslides resulted from bringing together the data collected during field stages and the ones taken from the 2005 orthophotos and the 1:5 000 scale topographical plans.

In order to estimate the average sedimentation rate within reservoirs the Cs-137 technique has been used. The sediment samples were collected at intervals of 50 mm and then analysed at the Institute of Physics and Nuclear Engineering „Horia Hulubei” Măgurele – Bucharest.

3. Results obtained

3.1. Soil erosion

Among the degradation processes, the largest spatial extension is associated with water soil erosion affecting with different intensity the slopes with gradients above 5%. This results in the displacement of soil and/or rock particles by rainsplash and runoff as dispersed and concentrated flow (Moțoc, 1963; Moțoc et al., 1975).

The extent and the intensity of soil erosion are strongly connected to some favourable natural conditions (the prevalence of Kersonian loose sedimentary layers, the large extent of the steep slopes, heavy rainfalls, low density of vegetation, soils with light texture and low organic matter content etc.), as well as an inappropriate land use.

Figure 3 and Table 1 give the image of the spatial distribution and intensity of soil erosion on the agricultural lands of the lower Crasna river catchment.

Half of the 13 872.5 ha agricultural land is subjected to moderate to excessive soil erosion and that area raises great concern regarding the implementation of soil and water conservation practices at a larger scale than today. The highest intensity of soil erosion characterizes the cuesta front slopes and degraded backslopes, with angles over 25%, while non-appreciable erosion is specific to floodplains, hilltops, structural-lithological plateaus and slightly degraded backslopes (Fig. 4).

Table 1. Soil erosion intensity on the agricultural land in the lower catchment of the Crasna River

Soil erosion classes	Surface (ha)	Weight (%)
Excessive	608.3	3.7
Very severe	1 397.2	8.5
Severe	1 883.5	11.4
Moderate	1 196.6	7.3
Slight	2 733.3	16.6
Non-appreciable	5 706.2	34.7
Total	13 525.1	82.1

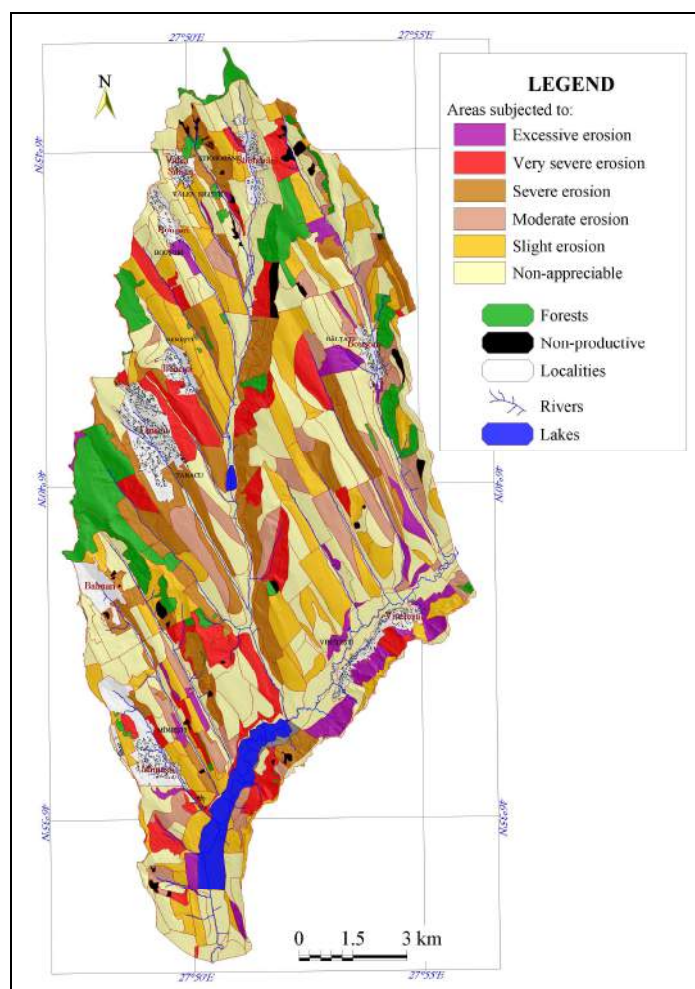


Fig. 3. The soil erosion intensity on the agricultural land in the lower Crasna catchment (based on the processing of pedological surveys from O.J.S.P.A. Vaslui)

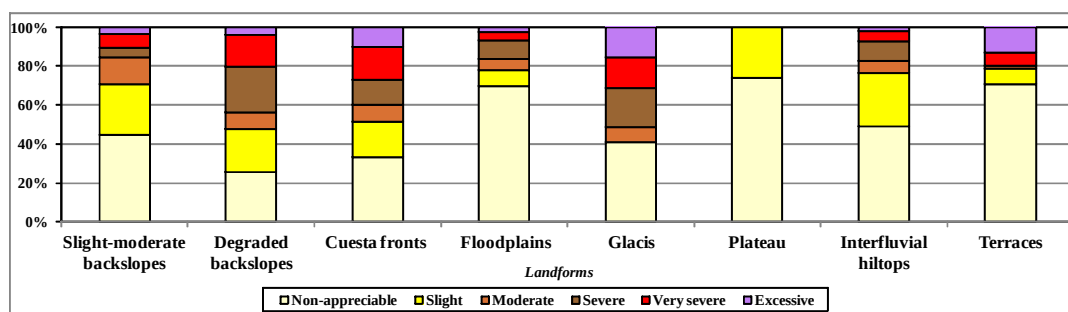


Fig. 4. The weight of soil erosion intensity classes on agricultural land by landforms

Soil erosion determines the changing of some physical, chemical and biological properties of soils, thereby reducing soil fertility and crop yields. The most affected soils by erosion are anthrosols, particularly the eroded ones and regosols, at the other end being aluviosols, solonchaks and gleiosols (Fig. 5).

The intensity of soil erosion is strongly related to the farming system, namely the traditional up-and-down farming or the contour farming. Of the total of 16 491 ha, agricultural land occupies 13 525 ha (82%), of which 9 072 hectares are arable land. The

poorly farmed complex agricultural land, the poor pastures and the abandoned vineyards and orchards are also depicted by the high intensity of soil erosion (Fig. 6).

Data collected in the Tutova Rolling Hills over a 30-year period on the runoff plots located on slightly eroded cambic Chernozems, indicate the following (Ionita, 2000c, Ionita et al., 2006):

- Mean annual precipitation is 504.3 mm and precipitation which causes runoff and erosion occurs during the crop-growing months of May-October.

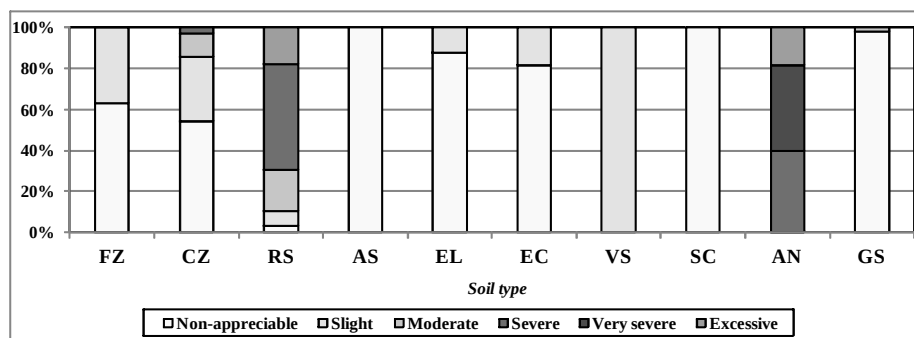


Fig. 5. The weight of soil erosion intensity classes on agricultural land by soil types

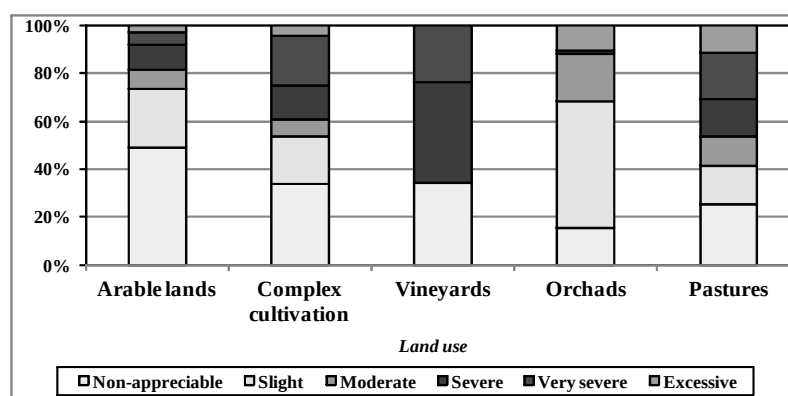


Fig. 6. The weight of soil erosion intensity classes on agricultural land by land use

- About 26% (133.5 mm) of annual precipitation induces runoff/erosion on continuous fallow and 18.5% (93.5 mm) on maize.
- Runoff ranges from 36.5 mm under continuous fallow with a peak of 12.0 mm during July, and 17.7 mm under maize with a peak of 6.5 mm during June.
- Mean soil loss is $33.1 \text{ t ha}^{-1} \text{ yr}^{-1}$ for continuous fallow with a peak of 12.8 t ha^{-1} during July, and $7.7 \text{ t ha}^{-1} \text{ yr}^{-1}$ for maize with a peak of 3.7 t ha^{-1} during June.
- The critical soil erosion season is the two months from late May to late July.

Soil losses have doubled on severely eroded forest soils due to their higher erodibility. Data collected from a continuous fallow plot and processed using a 3-year moving average revealed that over the period 1970-1999 there were three peaks. These are placed at 1975, 1988 and 1999 (Motoc et al., 1998; Ionita, 2000c).

3.2. Gully erosion

Gully erosion has a secondary role in the lower catchment of the Crasna, without reaching the magnitude noticed in other subunits of the Barlad Plateau, namely the Falcu Hills and the Tutova Rolling Hills.

By putting together field information with data retrieved from the orthophotos of 2005, 825 gullies were inventoried. These cover 150.4 ha representing 0.9 % of the total area (Fig. 7 and Table 2). Numerically, valley-side gullies prevail in the form of discontinuous gullies, which are either single (isolated) or successive (chain), and generally have small dimensions. Most of them developed due to runoff concentration along previous up-and-down hill roads. The valley-bottom gullies occupy a larger area, of 93.8 ha, and, unlike the first ones, they are more developed.

Table 2. The area under gullies within the lower Crasna catchment

Gully type	Number	Total area (ha)	Mean area of one gully (ha)	Weight	
				of the total gullied area (%)	of the total catchment (%)
Valley-side gullies	51	56.7	1.1	37.7	0.3
Valley-bottom gullies	774	93.8	0.1	62.3	0.6
Total	825	150.4	0.2	100.0	0.9

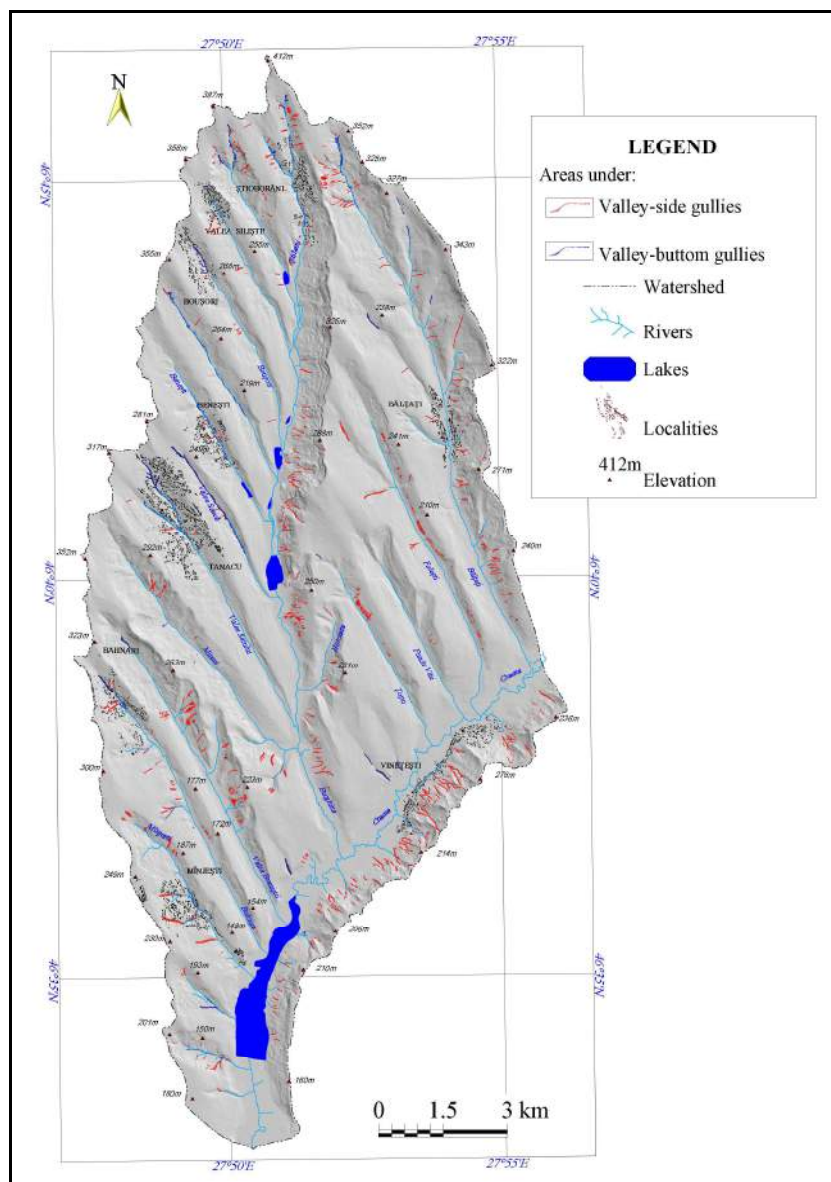


Fig. 7. Distribution of gullies within the lower Crasna catchment

The most significant areas affected by gully erosion are found on the cuesta fronts and on the highly degraded backslopes, while on hilltops, structural-

lithological plateaus and terraces, gullies are very poorly represented (Fig. 8).

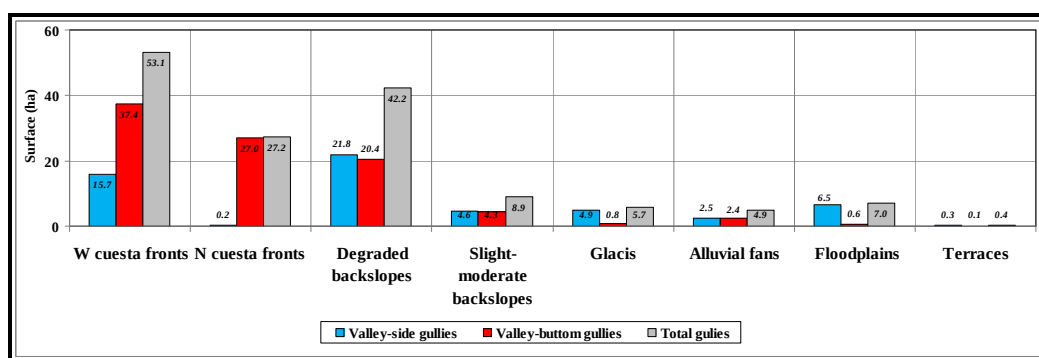


Fig. 8. The histogram of surfaces under gully erosion for each landform

Gullying is a serious problem of contemporary society causing significant damage to agriculture and to socio-economical objectives. For this reason, by 1990 a lot of land reclamation works have been deployed in the area, especially concrete dam structures which are currently in an advanced degradation stage and the setting of false acacia plantations.

As to gully development in the Barlad Plateau, the long term findings obtained by Ionita (1998, 2000b, 2007) and Ionita et al., (2006) are as follows:

- Gully erosion rates have decreased since 1960, but still remain at high levels.
- The mean annual regime of gullying over the period 1981-1996 exhibited pulsatory activity.
- During this 16-year monitoring period, 57% of total gullying occurred during the cold season (late winter), with the remainder occurring during the warm season.

- The critical period for gullying is during the four months between 15-20 March and 15-20 July.

3.3. Landslides

Landslides are the most representative degradation process, holding a critical role in land morphogenesis in the lower catchment of the Crasna river. The considerable development and the extent of landslides in the study area are the result of several factors. The category of potential factors includes the alternation of permeable and impermeable layers and the pre-existing landscape characteristics (slope, relief amplitude). Among the preparatory factors rainfall distribution and deforestation are to be mentioned. Important triggering factors are groundwater fluctuation, freeze-thaw cycles, slope angle changes by undercutting, some earthquakes, overloading of slopes with constructions, etc.

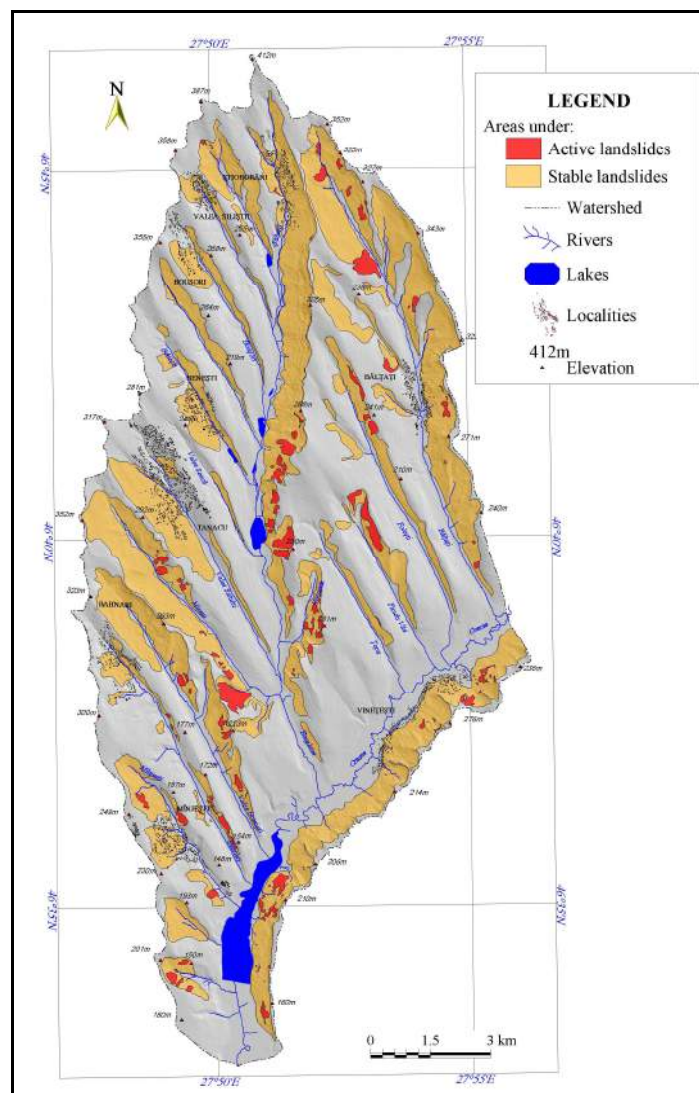


Fig. 9. Distribution of landslides within the lower Crasna catchment

Table 3. The surfaces under landslides in the lower Crasna catchment

Landslide type	Total area (ha)	Average weight (%)	
		of the total catchment area	of the area under landslides
Active	980.9	5.9	17.2
Stable	4 720.8	28.6	82.8
Total	5 701.7	34.6	100.0

Figure 9 and Table 3 show the distribution of landslides within the lower Crasna catchment, where these are extending on 5 701.7 ha representing 34.6% of the total area. Most of the landslides are stabilized, while those active occupy small areas, and have developed by reactivation of the old ones. The recent peak of landslides' reactivation was triggered by the higher amount of precipitation occurred over the 1968-1973 period.

The most sensitive slopes to landslides are found where the elevation varies between 150-250 m, and

the slope angle is above 25% (Fig. 10). By far, the northern and western looking cuesta fronts are subjected to moderate to deep-seated landslides covering about 4 165.5 ha (73% of the total area under landslides); the most affected are the Crasna, Burghina and Bălțați cuesta fronts (Fig. 11). They also develop on highly degraded backslopes.

Morphologically, many landslides in the study area are mixed, usually as step-like and waves-like landslides but the most typical are landslide amphitheatres, locally called *hartop* (Fig. 12).

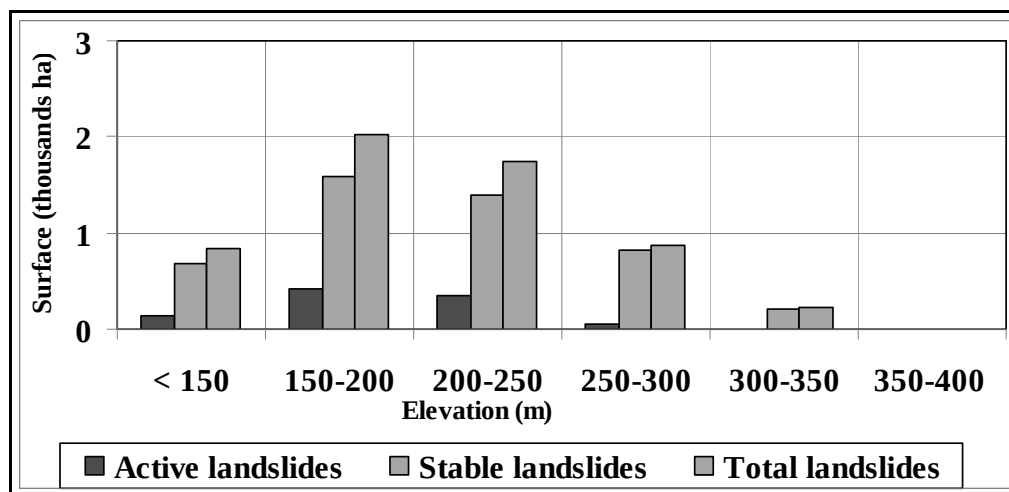


Fig. 10. The histogram of areas under landslides by elevation classes

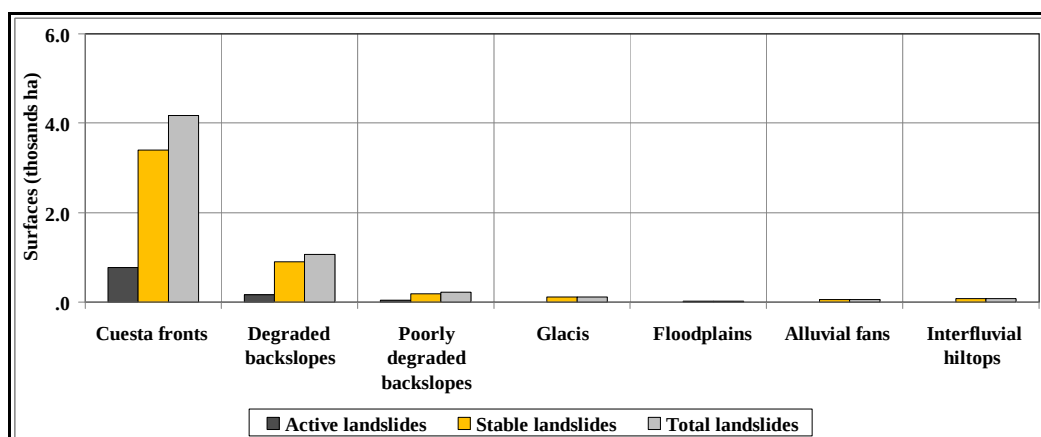


Fig. 11. The histogram of surfaces affected by landslides for each landform



Fig. 12. Simple landslide *hartop* (amphitheatre) on the left valley-side of the Crasna at SSW of Vinetesti. In the background the Lohan Valley appears (October 3rd 2013).

3.4. Sedimentation

From the soil detached through water erosion, gullying and landslides, small amounts either leave the catchment or are partly deposited on slopes, while another part reaches the floodplains, causing their aggradation and reservoir siltation.

By taking advantage of the Cs-137 technique as a tracer, it was possible to date the particular sediment levels associated to the Chernobil nuclear accident from April 26, 1986 or to the peak of the nuclear bomb testing in 1963. Then the rates of deposition for different periods of time were accurately calculated.

The Cs-137 depth profile in the Țopu reservoir, built in a small catchment of 1.192 ha associated to a right tributary of the Crasna river, shows us an average sedimentation rate of 1.7 cm yr⁻¹ between 1963-2011 (48 years). However, the average rate of sedimentation of 2.4 cm/year over the period 1963-1986 was double if compared with one of the 1986-2011 period (Fig. 13). The relatively high value of the sedimentation rate before 1986 resulted from the higher amount of precipitation between 1968 and 1973. Then, the sedimentation rate started to decrease due to the influence of implementing soil erosion control practices (Ionita et al., 2000 and 2007).

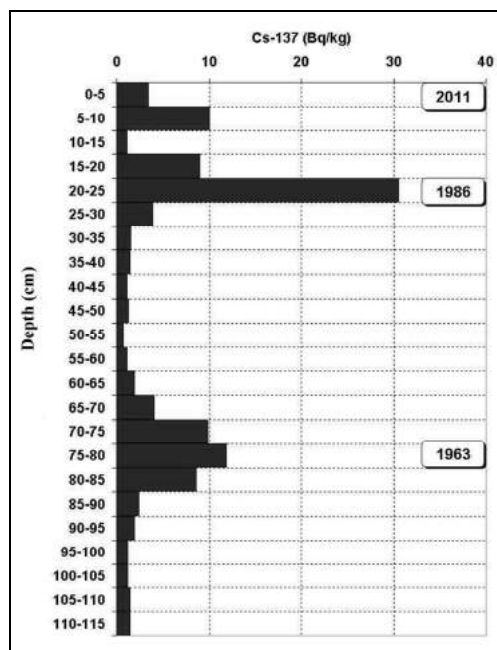


Fig. 13. Distribution of the Cs-137 in the Țopu reservoir (October 2th 2011)

4. Conclusions

1. The main controlling factors, natural and human, have induced significant land degradation within the hilly area of the Crasna catchment.
2. The change of the natural vegetation cover and improper farming decisively contributed to a high risk of soil erosion in more than half of the agricultural land.
3. Landslides represent the most typical degradation process and cover 5 702 ha representing 35% of the total area.
4. The recent reservoir sedimentation rate exhibits low-moderate values.

Acknowledgements

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Evolution of Sulina mouth bar (Danube river)

Marius BUDILEANU

Abstract. This paper studies the dynamics of the Sulina branch mouth by analyzing the influence of human intervention on sediment deposition at the point at which the Danube river empties into the sea. The surface and volume of the bar and southern spit at the Sulina branch mouth are calculated for the first time using advanced techniques.

The methodology consisted in georeferencing and vectoring the maps produced by the European Commission of the Danube (ECD), followed by a morphometrical separation of the bar and southern spit in the resulting models (from a 5 m depth to the surface). The ECD performed the first improvement works in the Danube Delta; the role of the jetties was to exceed the length of the bar which, in its natural state, extended over the entire mouth. The highest bar development rate was recorded between 1920 and 1925, when the volume of sediments in front of the jetties reached ~2.5 mil. m³. After 1930, both the surface and volume of the sediment deposition rates sharply decreased, due to the change in jetty direction and intensive dredging at the mouth.

Keywords: Sulina, Danube, European Commission of the Danube, jetties, bar, spit

1. Introduction

Deltas are accumulations of sediment deposited where rivers enter into the sea (Masselink, 2003). Delta systems are among the most important mediums of coastal sedimentation, with important underground resources such as oil, gas and groundwater (Giosan, 2006). Deltas have always been preferred as places of human habitation, approximately 25% of the world population living in deltaic areas or at the mouth of large rivers (Szvitski, 2005). The percentage is lower in Romania, where only 6.3% of the country population lives within 100 km distance of the coastline (Schwartz, 2005). According to the latest theory of Danube Delta genesis, based on modern analysis methods, developed by Giosan et al. in 2005, the formation of the delta started approximately 5200 years ago. A key aspect to mention is the evolution of the Sulina branch, which started approx. 3640 years ago and was completed approx. 2200 – 1800 years ago, and subsequently entered an erosion stage.

The mouth bar is formed where a delta branch discharges into the sea in *hypopical conditions* (the river water density is less than that of the water into which it discharges) (Schwartz, 2005). The difference in density is caused by the sea water salinity; in front of the Sulina mouth it is approximately 16 ‰ at the surface and 19 ‰ in deep water (Bondar, 2011). The mouth bar

represents a “*complex accumulative formation that forms at the mouth of a channel flow in the zone of sediment deposition because of the sea-water interaction*” (Dolgopolova & Mikhailova, 2008). The contact between the different masses of water is made via fluvial water flows under the influence of sea waves and tides (Bondar, 2011). This type of contact contributes to the formation of a cusped bar (Masselink, 2003), and further into the sea sediments can be redistributed under the influence of waves, with a subsequent phase of mouth asymmetry, with the bar anchored on one of the shores (Bhattacharya, 2003; Giosan, 2005).

2. Local characteristics

Articles 15 and 16 of the Treaty of Paris, signed on 30 March 1856, establish the European Commission of the Danube (Rosetti & Rey, 1931). This institution was “*charged to designate and to cause to be executed the Works necessary below Isatcha, to clear the Mouths of the Danube, as well as the neighbouring parts of the Sea, from the sands and other impediments which obstruct them, in order to put that part of the River and the said parts of the Sea in the best possible state for Navigation. The Flags of all Nations shall be treated on the footing of perfect equality.*” (Rosetti & Rey, 1931).

The Sulina mouth was chosen for the improvement works upon demand of the merchants in Brăila and Galați and initially the project was approved as a temporary measure, until the ECD

found the financial resources to initiate improvement works on the Sf. Gheorghe branch. The solution proposed by Chares Hartley, engineer-in-chief of ECD, was to guide the river runoff further into the sea, by a system of parallel jetties. Practically, this method increases the speed of the

fluvial current, thus enhancing the transport capacity. The expected outcome of these works was to exceed the length of the mouth bar (the main obstacle for navigation) and to cause the bar to form deeper into the sea and no longer affect navigation at the mouth.

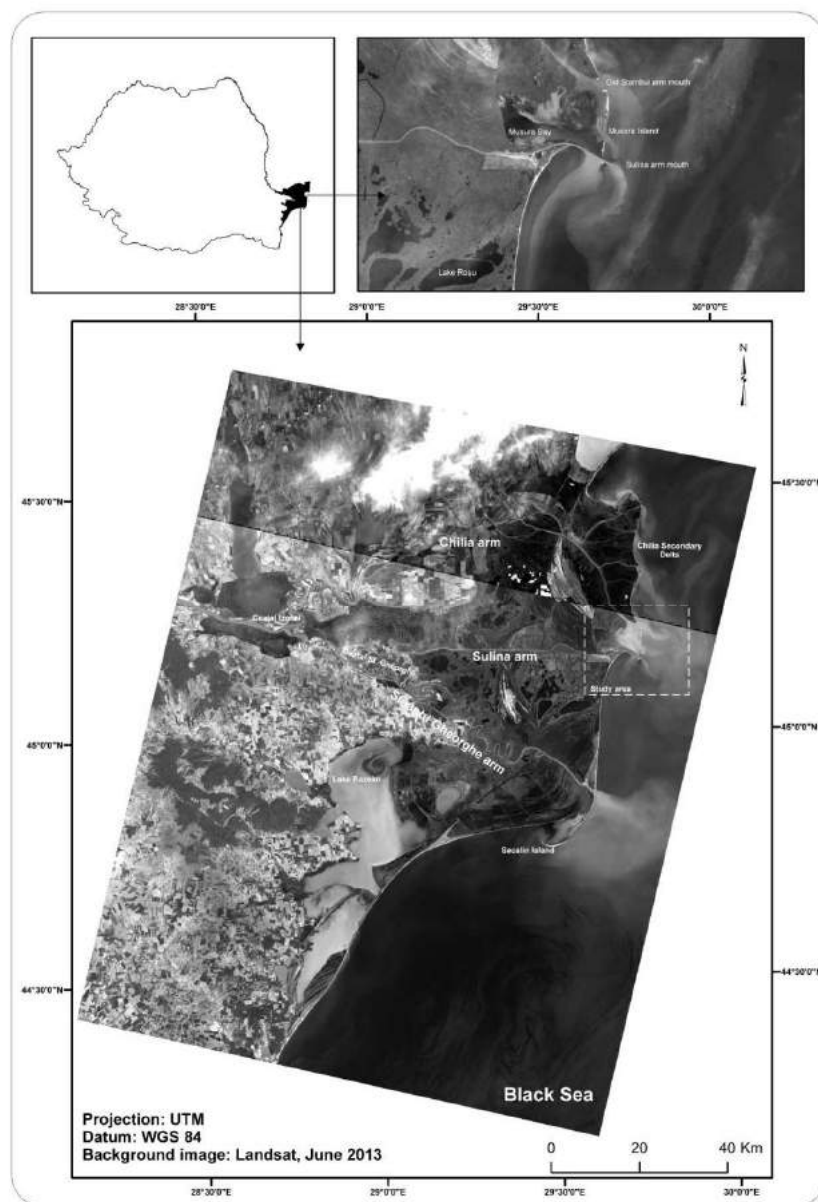


Fig. 1. Position of the Sulina mouth within the Danube Delta

The initial (temporary and then permanent) consolidation works started in 1858 and were completed in 1872; the jetties measured a total length of 2678.8 m (8789 feet), the northern jetty measured 1625.1 m (5332 feet) and the southern jetty measured 1053.6 m (3457 feet). (Hartley, 1862, 1873). The decision to elongate the jetties was taken in 1925, due to navigation problems caused by the southern spit. The works were performed in two stages and were completed in 12 years (1925-1932

and 1933-1937). The first stage started offshore towards the old jetties, to prevent complete obstruction of navigation in the area, and the second stage involved changing the direction of the jetties. The measure to change the jetty direction was taken to counteract the extremely high sediment deposition rates in the Musura Bay. The jetties were elongated further after 1944 and until 1982 (Vespremeanu, 1983). Two very active periods can be identified: 1944-1956 with an extension of 400 m

and 1956-1982 with an extension of 3000 m. The jetties currently measure 9300 m from the point where the construction works started in 1858.

Starting with 1894, the ECD also performed regular mouth dredging works (Rosetti & Rey, 1931), and after 1940 these works were resumed by the Romanian government, which took charge of fluvial navigation (via various government agencies such as the Direction of Maritime Danube, Hydrographic Direction of the Danube, River Administration of the Lower Danube, etc.).

Other works that influenced the bar and southern spit were the meander cut-off works performed by the ECD on the Sulina branch between 1868 and

1902, as well as the construction of the Ceatal Izmail embankment. These activities were intended to straighten and shorten the Sulina branch, thus the speed of the river current increased and a direct consequence was an increase in the distributary discharge between 1900 and 1960 (Bondar, 2010, 2011).

The solid discharge of the Danube was significantly influenced by the construction of hydrotechnical facilities, registering minimum amounts of 337 kg/s after the 1950s, as opposed to the maximum amount of 4428 kg/s reached in 1870. Rădoane (2005) indicates a number of 207 dams built on the Danube and its tributaries after 1940.

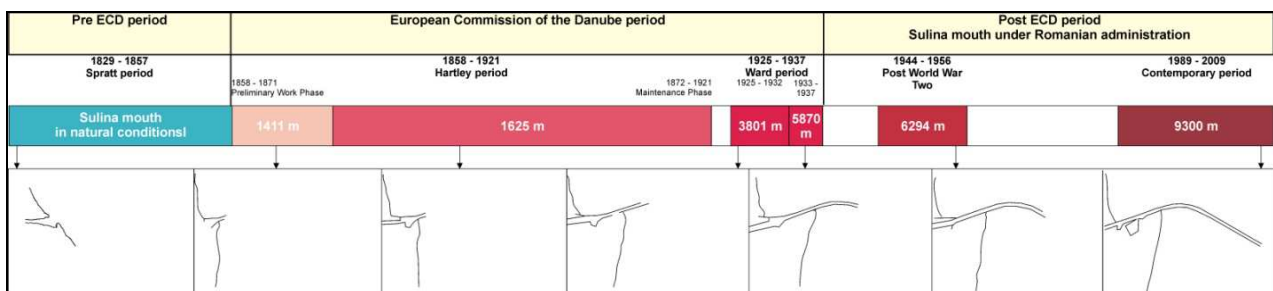


Fig. 2. Jetties at the Sulina mouth and length per periods

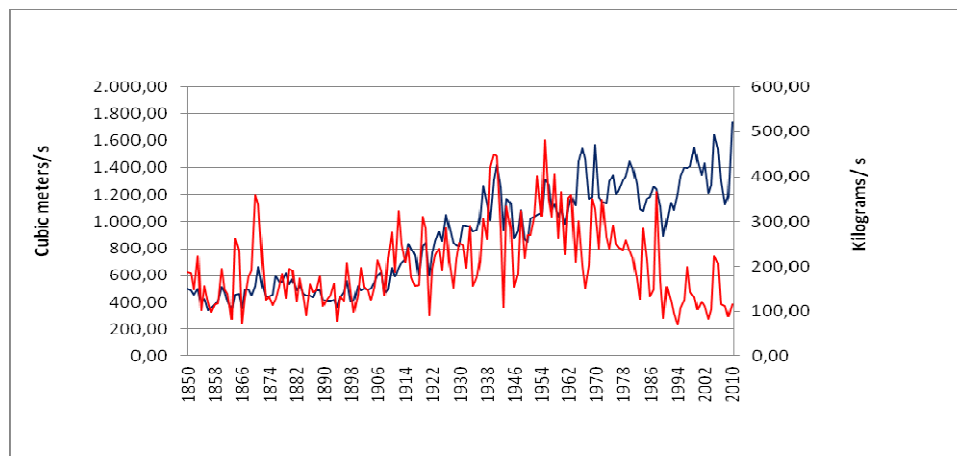


Fig. 3. Average fluid discharge (blue) and solid discharge (red) on the Sulina branch between 1850 and 2009 (adapted from Bondar, 2010 and 2011)

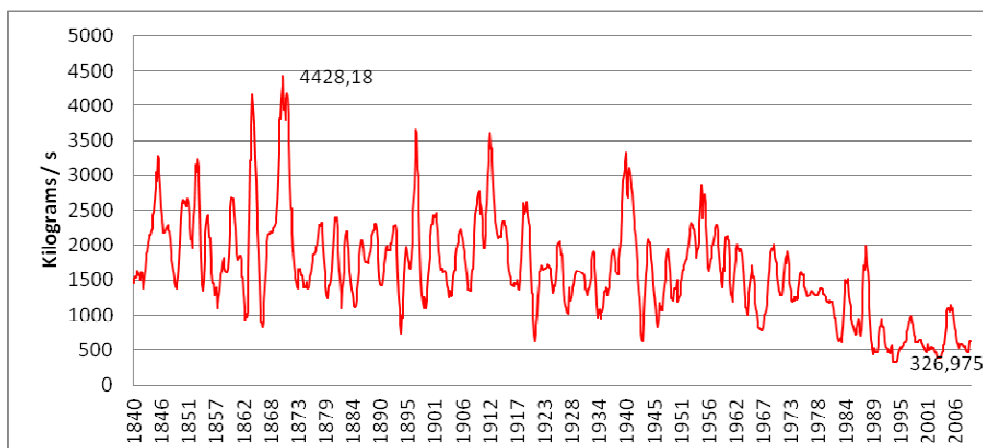


Fig. 4. Solid discharge at Ceatal Izmail (Bondar, 2010 and 2011)

3. Methodology

Research was primarily based on cartographic material of the European Commission of the Danube and the River Administration of the Lower Danube (AFDJ). The ECD maps have a 500-foot grid with the old lighthouse as a foundation, but there are no data concerning the geographic system of coordinates, projection, ellipsoid or datum (Constantinescu et al., 2010). The georeferencing method was *image to image*, using at least 10 control points. The UTM projection, datum WGS 84, area 35 N, was used (code EPSG 32635), the AFDJ maps were initially georeferenced using their own projection (6-degree Gauss-Krüger, zone 5, Datum S-42 [Pulkovo 1942]), and subsequently converted to UTM.

Georeferencing was followed by vectoring and creation of the digital bathymetric model (DBM). The interpolation method was *Natural Neighbor*,

and the resulting model had a 20 m spatial resolution. This method is the most appropriate in this context of high point densities in certain areas and low densities in others (Giosan et. al, 2006). A total number of 422 bathymetric maps of the Sulina mouth were indexed, 190 were georeferenced and 177 were vectorized in order to create a DBM and our analysis used a total of 111 maps.

The bar and southern spit were morphometrically separated using the 1856 Spratt map. This map contains a separate inset with a cross-section profile over the bar, indicating the 16-foot depth required for the 400-ton ships to enter the mouth. DBM was delimited between -5m and 0m to identify the bar position. These calculations were performed for 115 DBMs and our research uses 14 DBMs, representing the extreme years which determined the analyzed periods (1829-1856, 1857-1871, 1871-1900, 1900-1921, 1925-1932, 1933-1937, 1944-1956, 1989-2009).

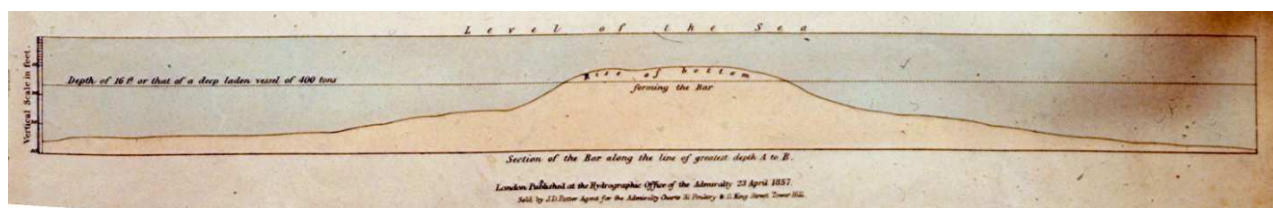


Fig. 5. The Spratt map inset used as reference for the morphometrical separation of the bar

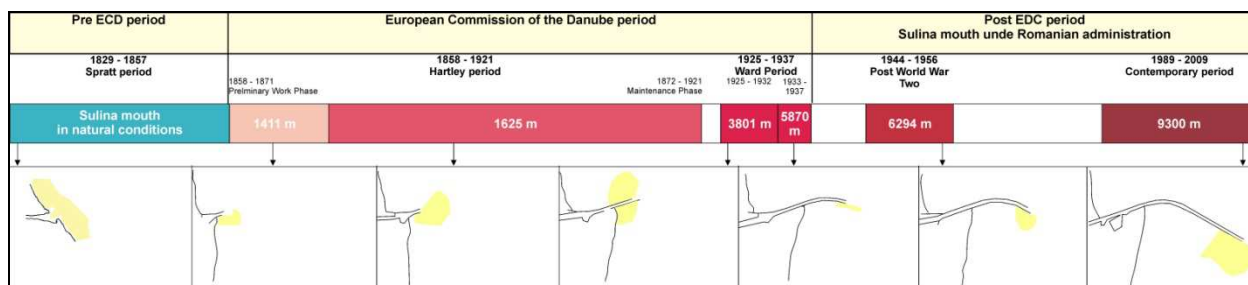


Fig. 6. Maximum elongation of the bar and southern spit (in front of the jetties) per period

4. Results and discussions

In its natural state, the Sulina mouth was covered by a continuous spit up to 5 m depth. Following the jetty construction and dredging works, the bar has a southern position, with different rates of elongation toward the North (in 1921 and 1925) and after 1937 the deposition tends to develop southward, partly due to the more and more southern direction of the jetties. It is important to note that the bar position in 1925, covering the navigable channel, is somewhat similar to the bar position in 1829. This cancellation of the jetty effects was mainly determined by the fact that ECD stopped its activities during the First World War.

The analysis of the southern spit volume and surface included the extreme years of the analyzed

periods (1829-1856, 1857-1871, 1872-1921, 1925-1932, 1933-1937, 1944-1956, 1989-2009). To achieve an accurate comparison between the volumes of sediment deposits, the volume was calculated using the standard 1 km² unit.

In its natural state, the surface and volume were very high (over 3.5 km² and ~2.1 m³), but this is due to the fact that the spit was not in its final form and the depth over the entire mouth was less than 5 m (the morphometrical limit of the spit). The largest sediment volume, 2.5 mil. m³, was recorded in 1921, and the largest surface of the mouth bar, 4.1 km², in 1925. These values correlate very well with the sediment deposition rates at the mouth (reaching 25 cm/year in the years between the two World Wars) and in the Musura Bay (the period between

1850 and 1920 showed significant southern development of the Chilia lobe and significant sediment deposition rates at the Musura Bay (Giosan, 2005). Between 1932 and 1956, the sediment deposition volume is approximately 1.5 mil m^3 , and the surface of the bar sharply decreases. This demonstrates the efficiency of the jetty elongation and direction shifting works. After 1937, the bar tends to become a spit, given that the mouth takes an almost southward direction. The shift in jetty direction and the north-south direction of the main current lead to the formation of longshore

currents (Stănică, 2007), and therefore the sediments end up being deposited behind the jetties. Between 1960 and 1980, the length of the southern spit increased significantly ($\sim 1.5 \text{ km}$) and the width doubled from 0.5 km to 1 km (Vespremeanu, 1983). In 1989 the southern spit had a considerable size, but, given that it endangered the navigation, intensive dredging works were initiated in this area. Consequently, between 1989 and 2009 the volume decreased by $\sim 1 \text{ mil m}^3$, and the surface decreased by more than 1 km^2 .

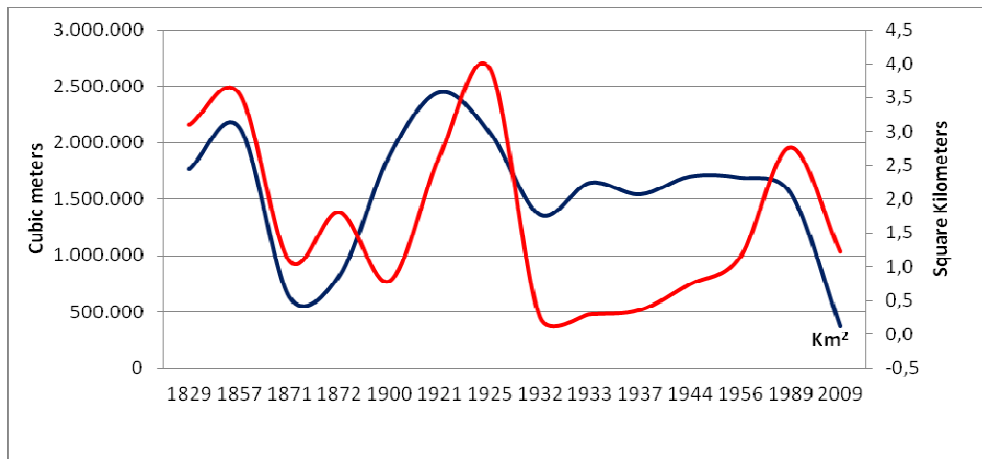


Fig. 7. Volume (blue) and surface (red) of the southern bank

A cross-section analysis of the mouth bar dynamics was only possible for the 1876-1921 period, hence a multi-annual dynamics, in 5-year ranges, was chosen instead. Restrictions were determined by the jetty elongation and advancement of the branch mouth into the sea. The research methodology consisted in creating profiles on the navigation direction, as indicated on the ECD maps, with the imaginary line between the jetty extremities as the starting point. This reveals how the bar influenced navigation.

Until 1911, the ECD engineers maintained the bar crest position at approximately 5 m depth. Later on,

the bar developed significantly, its crest reaching -4 m in 1916 and -2.5 m in 1921. This bar depth, even lower than the depth recorded in 1829, was reached in the context of the First World War and of the very high sediment deposition rates during these years (Fig. 3).

In 1921, the bar crest shifted 1.5 km offshore from the jetty mouth, which caused a complete obstruction of navigation on the normal routes. This shift is explained by significant sediment depositions at high depths transported from the North.

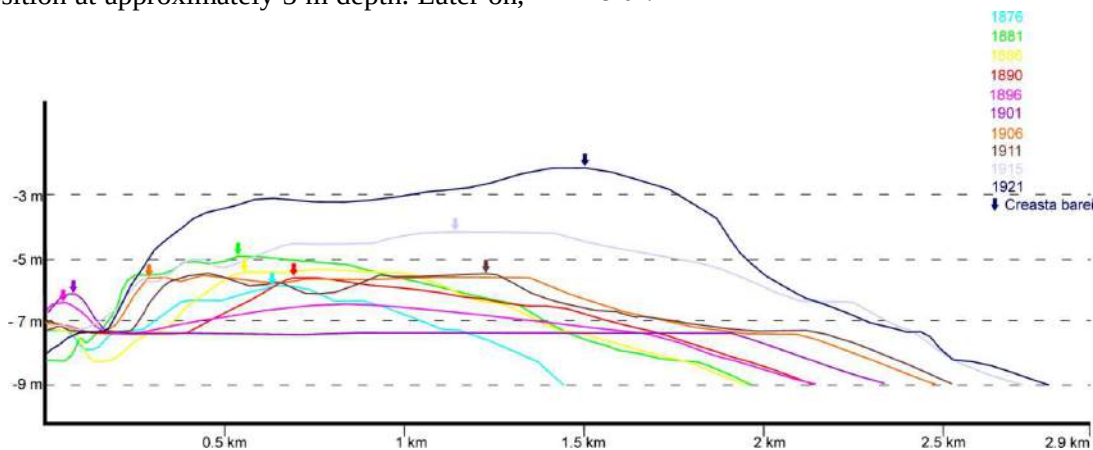


Fig. 8. Cross-section profile of the bar dynamics

5. Conclusions

The Sulina bar, the name given in the 19th century to the sediment deposition phenomenon at the river mouth, caused serious problems to navigation in the area, and the European Commission of the Danube tried to find a solution to this issue by building a system of jetties. The jetty elongation and dredging works at the mouth considerably influenced the bar morphodynamics.

These interventions separated the spit which normally extended over the entire mouth and represented the beginning of a new phase of permanent continuous asymmetry (Bhattacharya, 2003; Giosan, 2005). In the years between the two World Wars, the mouth bar increased in size to the level recorded in 1830, and this situation dictated the beginning of jetty elongation and direction shifting works. After 1940, the bar enters a new morphological phase, taking the shape of a spit located south of the jetties and permanently dredged to the north to prevent navigation issues. The dredging works significantly influenced the bar

morphometry, which was kept at high depths until 1911-1915. Subsequently, the dredging works continued only on the northern side of the spit, at high intensity between 1980 and 2000.

The bar dynamics and evolution of the southern spit can only be understood in close relation with the works at the Sulina mouth which started in 1858 and continue to the present day.

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Landslides and biodiversity conservation: the importance of an integrated approach.

A case study: the Subcarpathian part of the Doftana watershed (Prahova County, Romania)

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Abstract. Over the last few years mass-movements have been more and more perceived from an ecological standpoint, as natural disturbance factors, which may raise the geo- and biodiversity of an area. Mass-movements create a diverse microtopography, through material redistribution (Gertseema & Pojar, 2007), which form conditions for the installation of a rich diversity of plant and animal species, with different ecological requirements, some of them protected at national or EU level. Furthermore, at landscape level, the aquatic habitats formed in different elements of the landslides' microtopography have a network layout (on landslides body and due to spatial extension of landslide process in Subcarpathian area), providing suitable habitats and good dispersion possibilities to pond-reproducing or pond-depending fauna. The rich geodiversity (diversity of relief microforms, of soils and of hydrological / hydrogeological conditions) of landslide prone areas determines a mosaic of extremely diverse natural habitats (Aleksandrowics & Margielewski, 2010), very important for biodiversity conservation. We chose as a case study the Subcarpathian part of the Doftana river valley for illustrating the importance of studying, mapping and monitoring slow mass-movements for the conservation of insect, amphibian and reptile species, which depend on aquatic habitats for reproducing, developing and feeding.

Keywords: landslides, biodiversity, geodiversity, nature conservation

1. Introduction

Landslides are usually perceived as natural hazards (Alcantara-Ayara, 2002; De Blasio, 2011) or environmental hazards (Lee & Jones, 2004), being studied in relationship with the risks posed to the socio-economic system: land degradation, infrastructure or other material damages and sometimes human casualties. The ecological role and meaning of this kind of disturbance is rarely taken into account. It's a well known fact that the disturbances have an important role in nature, being a major source of temporal and spatial heterogeneity in the natural communities' structure and dynamics (Sousa, 1984). The role of this kind of disturbances – landslides – in maintaining a rich biodiversity was largely ignored (Geertsema & Pojar, 2007). Being slope-shaping processes, under the influence of climatic and geological factors, landslides induce an increase in the spatial heterogeneity (through erosional and deposition processes), with areas of exposed parent material in the upper part (scarps of landslides), with a humidity deficit, and areas with water-logged colluvial material. So, these slope-processes move along the altitude gradient crucial elements for

downstream ecosystems, like calcium and phosphorus, resulted from the erosional processes associated with landslides (Walker & Shiels, 2013). Thus, landslides have an important role in one of the crucial ecosystem service: nutrient cycling. Furthermore, landslides reset the “pedogenic clock” of areas affected by them back to Regosol-Brunisol-Podsol sequence, fostering the restart of ecological succession processes (Gertseema & Pojar, 2007). Consequently, the effects of landslides go far beyond their physical limits, due to their role in sediment loading of water courses, as well as in maintaining a rich regional biodiversity and dispersion of organisms (Walker & Shiels, 2013). At the landscape level, landslides create habitat discontinuities in a background matrix, like forests, shrubs or grasslands (Walker & Shiels, 2013), ensuring an increase in spatial and functional diversity. They also create networks of aquatic habitats (ponds, puddles, wet areas, rivulets), important in maintaining viable populations of pond-depending fauna, especially in case of species which form metapopulational structures (amphibians).

The increase of structural heterogeneity, driven by landslides, is not always perceived as beneficial in maintaining a rich biodiversity, some studies

emphasizing that landslides may facilitate the installation of invasive alien plant species (Restrepo & Vitousek, 2001), showing that landslides do not increase herbaceous species diversity, but rather decrease it (Koolaei et al., 2011), other arguing that landslides affect medicinal herb distribution (Lepcha et al., 2011), other showing that landslides affect the vegetation land-cover and biomass distribution, altering successional trajectories, and thus transforming ecosystems in irreversible ways (Restrepo et al., 2003). Other studies in turn, argue that landslides, acting as perturbation factors, have important roles in imprinting a certain dynamic in the structure of forest vegetation and in biodiversity enrichment (Seiwa et al., 2012; Walker, 1996). Other studies show that geodiversity (understood as relief, soil and hydrologic diversity) creates conditions for the existence of a mosaic network of extremely diversified habitats (Alexandrowics & Margielewsky, 2010). Other authors emphasize that landslides influence several types of diversity: site diversity, soil diversity and ecosystem diversity, creating suitable habitats for aquatic fauna, denning/nesting habitats, escape terrain, cliff habitats for vertebrates (Geertsema & Pojar, 2007). Landslides may form - depending on the geological strata and sliding mode - aquatic habitats, as shown above, the geological structure allowing sometimes for the persistence of ponds, in spite of material movements (Fleming & Baum, 1999). It is acknowledged that modeling / patterns / power law identification regarding the ecology of structures and functions at landscape level are part of a young discipline (landscape ecology), a synthesis between abiotic and biotic processes being needed (Brown et

al., 2010). The wide variation of patch sizes in different succession stages due to different landslide disturbances probably affects species diversity and ecosystem productivity at local to regional levels (idem). The aim of our study was to detail the influence of habitat structure created by landslides on pond-depending fauna species of conservation interest and its importance for biodiversity conservation.

The study area is located in the Curvature Subcarpathians, the subdivision of the Prahova and Buzău Subcarpathians, in the Doftana river basin. The Subcarpathian part of Doftana river basin was delimited eastwards and westwards by watersheds, southwards by Doftana – Prahova confluence and northwards by the geological limit between the Bobu Nappe (massive sandstones and conglomerates, sandstone-marl flysch) and the Teleajen Nappe (Curbicortical flysch, massive sandstones), which passes under the Paltinu storage reservoir and on which base the mountain unit may be delimited from the hill unit. The resulting study area covers 80.333 sq km, having a perimeter of 54.551 km, the lowest altitude of 360 m, highest altitude of 1.034 m and a mean altitude of 669 m a.s.l.. Using a DEM with a 30m pixel resolution and Slope analysis from ArcMap 10.1, we calculated the slopes angles within the study area, as following: minimum slope = 0.0027° , maximum slope = 35.84° and average slope = 8.89° , with a standard deviation of 5.0543° .

It is known from the scientific literature that most landslides from the study area are shallow (<1.5 m) or medium deep (2-5m), whereas deep-seated landslides (5-10m) occupy small areas (Armaş, 1999).

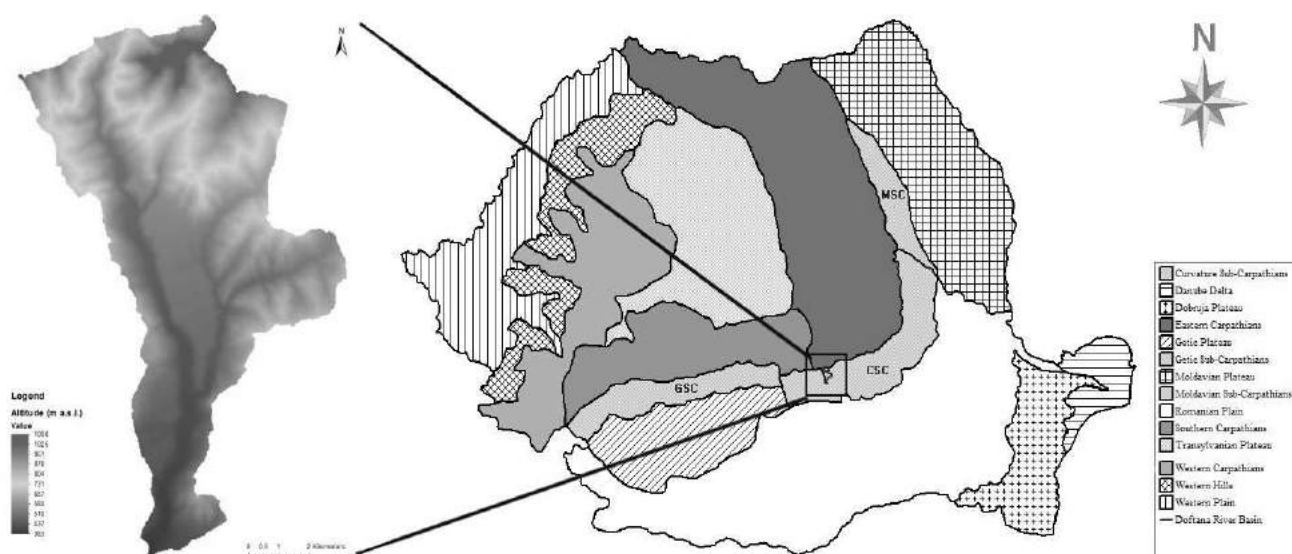


Fig. 1. Study area location – Curvature Subcarpathians

2. Materials and methods

The study was carried out during 2010 - 2013, in the above-mentioned study area. We mapped on field the active landslides on the basis of slope microrelief (cracks, slope discontinuities, wet habitats with hydrophilous vegetation, deranged material with pioneer vegetation), as well as of trees inclination. By using a GPS device from Garmin, model eTrex Legend Hcx, with a precision of up to 3 m, for field mapping, and by making use of photointerpretation of satellite imagery with a 0.3 m resolution (Bing Maps), as well as by analyzing topographic maps at a scale of 1:25 000 and geological maps 1:50 000 (Comarnic and Teleajen sheets), a number of 140 active landslides was successfully mapped. Aquatic habitats were also mapped in the field, using the same GPS device, in addition to a few aquatic habitats which were mapped through photointerpretation of satellite imagery due to their extent (exceeding 1000 m²) or difficult access. Thus, a number of 193 aquatic habitats (temporary and permanent ponds, puddles and swamps, lakes, artificial basins) were mapped in the Subcarpathian part of Doftana valley. Out of 193 aquatic habitats, only 75 are formed on active landslides, the rest being formed on stabilized landslides, subsidence sinkholes or dissolution lakes (Brebu Lake) or representing artificial lakes/basins. The pond-dependent fauna species were mapped on field, during the reproduction season (from March through July), using the scan searching method (Halliday, 2006), auditive transects (Cogălniceanu, 1997; Halliday, 2006) and for some aquatic habitats we used funnel traps, made from pet bottles of 2L, for newt species (Griffiths, 1985). Data were subjected to a spatial analysis using GIS-software, such as Global Mapper, SAGA GIS, Quantum GIS and ArcMap 10.1.

3. Results

The landslide inventory of the study area revealed the following types of landslides: slumps, mudflows and complex landslides. Of particular interest for the study were the landslides which may form aquatic habitats suitable for pond-dependent fauna: slumps and complex landslides. Although we mapped the mudflows, they are not of interest for this study, because they do not form aquatic habitats, due to high dynamic of viscous material. We were interested in those slope-processes (slumps and complex landslides) that may lead to apparition of negative micro-forms, in which aquatic habitats may form depending on the presence of clays. Those processes have to be slow enough (1cm–1m / year) in order for the aquatic habitats to be suitable for the development of pond-dependent species. Furthermore, the network of aquatic habitats formed on landslides have to be persistent through several years, allowing the development of metapopulational structures or at least of viable isolated populations, a crucial aspect for the long-term survival of the studied species.

Although the whole area is more or less prone to mass-movements, due to geological and climate conditions, the area affected by the mapped active landslides extends over 1 446 sq. km of the 80 333 sq. km large study area. We analyzed the spatial distribution of active landslides on different slope aspects and angles with the Zonal statistics histogram function of ArcMap 10.1, using the above-mentioned 30m resolution DEM and a binary raster with active landslides (1) and background matrix (0) with a cell grid of 0.00001 decimal degrees. The results are shown in the graphs of Figures 2 and 3:

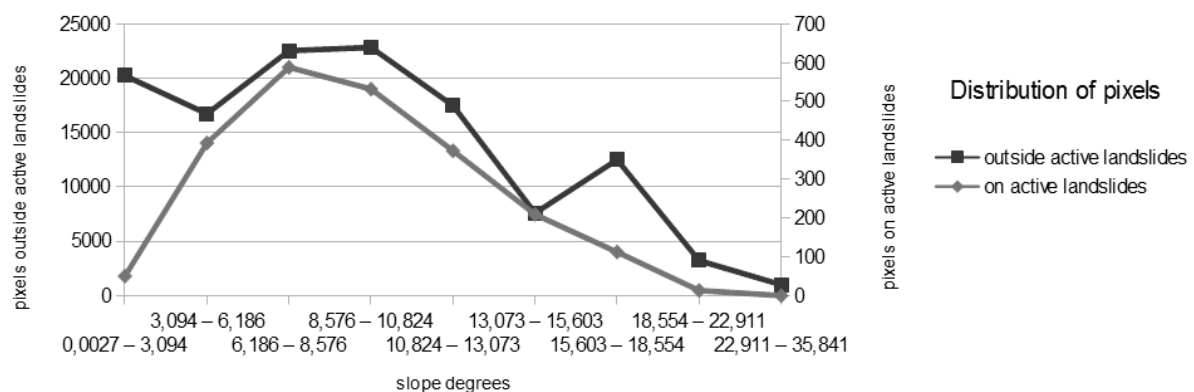


Fig. 2. Distribution of pixels affected by active landslides and of background matrix (area not affected by active landslides) on slope angle categories

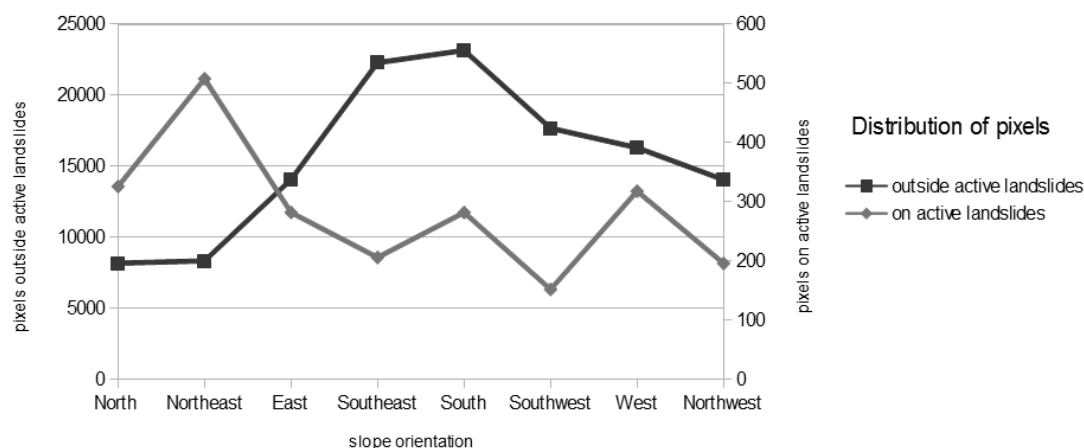


Fig. 3. Distribution of pixels affected by active landslides and of background matrix (area not affected by active landslides) on slope aspect categories

We identified during the study period (2010-2013) a number of 5 species (2 invertebrates: *Carabus variolosus*, *Lycaena dispar*, 2 amphibians: *Bombina variegata*, *Triturus cristatus* and 1 reptile: *Emys orbicularis*) listed in the IInd Annex of Habitats Directive (92/43/EEC), for the conservation of which special conservation area

designation is required (as part of Natura 2000 pan-European protected area network), and another 3 species of community interest (amphibians: *Hyla arborea*, *Rana dalmatina*, *Bufo viridis*), listed in the 4th Annex of Habitats Directive, which need strict protection measures.

Table 1. Pond-dependent fauna species with a special legal protection status identified in the study area

No.	Species	Taxonomic Group ⁺	Habitats Dir. Annex II	Redlist conservation status	Ecological requirements and relations to aquatic habitats
1	<i>Carabus variolosus</i> 	I	II	VU-CR*	Semi-aquatic, strictly stenotopic species, indicating (semi-)natural woodland brooks and ponds, preferring high soil moisture, circumneutral pH and light woodland. Exhibits untypically low population sizes for insects (Matern et al., 2008; Matern et al., 2009). Uses wet habitats for reproduction and foraging.
2	<i>Lycaena dispar</i> (Large Copper) 	I	II, IV	LC**	Occupies wet habitats (wet grasslands, puddles and ponds, fens), laying eggs on 3 species of a hygrophilous plant genus – <i>Rumex</i> sp. (docks). The larvae feed on docks, which grow in the above-mentioned wet habitats (Duffey, 1993; www.leps.it). The species is regarded as a low density species, with high dispersal ability – up to 5 km (Settele et al., 2000, <i>apud</i> Strausz, 2010)
3	<i>Bombina variegata</i> (Yellow-bellied toad) 	A	II, IV	NT***	The species breeds in temporary ponds and aquatic habitats with highly varying hydroperiod (Hartel, 2008). It can occupy virtually any pond or water accumulation, from little cattle imprints or small rivulets to more developed aquatic habitat, with aquatic vegetation (Cogălniceanu et al., 2000). Uses aquatic habitats mainly for reproducing and larval development, but sometimes also for foraging.

4	<i>Bufo viridis</i> (European green toad) 	A	IV	NT***	This species is much more terrestrial than the above one, undertaking long migrations for breeding. Uses aquatic habitats mainly for reproducing and larval development. (Cogălniceanu et al., 2000). Forages on land.
5	<i>Hyla arborea</i> (European tree frog) 	A	IV	VU***	This species represents the only tree frog from Romania. It possesses special adhesive structures at the tip of its fingers, by means of which it can climb on leaves of trees. It uses aquatic habitats mainly for reproducing and larval development (Cogălniceanu et al., 2000). Forages on land.
6	<i>Rana dalmatina</i> (Agile frog) 	A	IV	VU***	It is the most common woodland frog from the plain and hilly area from Romania. It uses almost every spring pond for reproduction and larval development. Forages on land (Cogălniceanu et al., 2000).
7	<i>Triturus cristatus</i> (Great crested newt) 	A	II, IV	VU***	It is the second largest species of newts from the plain and hilly area from Romania. It occupies fish-free aquatic habitats in an advanced stage of ecological succession, with rich plant and animal communities (Oldham et al., 2000). The species has throughout the year both an aquatic stage, in which it reproduces and forages in water, and a terrestrial stage, in which it lives near water bodies (Cogălniceanu et al., 2000). The larvae develop in the above-mentioned aquatic habitats, with hydroperiods sufficiently long (permanent ponds, puddles and lakes, or temporary ponds which last from March through July at least).
8	<i>Emys orbicularis</i> (European pond turtle) 	R	II, IV	VU***	The only aquatic species of turtles from Romania, occupies stagnant or slow flowing aquatic habitats, like meso- and eutrophic lakes, oxbow lakes, swamps, permanent ponds, stock ponds, requiring a certain aquatic vegetation, shore soil texture and basking sites. It reproduces, develops, forages, and hibernates in water (Fuhn & Vancea, 1961).

⁺ Taxonomic Group of the Class rank: I = Insecta, A = Amphibia, R = Reptilia

* The hygrophilous species of ground beetle *Carabus variolosus* was not assessed in terms of conservation status, neither at global level (IUCN Redlist v. 2013.1), nor at EU or national level. Some EU member states assessed the species conservation status between VU "vulnerable" and CR "critically endangered", in others the species went extinct (Switzerland, Italy), according to Matern et al. (2008);

** For the butterfly species *Lycaena dispar*, we used the European assessment of its conservation status (van Swaay et al., 2010), because Romania did not developed yet an invertebrate national Redlist;

*** For vertebrates (herpetofauna), we used the assessments from the Romanian Vertebrates Redlist, elaborated in 2005 by the National Museum for Natural History "Grigore Antipa" (herpetofauna was evaluated by Iftime, 2005). NT means "near threatened" species, VU means "vulnerable" species.

We recorded a total of 265 occurrences of the 8 species above-mentioned, in or near aquatic habitats situated on active landslides, on stabilized landslides or on flat ground having other forming processes (dissolving, subsidence). Because stabilized landslides are much more difficult and expensive to map, we divided the occurrences in: occurrences in/near aquatic habitats on active landslides and occurrences in/near aquatic habitats outside active landslides, as presented in Table 2.

We identified 6 negative microforms, which may form aquatic habitats suitable for pond-depending

fauna, due to the presence of clays in the slid material: slope discontinuities under the main scarp (1), slope and material discontinuities on the contact surface between the slid material and the fixed material (2), slope discontinuities on the landslide body, due to the sliding mode of the slumping blocks (3), transverse cracks in the landslide body (4), landslide foot, which is almost always water-logged (5), negative microforms lasting on stabilized landslides (6) (see numbers in Fig. 5).

Table 2. Occurrences of pond-depending fauna species on and outside active landslide areas. Red colour is for HD Annex II species, for which special conservation area have to be designated; yellow colour is for HD Annex IV species, which need strict protection measures. I = Invertebrate, A = Amphibian, R = Reptile

Occurrences in aquatic	Car_var	Lyc_dis	Bom_var	Tri_cri	Hyl_arb	Ran_dalm	Buf_vir	Emy_orb
	I	I	A	A	A	A	A	R

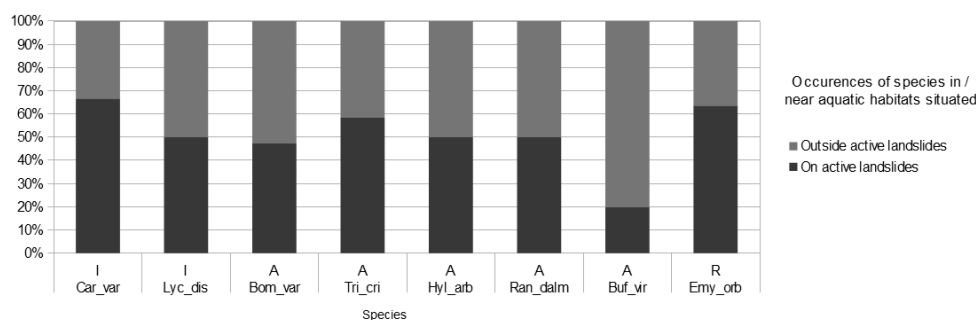


Fig. 4. Percentage of occurrences of the 8 species on and outside active landslide areas

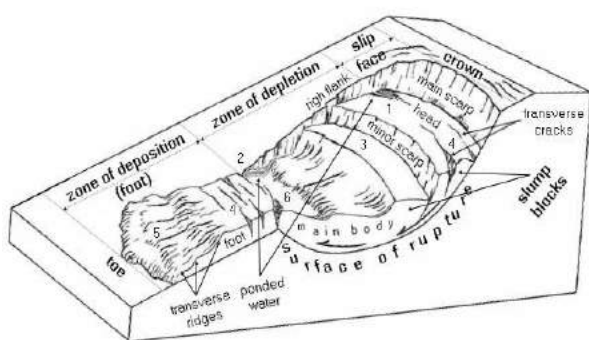


Fig. 5. Diagram of landslide elements, modified after Cruden and Varnes (1996)

We present below which of the 8 species with a legal protection status were found on each of the 6 negative microrelief forms, with aquatic habitats installed on their surface.

a) Under the main scarp of slumps, on the first slumping block, ponds can be observed, which



Fig. 6. Poned water on the head of a landslide

formed due to the reversed slope. This was the case for at least 6 landslides out of 140 landslides mapped in the studied area. Depending on the aquatic vegetation succesional stage, we could observe the following amphibian species: *Rana dalmatina*, *Hyla arborea*, *Bombina variegata*, *Triturus cristatus*.

b) On landslide flanks we could observe, depending on the sliding mode, material discontinuities between the slid part and the fix part (the slid material retires from one of the fix parts). On some landslides, through these longitudinal discontinuities small rivulets are drained and where these rivulets reach a slope discontinuity, water accumulates and ponds appear. These rivulets may fill also transverse crack or negative microrelief forms resulted from material accumulation. On the small rivulets situated along landslides flanks, we could observe adults and juveniles of yellow-bellied toad *Bombina variegata*. On the ponds formed by those rivulets when encountering reverse slopes or accumulated material, we could observe both invertebrate species: the ground beetle *Carabus* (*Hygrocarabus*) *variolosus* and the butterfly *Lycaena dispar*, and 2 species of amphibians: *Bombina variegata* and *Triturus cristatus*.

c) On the landslide body of almost every landslide appear slope discontinuities due to slump-blocks, transverse ridges and hummocks. Depending on the clay presence in the soil and/or in the bedrock, the slumps, transverse ridges and hummocks may shelter ponds being in any stage of succession, from simple ponded water having small areas, to puddles and up to eutrophic ponds. All 8 species could be found in these ponds and puddles, due to their spatial distribution (up to 10 ponds and puddles on one single slump, of 2.79 ha), to the permanent character of some of the aquatic habitats and to their rich trophic offer.

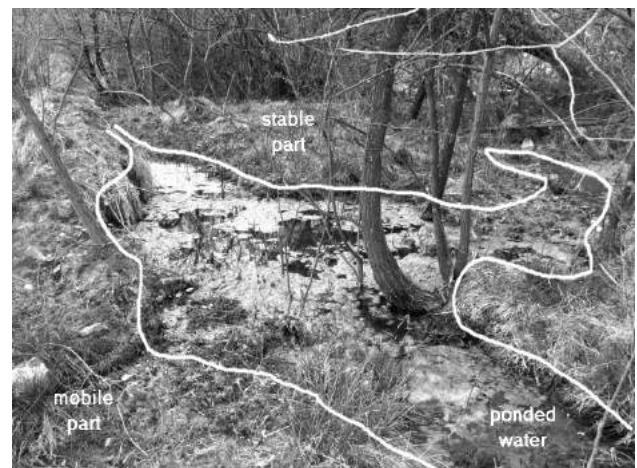
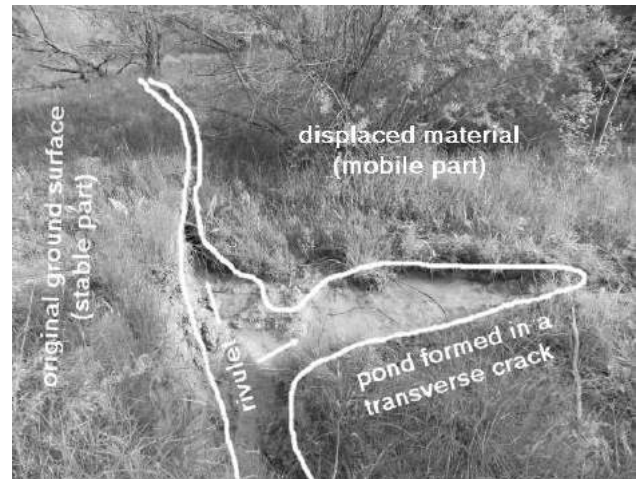


Fig. 7. Temporary (left) and permanent (right) ponds formed between the stable part and the mobile part



Fig. 8. Network of permanent and temporary ponds formed in microdepressions, on a slow-moving landslide (between 1-100 cm / year), triggered by slope-base erosion

d) Cracks appear on all landslides and some of them may retain water due to the presence of clays. Thus, small temporary ponds are formed, having no or scarce pond vegetation. On this kind of temporary aquatic habitats we could find only 2 species of amphibians, being known to be able to reproduce in very small temporary water bodies: *Bombina variegata* and *Rana dalmatina*.

e) The lower parts of landslides are almost always water-logged. Thus, ponds and puddles appear on the foot or toe of landslides, or even in front of landslides' toes. In this kind of aquatic habitats we observed the following amphibian and reptile pond-depending species: *Bombina variegata*, *Triturus cristatus*, *Rana dalmatina* and *Emys orbicularis*.

f) Negative micro relief forms may be observed on stabilized landslides (no cracks can be seen), especially towards the lower part of depletion zone or on slope discontinuities (reverse slopes, transverse ridges, zones with no slope gradient) remained after sliding. In such negative microforms rainwater and/or groundwater may accumulate and hydrophilous vegetation may colonize them (*Juncus* sp., *Carex* sp., *Epilobium* sp., *Potamogeton* sp., *Rumex* sp. etc.). In those ponds, which may be permanent, we could observe the amphibian species *Bombina variegata*, *Hyla arborea*, *Rana dalmatina*, *Triturus cristatus*.

In Table 3 we present a synthetic table of the 8 species with a special legal protection status that were observed in the study area and types of aquatic habitats within which they were observed.



Fig. 9. Pond formed in a transverse crack

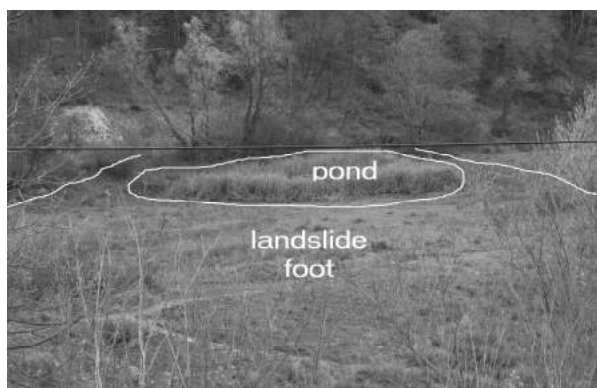


Fig.10. A slump' zone of deposition



Fig. 11. Temporary pond formed in a negative relief form, on a stabilized landslide

Table 3. Species of fauna associated with aquatic habitats and types of microrelief in which they were observed

No crt.	Species	Taxonomic Group	1	2	3	4	5	6
1	<i>Carabus variolosus</i>	I		•	•			•
2	<i>Lycaena dispar</i> (Large Copper)	I		•	•			
3	<i>Bombina variegata</i> (Yellow-bellied toad)	A	•	•	•	•	•	•
4	<i>Bufo viridis</i> (European green toad)	A			•			
5	<i>Hyla arborea</i> (European tree frog)	A			•			
6	<i>Rana dalmatina</i> (Agile frog)	A	•	•	•	•	•	•
7	<i>Triturus cristatus</i> (Great crested newt)	A	•	•	•		•	•
8	<i>Emys orbicularis</i> (European pond turtle)	R			•		•	

4. Discussions

Data gathered until now don't allow us to calculate degrees of correlation between species occurrences and aquatic habitats installed in negative microrelief forms. But taking into account that the area of active landslides sums up approximately 1.8% from the study area (1.446 sq km) and that the species occurrences on active landslides vary between 25% (European green toad) and 66.6% (*Carabus variolosus*), we may have an incipient image of the ecological importance of landslides, as far as the pond-dependent fauna is concerned.

During our study, the area most rich in herpetofauna species from the study area became a Natura 2000 Site of Community Interest for 3 pond-dependent species: *Bombina variegata*, *Triturus cristatus* and *Emys orbicularis* (Legal Act issued in November 2011 – Ministerial Order 2387). Since November 2011, we observed two other species listed in Annex II of HD: *Lycaena dispar* and *Carabus variolosus*. Those two invertebrate species are good indicators of the wilderness degree of the aquatic habitats formed on active landslides, at a landscape scale, as they are stenotopic species, with specific habitat requirements.

At a landscape level, the aquatic habitats created by active or stabilized landslides have a network structure, which is beneficial for maintaining viable populations of pond-dependent fauna species on a long term. It is acknowledged that a network of sufficiently close aquatic habitats is beneficial to

biodiversity for at least two reasons: 1) as far as the pond-dependent species richness is concerned (aquatic snails, aquatic beetles, damselflies, dragonflies, amphibians), a network of ponds and puddles of smaller area has a greater conservation value than a large water-body with the same area as the summed areas of the smaller ponds and 2) a network of ponds and puddles sufficiently close may sustain metapopulation structures, in which if one sub-population goes extinct, recolonisation from the other sub-populations is possible (Marsh et al., 2001). Though, the disappearance of a breeding habitat for pond-dependent fauna species (e.g., through desiccation) doesn't represent a major threat in a landscape where other options do exist. We further present a model of buffer zones of 100, 300 and 1 000 m around each aquatic habitat mapped in the field from an area of approximately 6 sq km, covering two patches of the above-mentioned Natura 2000 site (ROSCI0283 Cheile Doftanei), which reveals a certain connectivity between them with an important meaning for pond-related biodiversity. These units were modeled taking into account several maximal migration distances for amphibian and reptile species, according to the scientific literature. As far as the two invertebrate species are concerned, *Carabus variolosus* live in very small populations and have very short migration distances, not very well studied (several hundreds of meters, according to Matern et al., 2009), whilst *Lycaena dispar* may migrate several kilometers away (5 km according to Strausz, 2010).

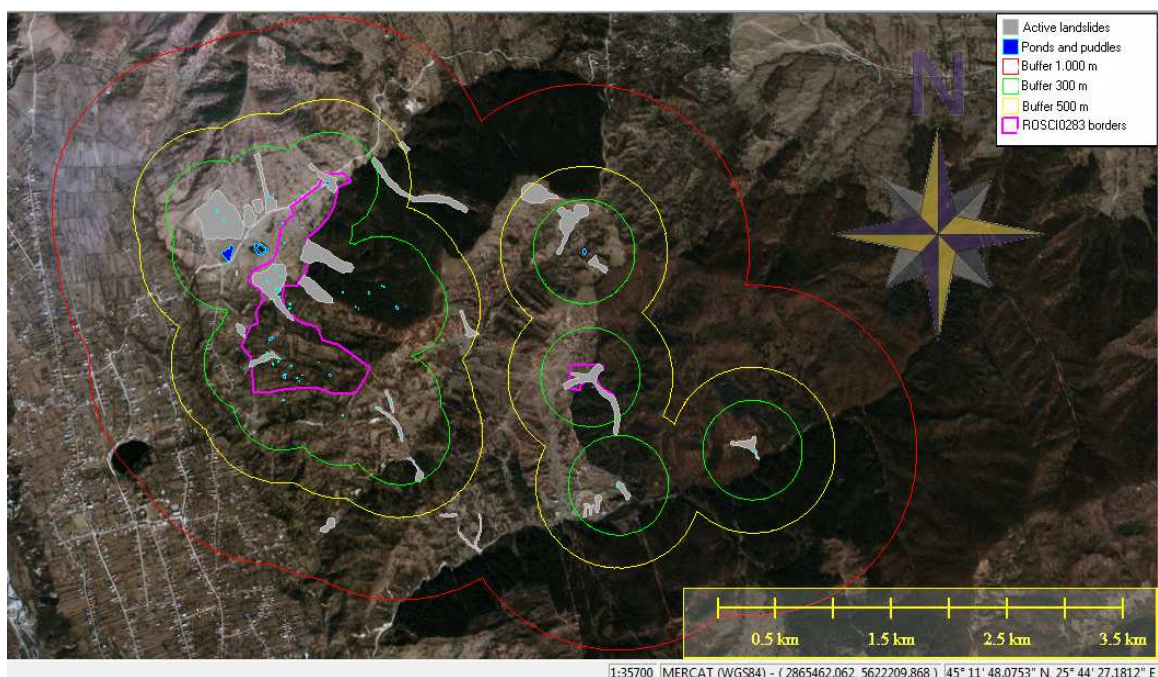


Fig. 12. Modeling of buffer zones of 100, 300, 1 000 m around the ponds (55 ponds and puddles in a 6 sq km area)

Besides the fact that landslides create aquatic habitats in a network disposal, some ponds formed by the sliding mode of slump blocks are deeper, having thus longer hydroperiods. We observed that even when evaporation exceeds precipitation (summer months), at least 10 ponds remain in the 6 sq km area, finally maintaining a similar theoretical connectivity (we didn't model a habitat permeability matrix for each of the 8 species, as presented by Ray et al., 2002), with a smaller area (8.88 sq km at 1 000 m buffer, instead of 14.33sq km at 1 000 m buffer), as presented in Fig. 13.

We propose, on the basis of our findings, that the further process of designating natural protected

areas especially for hygrophilous plants, wetland habitats and pond-dependent fauna in landslide prone areas (between 300 and 1.000 m a.s.l.) should take into account the following factors:

- i) slope angles varying between 3 and 15 degrees;
- ii) slope orientation: especially northeastern and western slopes;
- iii) lithological composition: clays and marls (Quaternary deposits);
- iv) precipitation amounts: over 600 mm/year;
- v) landcover: secondary grasslands, orchards, woodlands, trees and shrubs.

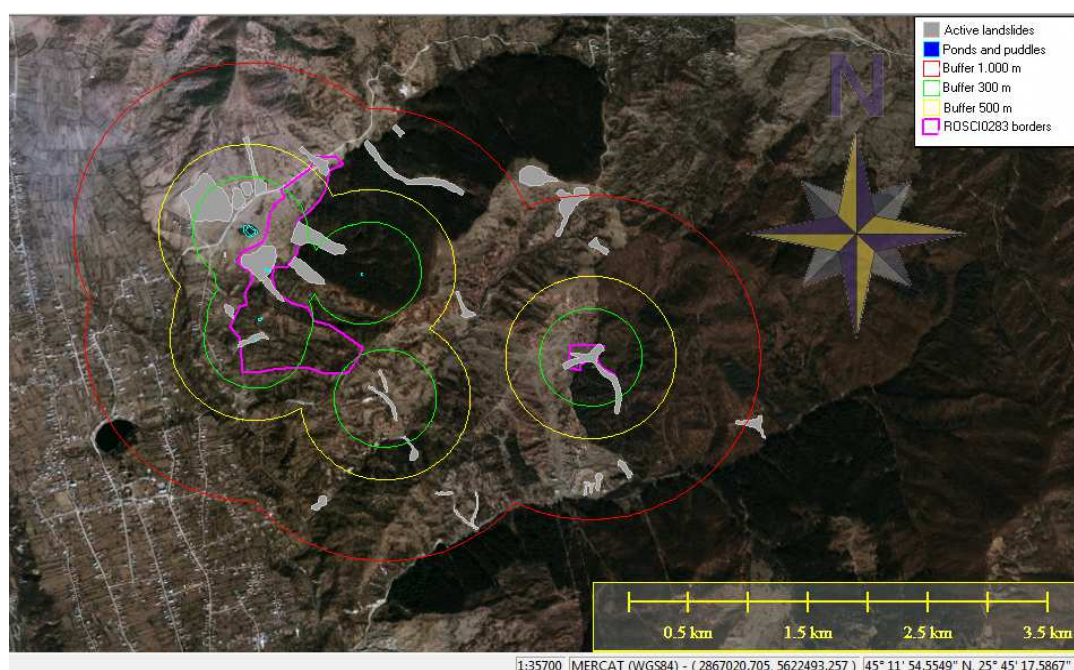


Fig. 13. Modeling of buffer zones of 100, 300, 1 000 m around the ponds in the warm season
(June-August) (10 ponds and puddles in a 6 sq km area)

Studies should further detail conditions of landslides forming aquatic habitats, as a new branch of Ecology has emerged (Landslide Ecology, see Walker & Shields, 2013) and as more and more wetlands are lost (Gibs, 2000). Many pond-dependent fauna species live in multiple local populations sustained by occasional migrations, which means through metapopulation structures (Hanski & Gilpin, 1991; Semlitsch, 1998; cited by Gibs, 2000). Protecting aquatic habitats formed by landslides means protecting local sub-populations of wider metapopulations and assuring long-term survival of endangered wetland animal species. Landslide mitigation should be balanced with ecosystem services preservation, where those two directions would come in a possible antagonism. Both are required for human well-being, an equilibrium of both action directions being a

prerequisite of local and regional sustainable development. The more localized the landslide mitigation solutions are and the natural evolution of hillslope is taken into account, the more efficient are the ecosystem services preserved (through conservation of wet habitats and associated pond-dependent species). Case-by-case judgement should ensure this balance between landslide mitigation projects and ecosystem services preservation (through biodiversity conservation), taking advantage of the coherence and framework of the EU-wide protected area network Natura 2000, which is very flexible in balancing development needs with conservation needs. Where landslide mitigation projects should prevail over biodiversity conservation interests, because of the importance of the infrastructure being threatened by landslides (overriding public interest of social or economic

nature, according to EU Habitats Directive 92/43/EEC/1992, art. 6.4.), compensatory measures (e.g. in other Natura 2000 sites) will be taken in order to assure the overall coherence of Natura 2000 protected area network, the ecosystem services preservation, and, finally, the human well-being.

5. Conclusions

Landslides produce spatial heterogeneity at the landscape level (Walker & Shiels, 2013) and create networks of aquatic habitats, due to geological and climate conditions. This geodiversity sustains suitable habitats for pond-depending fauna, especially for threatened wetland species, some of them being very rare at EU level and of particular interest for conservation measures (*Carabus variolosus*). Therefore, slow moving landslides should be taken into account in the process of designation of natural protected areas in the future,

both for their suitable wet habitats and for migration dynamics.

Acknowledgement

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River channel planform changes based on successive cartographic data. A methodological approach

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Abstract. The boost in the national and international research on the centennial and multicentennial-scale changes in the configuration of river channels has led to a need for standardisation of database acquisition methods, so that the final results may be accurately compared regardless of the size of the analyzed river and its physical environment. This paper introduces: the working materials needed for such studies (sources available in Romania and their preparation); landmarks necessary for the delimitation of the study area, typological classification of the channels, delineation of the representative channel sectors; methods for acquiring morphometric data (planform). The literature (with illustrative case studies cited in this paper) provides examples on how the results can be processed and interpreted in order to obtain valuable indicators of the trends in channel changes and the stages in the evolution of their configuration. Moreover, they may also indirectly deliver information on the historical changes in the controlling factors (i.e. climate variation or anthropogenic interventions) which generate changes in the morphology and morphometry of river channels.

Keywords: river channels, historical maps, aerial photos/orthophotos, planform morphometric methods, Romanian examples

1. Introduction

The recent amplification of scientific interest regarding the centennial-scale changes in river channels, both nationally (Dumitriu, 2007; Canciu, 2008; Feier & Rădoane, 2007; Ioana-Toroimac, 2009; Perșoiu, 2010; Rădoane et al., 2010; Cristea, 2010; Floroiu, 2011; Perșoiu & Rădoane, 2011; Chiriloaei, 2012; Zaharia et al., 2011), but more so internationally (e.g. Winterbottom, 2000; Gurnell et al., 1997; Surian & Rinaldi, 2003; Rinaldi, 2003; Liébault & Piégay, 2001, 2002; Surian & Cisotto, 2007; Wyzga, 2008; Zawiejska & Wyzga, 2010; Swanson et al., 2011; Ziliani & Surian, 2012) compels us to grant special attention to the matter of necessary resources and research methods.

The present study aims at approaching this matter, such that the quantitative investigations of channel planform changes in Romanian rivers may have a common ground for comparison. Furthermore, this database could be compared with corresponding continental-scale databases or even broader.

The results obtained until now (on rivers pertaining to Siret drainage basin – Rădoane et al., 2010; Cristea, 2011; Chiriloaei, 2012, Prut basin – Rădoane et al., 2008, Prahova basin – Ioana-Toroimac, 2009; and Someș drainage basin – Perșoiu, 2010) were not the product of unitary methods, so that the deriving information on the behavior of rivers during the past 100-150 years

may be unequivocal. By the intended outcome of this work, we wish to provide a framework for researchers, master and doctoral students, and anyone who is interested in measuring planform changes in river channels over variable periods of time. Moreover, the resulting database could be conceived as patrimony for synthetic analyses.

The approach is focused on two major parts: the working materials (available sources and their preparation), the preparation for the measurements (ranging from selecting the channel corridor and the reach to segmentation of the channel), and the actual morphometric measurement methods (various techniques for acquiring morphometric data from historical maps).

2. Materials for river channel geomorphometry research

The materials necessary for such studies are historical documents, mainly maps and aerial photos/orthophotos, which have recorded certain configurations of the river channel. We will focus, as expected, on records of the Romanian territory which are available to the academic community. For comparison, a comprehensive paper summarising the nature and diversity of historical materials currently used internationally in such investigations was published by G. M. Kondolf & H. Piégay (2003).

2.1. Cartographic sources available in Romania

In order to properly identify the documents and historical maps instrumental to the study of rivers, it is necessary to appeal to the history of Romanian cartography through works such as the guide by M. Popescu-Spineni (1978), but also more recent papers (Osaci-Costache, 2006) and dedicated websites (www.geo-spatial.org).

The sequence of cartographic documents used to study the changes in the channel of Someșul Mic River over a time period of 145 years (Perșoiu, 2010) is shown in Fig. 1. This series of images readily illustrates the dynamic potential of river channels. The sinuous sector of the river in 1860

(though clearly maintaining two generations of meanders within the floodplain from an earlier period) has morphed into a channel with straight reaches in 2005 (under anthropogenic intervention); a highly meandering sector in 1860 has evolved into a sinuous channel in 2005; an anastomosed reach in 1860 developed into a sinuous, unitary channel in 2005 (also, by undergoing significant anthropogenic intervention).

The main historical maps of the Romanian territories which have been used up to date in relevant studies of fluvial geomorphology are shown in Tables 1 and 2 (comprised all the data provided by the authors of the papers).

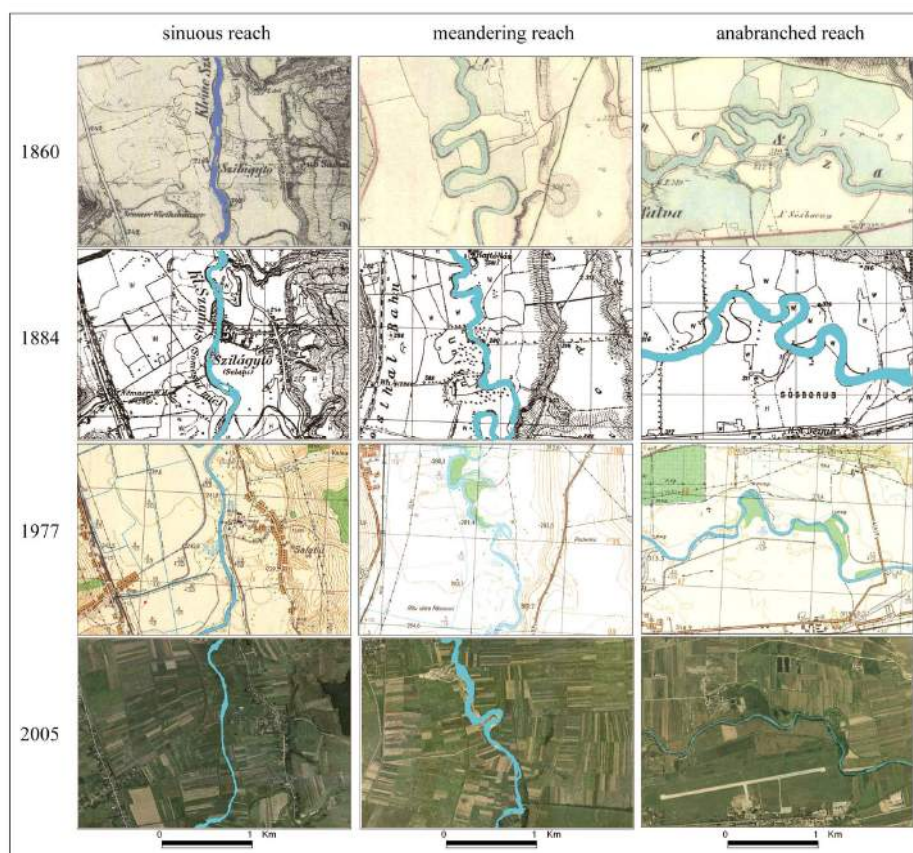


Fig. 1. Reaches with different typology according to successive cartographic documents

Table 1. Historical documents and maps employed for the analysis of planform changes in river channels from southeastern Romania (Ioana-Toroimac, 2009; Cristea, 2011)

Source name		Century, year	Scale
Historical documents	Documente privind Istoria Românilor, Documenta Romaniae Historicae, Documente tecucene, Documente putnene (pentru câmpia joasă a Siretului)	XV, 1423–1495	
		XVI, 1514 – 1589	
		XVII, 1642 – 1677, 1677 –1688	
Historical maps	Harta lui N.Sanson	1655	
	Harta lui C.Cantacuzino	1700	
	Harta lui Dimitrie Cantemir	1737	
	Harta lui von Bawr	1770	1:288000
	Harta lui von Otzellowitz	1790	1:28000
	Harta lui Specht	1790 – 1791	1:57600
	Harta rusă	1835 1853	1:420000
	Harta Szathmary	1855 – 1857	1: 57600
	Planuri directeoare de tragere, proiectie Lambert	1897 – 1902	1:20000

Table 2. Cartographic documents employed for the analysis of the planform shape of Someșul Mic channel (Perșoiu, 2010)

Name of the map	Date of the survey	Publishing year	Scale	Projection	Institution	Resolution	Year referenced in the text
First Austro-Hungarian military surveying	1763 – 1773 1785 / 1787*	1787*	1:28800	No projection	Institute of Military Geography, Vienna	No geo-referenced	1764
Second Austro-Hungarian military surveying	1859 – 1860	1869 – 1870	1:28800	Cylindrical projection Cassini – Soldner, ellipsoid Zach-Oriani	Institute of Military Geography, Vienna	4 m/pixel	1860
Third Austro-Hungarian military surveying	1869 – 1884	1890 – 1910	1:25000	Stereographic projection Proiecție stereografică Tg. Mureș pe elipsoid Besel 1841	Institute of Military Geography, Vienna	2m/pixel	1884
Topographi maps	1940*	1943	1:50000	Stereographic projection Tg Mureș	Hungary	No geo-referenced	1940
Topographi maps	1908 – 1914 Aerial photography reambulating: 1956	1957	1:25000	Gauss – Krüger Pulkovo, Cylindrical Projection 1942 Proiecție cilindrică Gauss – Krüger Pulkovo 1942	Romanian Military Topographic Service	2m/pixel	1956
Topographi maps	Updated: 1968 Mapped 1969	1970	1:50000	Gauss – Krüger Pulkovo, Cylindrical Projection 1942 Proiecție cilindrică Gauss – Krüger Pulkovo 1942	Armed Forces Ministry Socialist Republic of Romania	6.6m/pixel	1968
Topographi cal plans	Aerial photography: 1968-1976 Field: 1970-1977	1971-1979	1:5000	Stereographic projection Stereo 70 ellipsoid Krasovschi	IGFCOT	0.4 m/pixel	1970
Topographi maps	1977	1978 – 1979	1:25000	Gauss – Krüger Pulkovo, Cylindrical Projection 1942	DTM	2 m/pixel	1977
Orthophotos	2005	-	1:5000	Stereographic projection Stereo 70 ellipsoid Krasovschi	ANCPI	0.5 m/pixel	2005

*Uncertain data or incomplete; IGFCOT = Institut of Geodesy, Photogrammetry, Cartography and Land Management; DTM = Military Topographic Department; ANCPI = National Agency for Cadastre and Land Registration

2.2. Preparation of the materials

This section is dedicated to some practical aspects regarding the proper manner used to analyse each cartographic document and the necessary know-how for this operation, as well as the risks to the quality of the measurements posed by a superficial approach of this stage (i.e. “preparation of the materials”). Specifically, it involves scanning the available cartographic materials, georeferencing in the Stereo 70 projection or establishing map location based on control points, and a statistical estimation of the errors generated by georeferencing.

2.2.1. Scanning / acquiring the available cartographic materials

Scanning the source materials, e.g. transferring the data from analog to digital format, is a mandatory step in the graphic processing of the data by using a specialised software. Furthermore, the quality of the scan contributes to establishing the mapping scale; e.g. when scanning a 25 000 scale topo map at 300 dpi (dots per inch), the resulting resolution of the pixel after georeferencing the map will be approx. 2.1 m (according to the calculation shown below). Scanning the map at 150 dpi will generate a pixel resolution of approx. 4.2 m, thus a generalisation.

While these differences do not interfere with the degree of accuracy of the original map, they will, however, influence the quality (scale) of vectorization of some elements (i.e. banks, thalwegs).

$$1 : 300 \text{ (dpi)} = 0.003; 0.003 * 25000 \text{ (map scale)} = 83.33; 83.33 * 2.54 \text{ (conversion of inch to cm)} = 211.66 \text{ cm (pixel resolution after georeferencing, 2.11 m)}$$

Considering the fact that military and cadastral maps, with relatively restricted accesibility, are the most commonly employed cartographical documents for such purposes, the access to such data in analog format is rather difficult. Moreover, the movement of maps and survey plans is considerably facilitated when they are in digital format (e.g. the Austrian maps dating back to the 18th and 19th centuries – distributed by ARCANUM, Timar et. al., 2010, *Planurile Directoare de Tragere* – distributed by www.geospatial.org, Crăciunescu et. al., 2011), and the user is unable to intervene on the scanning settings. However, we believe it is pertinent to highlight the quality of the digital materials employed in the analysis (i.e. the resolution) in order to accurately assess the vectorization errors.

2.2.2. Georeferencing and statistical estimation of georeferencing errors

Through the georeferencing process, cartographic materials published in different chronological stages and projections are assigned geographical

coordinates by means of a specialised software in order to achieve an accurate positioning on the Globe as a basis for comparative analysis.

The information necessary in this stage (name of the projection and *datum*, the known geographical or rectangular coordinates of several points – considered *control* points during this process) is commonly printed on the map sheet, including the year/period when it was elaborated. However, this data is lacking in older maps; therefore, in these situations, the georeferencing process needs to be carried out based on previous cartographical studies comprising information regarding the coordinate system used for that particular generation of maps or plans, or, ultimately, by identifying pairs of common points (whose position has not been altered over time – i.e. buildings, crossroads, bridges) on old cartographic materials and the more recent ones, which have already been georeferenced.

The accuracy of the process requires the materials to be georeferenced in their original projections and to subsequently be re-projected in a different coordinate system, as needed. This matter is of particular importance in historical change analyses, considering the fact that several types of projection systems have been employed for the Romanian territory over time, each with distinctive types of errors. Aside from the projection systems used on a regional scale, it can be noted (Table 3) that the entire Romanian territory has been covered during the 19th century by maps made in either conical, azimuthal or cylindrical projection, each with different parameters and degree of distortion of distances and areas.

Tabel 3. Characteristics of projections and ellipsoids used in different chronological stages for the elaboration of maps covering the entire territory of Romania

Features	Lambert-Cholensky*	Stereo 70	Gauss - Krüger		U.T.M.	
Characteristics of map projections	Conic projection (conformal)	Azimuthal projection on a secant plane (conformal oblique stereographic / double stereographic **)	Transverse cylindrical projection (conformal)		Transverse cylindrical projection (conformal)	
			Zona 4	Zona 5	Zona 34	Zona 35
Central meridian	24°18'44,99" E (24.31249722 E)	25° E	21° E	27° E	21° E	27° E
Origin latitude	45°02'29,216" N (45.04144889 N)	46° N	0°	0°	0°	0°
Scale factor	0.99844674	0.999750	1.00000		0.99960	
False easting	500000	500000	4500000	5500000	500000	500000
False northing	504599.11	500000	0			
Datum	NA	Dealul Piscului 1970	Pulkovo 1942 (S-42 Romania)		WGS 1984	
Ellipsoid	Clarke 1880	Krasovski 1940	Krasovski 1940		WGS 1984	
Semi-major axis	6378249,2 m	6378245.0 m	6378245.0 m		6378137.00 m	
Semi-minor axis	6356515,00 m	6356863.02 m	6356863.02 m		6356752.31 m	
Inverse Flattening	293.47	298.30	298.30		298.26	

*Rus et. al. (2009); **ESRI software

The official cartographic projection currently used in Romania is Stereo 70 (*datum* Dealul Piscului 1970); consequently, most databases were built up in this coordinate system. Thus, old cartographic materials are georeferenced and then re-projected in this system in order to ensure the homogeneity of the subsequent analysis. However, the precision of map overlay is influenced in some instances not only by the accuracy of the coordinate conversion from a different projection system, but also by a number of parameters related to the geocentric conversion between the ellipsoids employed (in terms of *datum*). In the case of the data re-projected from Gauss-Krüger to Stereo 70 no transformation of the geodetic *datum* is required (as they are referenced to the same ellipsoid), whereas the re-projection from WGS 84 to Stereo 1970 would result in planform differences between the point positions ranging up to 125 m in the absence of transformation parameters. The accuracy of the transformation parameters depends on the method employed to generate them (i.e. their number - 3, according to the Molodenski method, and 7, according to the Bursa-Wolfe method). Thus, it is considered that in the case of the most commonly used WGS84 – Dealul Piscului 1970 transformation, with three translation parameters of the coordinates

($\Delta X = -28$ m, $\Delta Y = 121$ m, $\Delta Z = 77$ m), the position errors can amount to approx. 5 – 10 m (Bănică et al., 2008).

The information regarding the coordinate systems employed in cartographic materials created over the past 50 years and the transformation parameters for their *datum* is rather common knowledge, therefore these materials generally allow for an analysis of channel planform changes with relatively small errors. However, the matter is considerably more complex in the case of older maps; e.g. for an approx. 33 km-long sector of Buzău valley (Vernești – Găvănești), *Planurile Directoare de Tragere*, georeferenced according to the parameters shown in Table 3 and re-projected to Stereo 70 (the maps are available online as part of the eHarta project, on www.geospatial.org; Crăciunescu et. al., 2011).

In order to evaluate the precision of the overlay of *Planurile Directoare de Tragere* and the 25000 military topographic map (edition 1980) we assessed the differences in the positioning of several fixed points (churches) appearing in both sets of maps. A total of 22 unevenly distributed pairs of such points, according to the degree of humanization of the territory, were identified on the 4 sheets comprising the channel sector under study (Fig. 2).

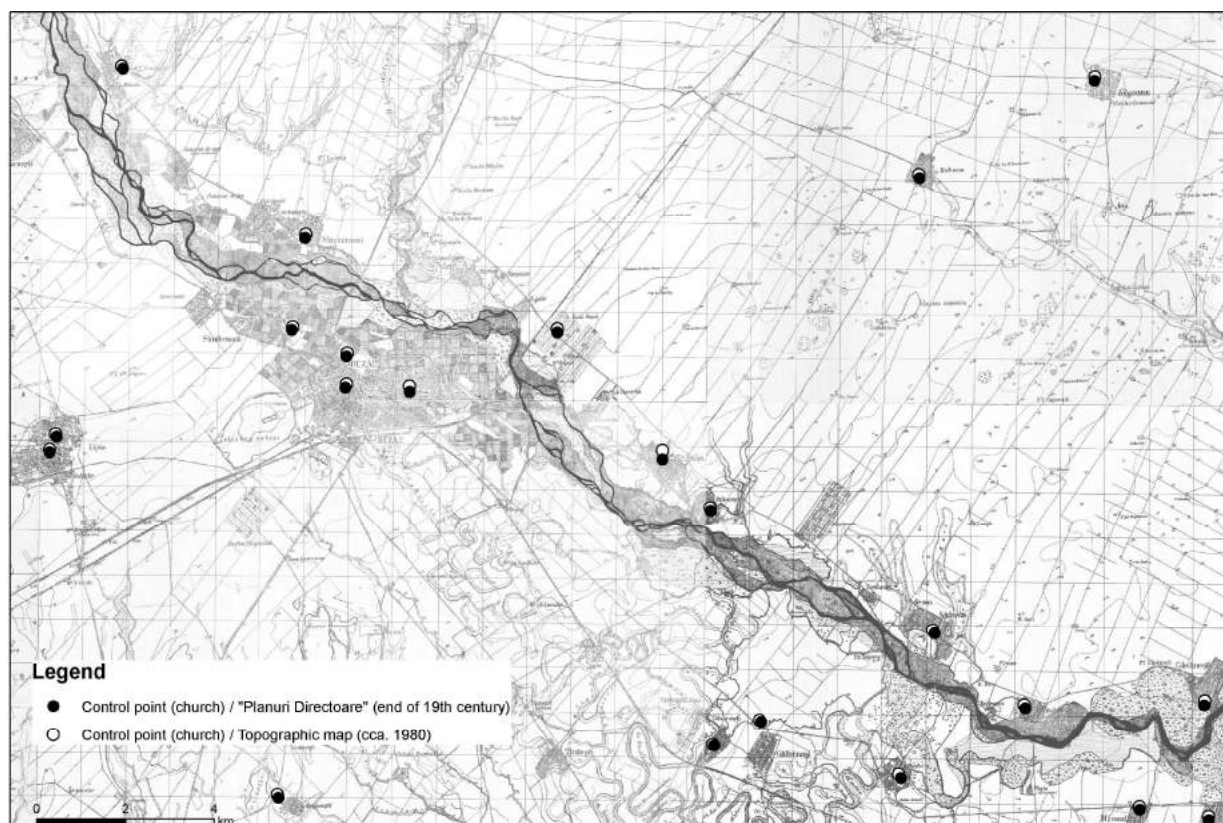


Fig. 2. Differences in the position of several fixed points (churches) on *Planurile directeare* georeferenced within the eHarta project (background), sc. 1:20000 (1895 – 1900) and on Topographic Map of R.S.R. (*Harta topografică a R.S.R.*), sc. 1:25000 (cca. 1980) – both re-projected to Stereo 1970

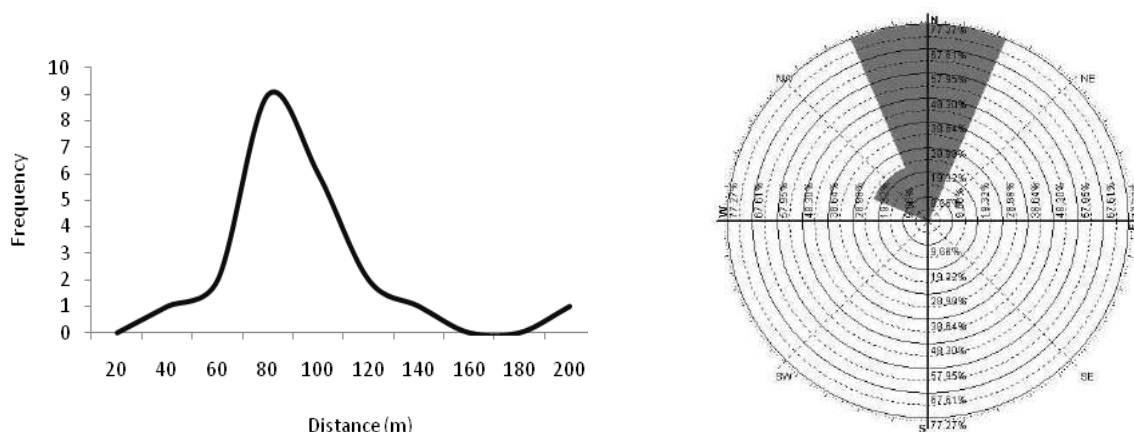


Fig. 3. Magnitude of difference-vectors and their orientation (azimuth)

By comparing the two datasets (pairs of points) we were able to identify deviations ranging from 50 to 110 m, with the majority of the deviations ranging from 60 to 90 m (70% of the instances) (Fig. 3). By analyzing the orientation of vectors (generated by the pairs of coordinates from both maps), it became apparent that approximately 80% of the occurring differences were generated by a southward deviation of *Planurile Directoare de Tragere* compared to the more recent maps. This could be explained by an insufficient knowledge of the transformation parameters for older maps *datum* in the course of re-projection.

Map overlay errors are significant to the analysis of river channel dynamics, thus, it is necessary to make corrections of the geographical location of older maps. This can be achieved by repeating the georeferencing process by using the common elements in both maps – e.g. churches. Human settlements are commonly located along the floodplains of large rivers, therefore the identification of such pairs of points is relatively facile. Although this method based on unevenly distributed control points does not necessarily guarantee an increase in the overall map overlay precision, it can, however, provide a more accurate frame of analysis of the floodplain.

Thus, in the case of the aforementioned valley sector, the repositioning of the old map sheets according to the newer edition based on the 22 control points (churches), ensued by an analysis of the residual values resulted from the adjustment of the coordinates and the elimination of the ones far exceeding the average, have greatly contributed to the increase in the overlay precision (< 30 m). This is influenced by the type of conversion of the images used within the georeferencing software (which may include translation, rotation, uniform scaling – image-wide, or uneven scaling – local, by

distorting the image), and the degree of accuracy of repositioning of the control points can be assessed by the RMS total error.

3. Preamble to the morphometric investigation of river channels

3.1. Typological classification of river channels under review

Any quantitative or qualitative approach to river channel analysis should be preceded by the typological classification of the planform configuration of the river, as the type of channel is the criterion which determines the ensuing steps: the sectorisation and segmentation of rivers, the actual morphometric measurements and determining the planform migration of river channels. The geomorphological classification of channel types is relevant because it contributes to a better understanding of the relationships between processes, forms and stability.

The progresses made in classifying channel planform shapes resulted in some changes in this regard compared to the earliest classifications made by L. B. Leopold & M. G. Wolman (1957) or S. A. Schumm, (1985). The recent typology published by M. Rinaldi et al., (2011) combines the latest developments in terms of the classification of channel planform configurations (Fig. 4). The transition of channels from one type to another can occur along the same river without any obvious delineating thresholds, as the type of underlying sediment and the stability of the channel changes (Thorne, 1998). The types of channel assembled in Fig. 4 are characteristic for the Romanian geographical environment and are based exclusively on the channel planform shapes observed in the field, on historical maps or orthophotos (e.g. Fig. 1).

A brief description of the main types of channel illustrated in Fig. 4 is as follows.

- The **straight (R)** type is extremely rare in nature. It depicts straight channels with relatively uniform widths, low sediment loads, low slope gradients and stable banks which are usually shaped in deposits with high contents of silt and clay. The sinuosity index (I_s) ranges from 1 to 1.05, whereas the anastomosis index (I_a) is below 1.5.

The **sinuous (S)** type describes a channel with an I_s ranging from 1.05 to 1.5 carrying a mixed solid load (suspended and dragged), which contains small bars positioned alternately in the context of a sinuous thalweg, indicating that accumulation on the bank will be ensued by erosion due to the upstream migration of the bar.

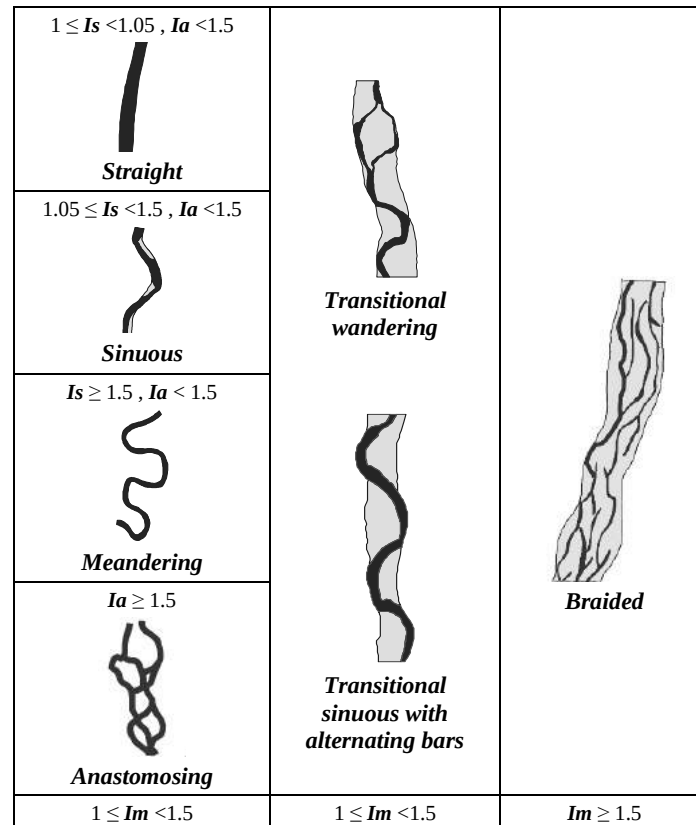


Fig. 4. Diagram of fluvial morphology and relative areas of variability of the planform morphological indices (Sinuosity index, I_s , Braiding index, I_m , Anastomosis index, I_a) (Rinaldi et al., 2011)

The **meandering (M)** type describes a whole array of meandering channels (I_s equal to or above 1.5) ranging between two extreme situations: a) channels with high sinuosity where the suspended solid load is prevalent, which have high dynamic stability and their typical evolution is towards meander cutoff, and b) less stable meandering channels, due to the mixed solid load with increasing dragged sediments content. The channel width is greater within the meanders. Processes such as meander migration and meander cutoff are characteristic for this subtype of channel.

The **sinuous type with alternating bars (SBA)** and the **wandering (W)** type are transitional from meandering to braided channels. The solid loads carried by the channels in this class are typically high, comprising mainly sand, gravel and boulders. The channel width is relatively high in relation to

the depth. Alluvial banks and bars commonly develop within the channel bed, which play an important role in localising bank erosion. The distinction between the two types of channels is provided by the braiding index ($I_m \sim 1$ for SBA and $I_m < 1.5$ for W).

The **braided (AI)** type is a category of channels commonly occurring in cases where the rivers have a significant dragged sediment load, braided channels enclosing rhomboidal bars, high slope gradients and highly unstable channel, which, in some cases, may lead to avulsion (sudden abandonment of the previous channel).

The **anastomosing (A)** type includes channels comprising of branches divided by islands covered with vegetation, low slope gradients and cohesive banks, and are typically more stable due to the prevalence of suspended solid load.

3.2. Delimitation of the study area

The selection of the study area in the field of river channels must take into account several considerations (listed below) in order to ensure the representativeness of the results in terms of the historical evolution of channels (approx. 150 years for Romanian rivers):

a) The selection of the entire river or a certain reach displaying particular traits according to the position within the fluvial geomorphological system.

In both cases, it should be taken into consideration that a river has certain characteristics imposed by the dominant control factors according to the position within the fluvial geomorphological system (Fig. 5).

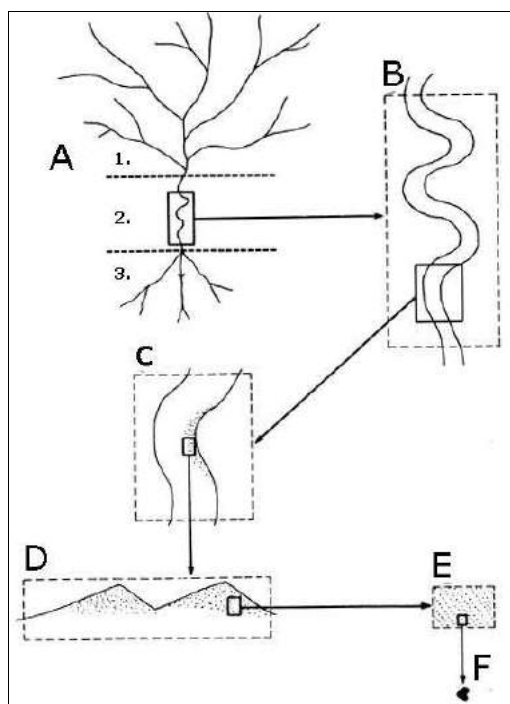


Fig. 5. Generalized scheme of a fluvial system (Schumm, 1977). The particularization of the investigations on the fluvial system varies according to the objectives pursued. A geologist or a geomorphologist may be interested in the river basin or the drainage area (zone A) over a long geomorphological time (at least 1 mln. years); a geomorphologist or a hydrologist can be interested in a reach (B) over a time frame ranging from tens to thousands of years; a sole meander (C) may be the focus of a geomorphologist or a hydraulic engineer over a period of merely a few years; the formation of a bar within the channel and the distribution of the sediments fall under the scope of the sedimentologist (D; E) (after Ichim et al., 1989)

Thus, the study area can be either located in the 1st zone of the fluvial system (where the organisation and the evolution of the river network is mainly under the control of valley slope

processes), in the 2nd zone of the fluvial system (the domain with the highest complexity of the water + sediment transport), or in the 3rd zone (where the sedimentation of the products originating upstream generate specific terminal morphologies).

The 2nd zone of the fluvial system is the area where the most typologically complex river channels commonly develop, which has prompted S. A. Schumm (1977) to define this as the fluvial zone. It is, thus, inherent that within the 2nd zone, a river can include all the morphological types of channel described in the previous chapter. However, this does not imply the absence of river channels in the 1st and 3rd zone, but their presence is not as representative as in the case of the 2nd zone.

Identifying and observing these zones will enable us to move on to the following methodological stage, namely the delimitation of study sectors.

b) Delineation of representative reaches along the investigated river

According to the definition of fluvial geomorphology, the **reach** describes a unit of the natural channel whereby the length is the *wavelength of a meander* (in the case of sinuous, meandering or wandering channels), the *distance between two successive pools or riffles* (in straight channels), or the *distance between two consecutive braiding nodes* (in braided channels). These lengths can be derived based on the channel width; e.g. for a channel below 1 m wide, the length of the reach can amount to 5–7 m; a channel width of 200 m commonly results in a length of the reach of approximately 1.5 km (Leopold et al., 1964).

We believe that, in the context of the research on the historical dynamics of Romanian river channels, the selection of the reach length according to the aforementioned criterion is restrictive. A reach of 5 – 7 m bankfull channel width can be illustrative of the changes in the micromorphology and the subsequent fluvial processes over a relatively short period (i.e. a flood event, a season, or changes occurring over several years). However, a broader approach in terms of the reach length is required in order to document the historical-scale changes in a river channel. Therefore, the length of the reach suitable for this type of approach has been extended to the order of tens of kilometres. We also took into account the recommendations of N. Surian et al., (2009) or C. F. Rapp and T. B. Abbe (2003), who suggested that the reach length should be of 10 to 14 fold the width of the channel, or 10 to 20 fold, respectively. We ensured that in no instance did the length of the reaches in the river channels under

analysis fall below the length recommended in the literature, but, on the contrary, it exceeded this limit (Table 4). In the case of rivers shown as example in table 4, the length of the reaches ranges from 136 km (approximately 85% of the total length of the river) to 35 km (11.5% of the total river length).

c) Establishing the confinement degree of the channel

Regardless of its planform, the channel can be influenced in terms of its evolution by the degree of limitation of lateral migration by various obstacles (e.g. the contact with the hillslope). This aspect is assessed quantitatively by means of the degree of confinement (G_c) (Fig. 6).

This parameter assesses the degree of lateral confinement of the channel along the river at reach and subreach-scale. It represents a ratio between the length of the banks (L_m sum) which are in direct contact with valley slopes, terrace scarps, etc., and the total length of the banks within the study reach

(L_{tm}) and is estimated as a percentage value. The sectors where the degree of confinement (G_c) is above 90% are considered reaches with confined channels, whereas a $G_c > 10\%$ -<90% indicates a semi-confined channel, and a $G_c < 10\%$ indicates a reach with a non-confined channel.

In addition, the index of confinement (I_c) evaluates the degree of confinement within a measured cross section, as opposed to the G_c , which is a longitudinal approach of the confinement along the reach. This index represents the ratio between the width of the floodplain (including floodplain terraces) and the bankfull channel width. The value of the confinement index is 1.0 (when the floodplain is lacking). In order to measure it, we use the cross sections delimiting the reach. In turn, the confinement index allows for a subdivision of the reaches in the following classes:

- *high confinement*, index ranging from 1 to 1.5.
- *medium confinement*, index ranging from 1.5 to n.
- *low confinement*, index $> n$.

Table 4. General data on the study reaches in Romania in terms of the contemporary and historical evolution

River	Drainage basin area A (km ²)	River length L (km)	Reach name	Reach length Ls (km)	Percentage of analyzed reach (%)	General slope gradient Ig (m/1000 m)	Drainage basin area		Discharge Qmean annual (m ³ /s)	Suspended load Qmean annual (g/s)
							Upstream Aam, (km ²)	Downstream Aav (km ²)		
Someșul Mic	3595	176,8*	Gilău – Dej	105	59.4	No data	No data	No data	22,5	9,5
Buzău	5238	303.4	Cândești - Săgeata	35	11.54	0.002	2783,2	3871,8	27,7	63,7
Putna	2518	160.3	Lepșa – confl. Siret	136	84.8	0.004	149	2518	16,1	91,8
Moldova	4316	213	Gura Humorului-Roman	110	51.6	0.002	1887	4316	35,1	43,2
Prut	28463	946	Ungheni – Fălciu	253,4	No data	0.00007	19275	25200	85,3	20,1

*Length calculated from the springs of Someșul Cald River

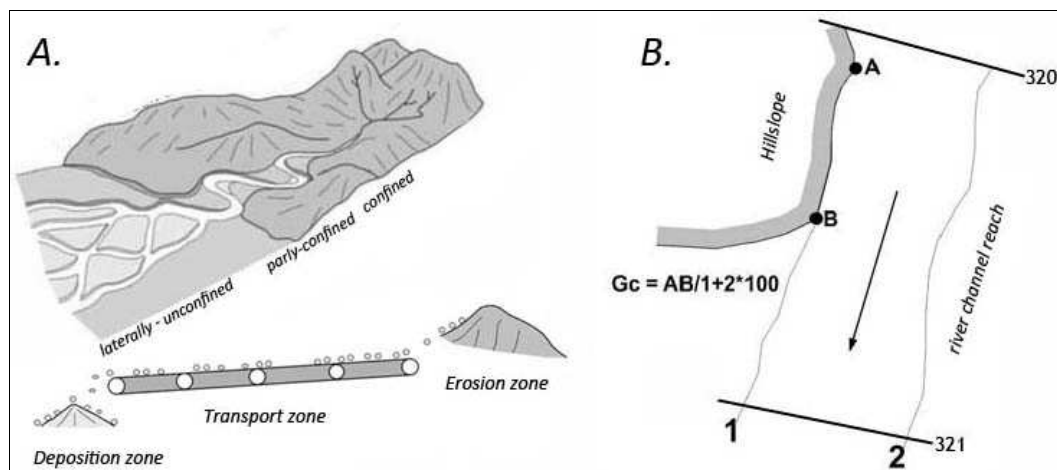


Fig. 6. A. The degree of confinement and the size of the river course in various zones of the fluvial system; B. Illustration of the method of measurement of the degree of confinement, G_c , of the channel (processing after Rinaldi et al., 2011, Brierley & Fryirs, 2005, Church, 1992)

The n value, which is designed to distinguish between medium and low confinement is also related to certain types of channel (Rinaldi et al, 2011), as follows:

- $n = 5$ for single channels and *sinuous with alternating bars* transitional channels;
- $n = 2$ for braided channels and *wandering* transitional channels.

Based on the values of these two indices, reaches can be divided into 3 classes: confined, semi-confined and non-confined.

3.3. Delineation of typologically distinctive channel subreaches

The delineation of **channel subreaches** implies identifying abrupt changes in the width and sinuosity of the channel, its morphology and lateral dynamics (stability vs meandering, avulsion) occurring prior to potential significant human interventions. The actual delineation is performed on the most representative set of maps available and requires a good knowledge of the study area, particularly in instances when the control factors, such as geology, by means of structure and tectonics, and the sediment input from the tributaries, result in changes of the channel typology. A brief description of the respective

subreaches is required, including the criteria used for the delineation. Whenever possible, the validation in the field of this delineation should be undertaken.

Subsequent detailed morphometric measurements, regardless of the historical set of maps used, will take into account these subreaches. The model for the selection of subreaches is the one proposed by S. A. Schumm et al. (1994) when investigating the historical dynamics of the Mississippi (Fig. 7).

The delineation of subreaches was performed on survey maps dating back prior to large-scale meander rectifications (i.e. before 1915). It was established that the length of the subreaches is uneven, as they delineate a meander wavelength (e.g. segments 9 or 13, Fig. 7), a straight (segment 10) or anastomosing channel (segment 11). Thus, it is recommended that subreach delineation is made on accurate maps preceding large anthropogenic interventions on the fluvial systems under study. For example, in the case of Someșul Mic (Perșoiu, 2010), the non-georeferenced maps (1764 and 1940 editions) served a consultatory function, whereas the maps from 1869-1870, assisted by those published in 1890-1910, served as the map base for reach delineation and performing morphometric measurements.

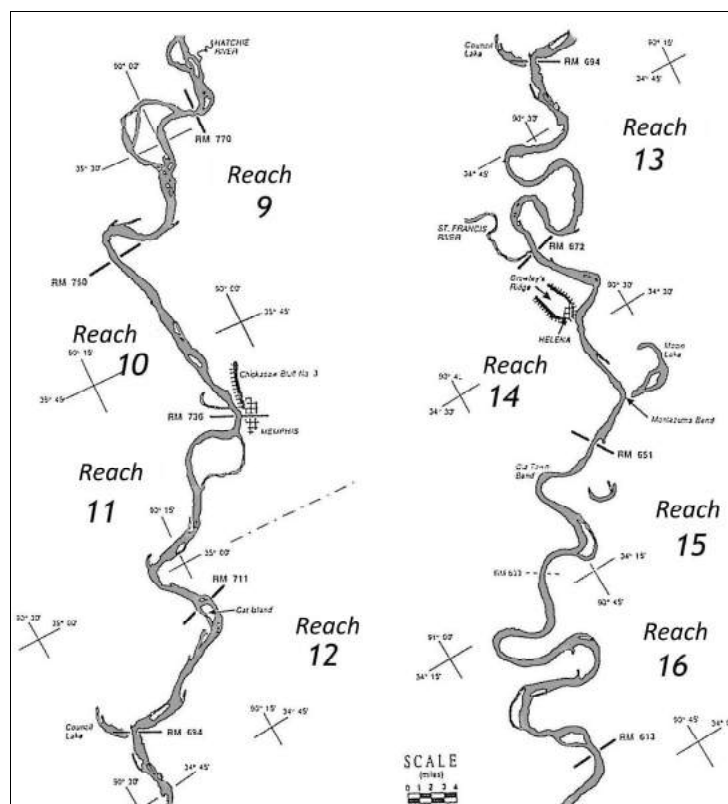


Fig. 7. Model of segmentation of a reach for the study of the historical dynamics of the channel (the case of a channel with a succession of types ranging from straight to sinuous and meandering) (Schumm et al., 1994)

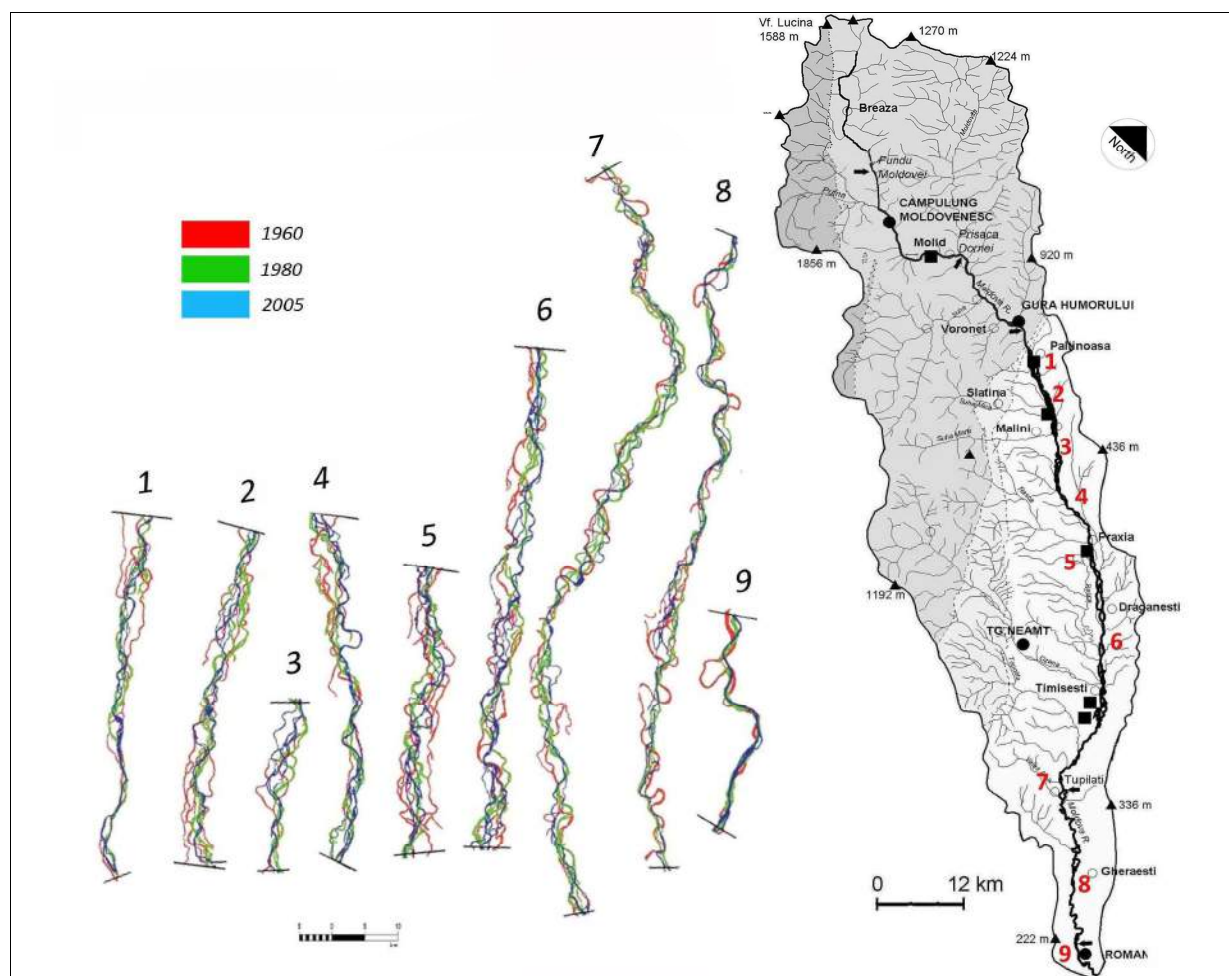


Fig. 8. Diagram of the channel reaches along a wandering and braided river (the case of Moldova river between Gura Humorului and Roman) (Chiriloaei, 2012)

To illustrate the case of a braided and wandering channel, we present the method of subreach delineation used for Moldova River. The most representative set of cartographic documents used for this purpose were the orthophotos from 2004 – 2006. Several factors were taken into account, such as the degree of confinement, the detail geomorphology of the channel, potential discontinuities along the channel, the extent of sedimentation zones, the position of nodes, etc. The result is shown in Fig. 8, wherein the 110 km-long river was divided into 9 relatively uniform reaches.

4. Methods for measuring the planform changes of the channel under investigation

Several methods are currently used to investigate the spatial behavior of the channel during a given time frame or in successive time frames, by manually or automatically (GIS applications) determining the morphometric parameters of the river. Opting for one or more such methods depends on the degree of coverage of the territory with detailed maps, the type of channel under investigation, the purpose of the study and the training of the researcher. After the database is

generated, the researcher can either opt for an analysis on the temporal and spatial variations of the detail values, or an analysis on the mean values determined for the channel reaches defined according to Figures 7 and 8.

Below we briefly present three of the methods used to investigate planform changes, as applied in the cases of rivers Someșul Mic, Prut, Putna and Moldova: successive cross section measurements of the floodplain; measurements along the central axis of the bankfull channel (single channel or main drainage channel); surface morphometric measurements.

4.1. Cross section measurements on the bankfull channel and floodplain

The morphometric variables subject to measurements are summarised in Table 5, where each variable is accompanied by a review on the manner of extraction from historical maps. These variables were determined and used in the morphometric analysis of Romanian rivers and do not exclude other viewpoints. However, these parameters are essential for the quantitative assessment of the planform dynamics of the channel.

Table 5. Examples of morphometric variables which can be determined using the floodplain cross section measurement method, for each time frame

Parameter	Method of extraction of the parameter
Floodplain width (including floodplain terraces, alluvial plain), L_m , in m	Length of the floodplain cross sections, perpendicular to its central axis, at even intervals of 100... 1000 m. It has a fixed value for the entire analysed period.
Bankfull channel width, L_a , in m	Measurements perpendicular to the axis of the channel, in the points of intersection of the cross sections with the central axis of the river (single channel/main drainage channel). It is determined for each time frame.
Width of the active discharge strip, L_{fa} , in m a) Sinuous or meandering channel b) Wandering or braided channel c) Anastomosing channel	Measurements perpendicular to the axis of the channel, in the points of intersection of the cross sections with the central axis of the river (single channel/main drainage channel). It is determined for each time frame.
Number of channels, N_c a) Unorganized meandering channel or braided channel b) Anastomosing channel	Measurements perpendicular to the axis of the channel, in the points of intersection of the cross sections with the central axis of the river (single channel/main drainage channel). It is determined for each time frame.
Braiding index, I_m , / Anastomosing index, I_a (after Ashmore, 1991)	Average value of the intersecting channels in floodplain cross sections, within the investigated reach.
Channel length, L , in m a) Sinuous or meandering channel b) Unorganized meandering channel or braided channel c) Anastomosing channel	Channel length along its central axis (single channel/main drainage channel) between two floodplain cross sections. It is determined for each time frame.
Sinuosity index, I_s	Ratio between the length of the single/main drainage channel along its central axis and the length of the aerial distance between two floodplain cross sections. It is determined for each time frame.
Position of the channel within the floodplain	Measurements in the point of intersection of the floodplain cross sections with the central axis of the single/main drainage channel or the channel banks. It is determined for each time frame.
Rate of lateral migration, R_m , in m/yr	The difference between the positions of the channel within the floodplain in two consecutive time frames. The ratio between the value and the number of years between the two moments reflect the annual rate of lateral migration.

The morphological and morphometric variables must be defined clearly (some need annotations) in order to eliminate confusions when performing measurements.

The floodplain or alluvial plain (Fig. 9) purports the same genetic significance. The matter of these terms was discussed by Ichim et al. (1989) and they concluded with the following definition: the floodplain is the relatively smooth surface adjacent to the channel, formed during the last period of geological time (last Glacial – Holocene) through the prevalence of vertical and lateral accretion, delimited by structural scarps (often directly by terrace scarps developing on each side of the valley and interfering with the lateral migration of the river). Other steps (1 – 2 m, 3 – 4 m) can occur within this relatively smooth surface which do not interfere with the lateral migration of the channel, thus they were included in the floodplain. The alluvial steps with relative elevation higher than 5 – 7 m were not included (as they can constitute obstacles in the way of free migration of the river).

Bankfull channel width. The channel (Fig. 9) (the elongated concavity within the terrain topography which provides the natural drainage with the free surface of water) is shaped

predominantly by the bankfull discharge or dominant discharge. Their recurrence periods range to 1.5 years (in the mid part of the USA), 1.85 years (Australia), 0.45 years (England and Wales), 0.7 – 5.3 years (Belgium) (Malavoi & Bravard, 2010). Following the initiation of the channel, throughout its length, its entire geometry, be it the channel planform or the hydraulic geometry, is governed by the same laws. Any assessment on causality relations between the vast majority of the processes and subsequent geomorphology and nature of transiting deposits is referenced to the state of the channel at bankfull discharge. Therefore, these discharges are highly significant in terms of morphogenetic impact. Identifying the width of the bankfull channel on survey maps, satellite images and orthophotos should take into account the principle of the bankfull channel. The images from Fig. 10 are illustrative for this phenomenon. The bankfull discharge value of 68 m³/s recorded in July 2010 on Moldova River had maximum efficiency in terms of shaping the cross section, whereas the extremely low discharge value of 5.62 m³/s from July 2012 left uncovered the largest part of the channel, which is no longer shaped by the water discharge for a certain period of time.

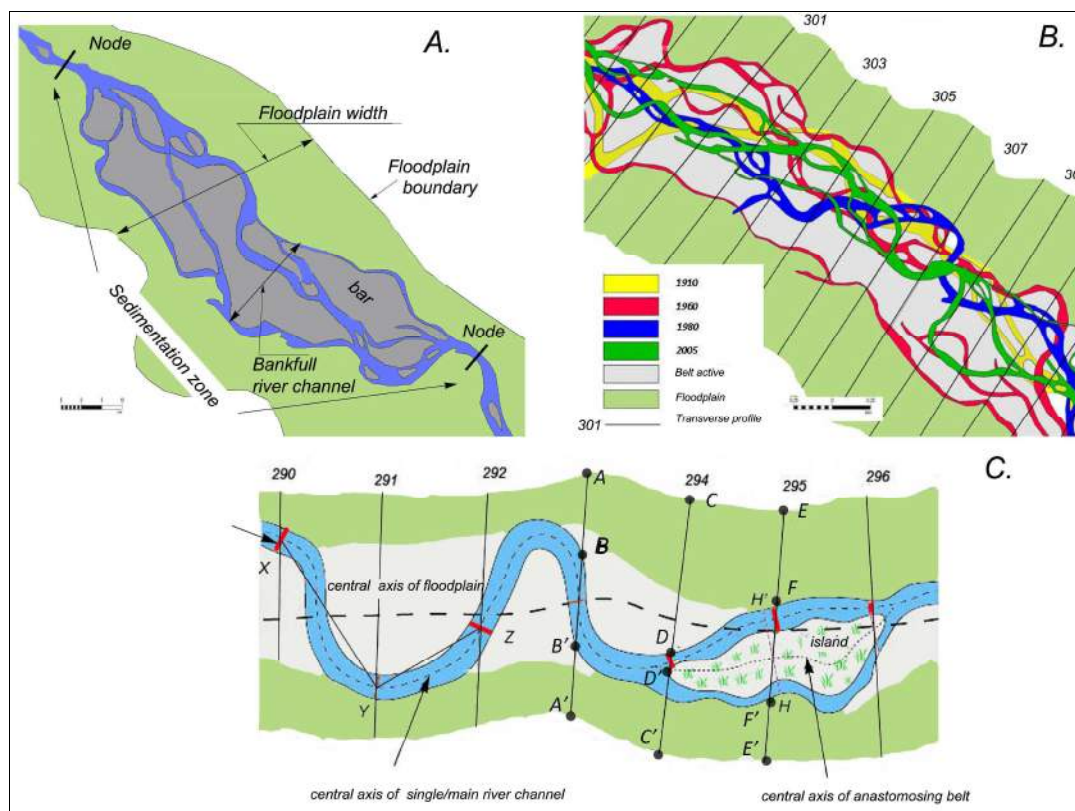


Fig. 9. A. Components of a braided channel and the relation with the dimensional elements of the floodplain and channel; B. Floodplain cross sections perpendicular to its central axis, equally spaced at 100 m – the morphometric measurements on the channel / active drainage strip are performed next to each floodplain cross section: e.g., Moldova River channel (Chiriloaei, 2012); C. Sample of morphometric parameters determined in the cross section, along Someșul Mic River (sequence of meandering and anastomosing channel): XY, YZ – linear distance between the extremities of consecutive reaches; HH' – width of the anastomosis active strip; A-B/A'-B', E-F/E'-F' – distance to the left/right from the edge of the floodplain to the left/right bank of the channel (single/main drainage channel) (Perșoiu, 2010)



Fig. 10. Moldova River in sections Gura Humorului (top) and Praxia (below), bankfull channel (left) and minimum discharge (right) (photos N. Rădoane)

The **width of the active belt** (Fig. 9) (also called low floodplain) where the river migrates unimpeded depends on the type and size of channel. In the case of meandering channels, the active belt approximately equals the maximum amplitude of the meanders and includes both abandoned meanders and active ones. In braided channels, the active belt equals the width of the bankfull channel, whereas in anastomosing rivers all the channels need to be taken into account in delimiting the active belt. Several researchers established a direct relationship between the width of the active belt and the floodplain width as follows: the floodplain width is approximately tenfold the width of the active belt (Bridge & Leeder, 1976) and even up to 20 times the width of the active belt (Bridge, 2003).

The **sinuosity index** (Fig. 11 I). The sinuosity of the channel within a given reach is described by the ratio between 2 lengths: the distance between the extremities of the reach measured along the axis of the main channel, and the length measured along the axis of the valley. Unlike the braiding index,

which is applied in evenly distanced cross sections, sinuosity can be quantized on reaches of varying lengths, according to the morphology of the channel (also see Fig. 7). Fig. 11 I illustrates the method to measure and calculate the sinuosity index by reach.

Cross section morphometric measurements on the bankfull channel and floodplain are performed in sections perpendicular to the central axis of the floodplain and are equally distanced. The measurements for each time frame are made in the points of intersection of the respective cross sections with the river and its central axis, in accordance with the morphometric parameters considered (Fig. 8). The measuring interval is determined according to the level of detail required and the size of the investigated river/reach. For example, for the rivers listed in Table 4, the intervals of the cross sections ranged between 100 m and 250 m. Once established, the floodplain cross sections remain fixed throughout the entire period under investigation, regardless of how many sets of historical maps and satellite images are employed.

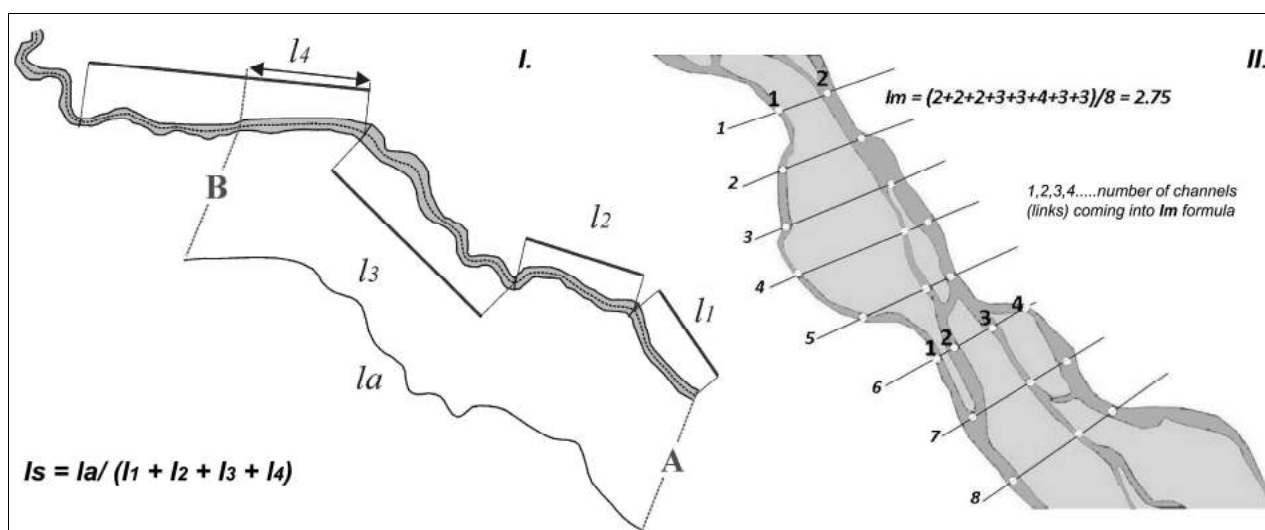


Fig. 11. I. Measuring the sinuosity within a reach between points A and B, with variations of the path axis (l_a - length measured along the channel axis; $l_1 + \dots + l_4$: length measured along the axis of the planform path) (Surian et al., 2009); II. Method for measuring the braiding index (Egozi & Ashmore, 2008)

Establishing the location of the cross sections must be made according to the following aspects:

a) the state of the channel at bankfull discharge must be considered;

b) the channel is not always represented at bankfull discharge on historical maps and satellite images. Thus, it is necessary to follow in each case the morphological step delineating the channel within the floodplain, regardless of the depicted width of the riverbed. Moreover, special attention needs to be granted in this regard to braided and wandering channels, whereby the bankfull channel width comprises multiple channels (Fig. 8).

The braiding index has been the subject of numerous calculation formulas, albeit it was concluded (Thorne, 1997; Egozi & Ashmore, 2008) that the fewest errors are obtained by totaling the number of channels (links) transected by the cross section instead of measuring the length of channels or bars (e.g. Brice, 1964). Therefore, we propose that the most reliable method of calculation is the one illustrated in Fig. 11 II, according to R. Egozi & P. Ashmore (2008):

I_m = number of transected channels (mean values obtained/number of cross sections considered)

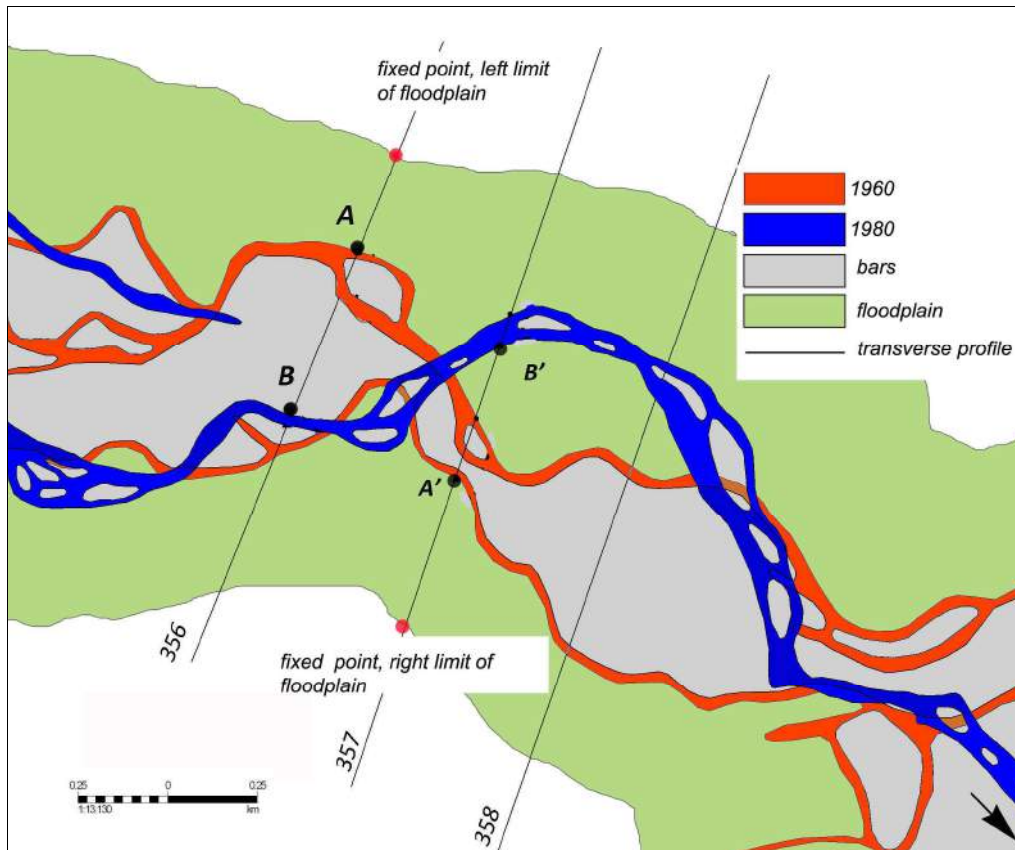


Fig. 12. Method for measuring the left-right migration of Moldova River

The *rate of migration of the channel* is determined based on the position of the channel at a given time within the floodplain. In order to compute the temporal mobility of the channel, a reference point is required. The model shown in Fig. 12 illustrates how such measurements are performed in the case of Moldova river. The same cross sections used for measuring the braiding index are employed here, but it is also necessary to know the position of each channel bank compared to a fixed point in 1910, 1960, 1985 and in 2006.

In this case, we established the fringe of the floodplain (the contact of the valley slopes with the terrace scarps over 5 – 7 m elevation) as the fixed benchmark. The method used for meandering or anastomosing channels is illustrated in Fig. 9C. Once the distances in meters from the fixed benchmark to the right bank were measured, the values obtained were recorded in a data table. The value measured for the following reference year is also recorded in the table. The difference between the two consecutive positions of the channel, in meters, indicate the migration of the channel (by erosion or accumulation, which can be quantized by dividing the migration distance by the number of years elapsed between the two positions).

4.2. Measurements on the morphometry of sinuous, meandering and anastomosing channels (sinuous or meandering channels)

This type of measurements refers to the morphometry of sinuous channels, namely of meanders as they were first introduced by L. B. Leopold and M. G. Wolman (1957, 1960). The knowledge of these methods comes to support the indirect determination of bankfull flow of paleomeanders (Dury, 1970; Rotnicki, 1991) and can provide information for the millennial-scale reconstruction of channel dynamics.

In the analysis of a sinuous channel, the basic morphometrical unit is the *channel loop* or *meander loop*. The planform of a meander loop can be described by the following elements (shown in Fig. 13): the *meander loop length* (c), corresponding to the length of the meander loop chord (in Fig. 13 are indicated the two meander loop chords by c_1 and c_2); the *meander loop height* (h), measured on the perpendicular line uniting the center of the chord and the intersection with the axis of the channel (at medium discharge values) and corresponding to the meander loop axis; the *mean radius of the meander loop* (r_c), e.g. the radius of the arc of circle circumscribing the meander loop; the *meander loop*

flattening, defined as the ratio between the length and the height of the meander loop (c/h); the *meander loop sinuosity*, as the ratio between the channel length measured along the river course between the points of intersection of the chord (lc) and the length of the chord (c_1+c_2); the *meander loop orientation*, or the azimuth of the meander loop axis, which indicates the direction of migration of the meander; the *meander loop apex*, is the point of intersection between the meander loop height and the concave bank; the *inflection point* is the spot on

the channel axis where the *riffle* is located. Two consecutive meander loops form a *meander*. Depending on the context, the elements of meander loop morphometry also include: the *wavelength* (λ), which measures the distance between the ends of the two successive loops; the *meander amplitude* (A) is the distance measured perpendicular to the meander length, between the apices of the two meander loops or on the centroid, and provides an insight on the active meandering strip.

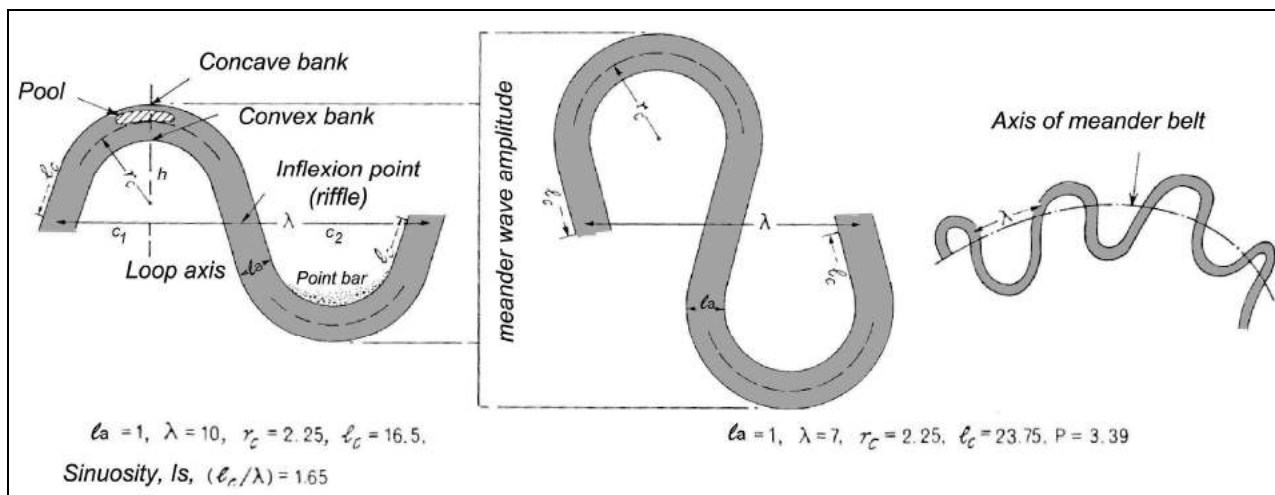


Fig. 13. The main components of meander geometry
(Leopold et al., 1964 ; Selby, 1985) (further explanations in the text)

The delimitation of each meander loop is based on the curvature radius, taking into account that the adjacent arcs are linked to them by straight line segments. For a channel sector to be considered a meander loop, the chord of the loop has to be larger than the radius and not more than sevenfold the channel width. The loops may occur individually and are not necessarily combined in meander formations. In this case, we can distinguish between *simple symmetrical loops* (have only one constant curvature segment); *simple asymmetrical loops* (have only constant curvature segments, but the length of the segment of one of them is larger than the radius); *composite loops*.

When highly detailed satellite images are available (i.e. Corona KH7), numerous elements of micromorphology can be identified (chute bars, bars, old channels whose age can be deduced based on the vegetation) and detail measurements can be applied (Cristea, 2011).

This method of investigation was employed by A. I. Cristea (2011) on Putna River, as follows: for

each set of images the axis of the channel was extracted in ArcGIS, and further on the circle circumscribed to the two points of the segment and the point of maximum inflection was generated for each meander loop. Generating the circles based on the three points can be easily achieved in ArcView 3.x, with the extensions Polytools and Trace MS. The center of each circle marks the radius of the meander in the respective sector. Tracing the movement of the loops can be based on the differences occurring in the central points, as pairs, of the circumscribed circles from each historical stage, both in terms of distance and azimuth (Fig. 14).

4.3. Surface morphometric measurements

Whenever highly detailed cartographic materials in terms of the channel and floodplain morphology are available, the method of surface morphometric measurements can be applied in order to investigate the spatial and temporal behaviour of several elements of interest, summarized in Table 6.

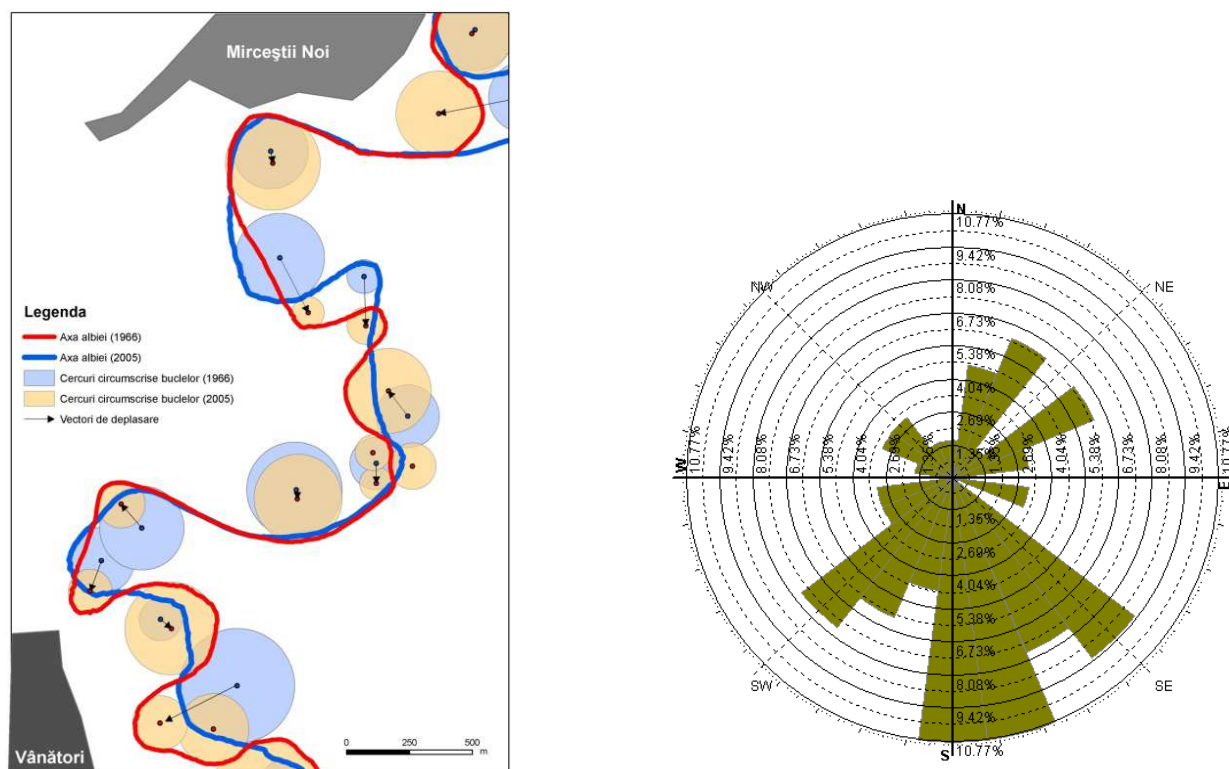


Fig. 14. Method for determining the dynamics of meander loops based on the dynamics of the centroids of the circumscribed circles; the magnitude of the movements of the meander loops in the analysed reach, and the preferential directions of movement of meanders are shown on a polar diagram (Cristea, 2011)

Table 6. Examples of elements of interest along the channel, active discharge strip and floodplain, which can be measured by using the polygon method in GIS

1. Channel
Active channel (sinuous or meandering river course)
Active channels (unorganized meandering river course, braided or anastomosing river course)
Riverbank surface
Bars
Islands
Chute bars
Areas with vegetation within the channel (trees, shrubs, herbaceous vegetation)
2. Meandering active strip
Meander scrolls
Natural levees
Riparian vegetation (trees, shrubs, herbaceous vegetation)
3. Abandoned strip, Floodplain
Paleomeanders
Wetland, other than paleomeanders
Terrains with various agricultural uses
Areas affected by relatively isolated constructions (i.e. buildings, airport)
Perimeters with archaeological findings
Built-up area
Landfills
Perimeters affected by gravel mining
Hydrotechnical works (lakes, reservoirs, drainage channels, levees)
Roads, railways

Depending on the nature of the investigation (i.e. the purpose), the data generated for each considered time frame can be used for: a) characterising the channel, the active discharge strip or the floodplain at a certain time (e.g. the percentage value of the

elements of interest within the investigated area); b) analysing the spatial dynamics of the elements of interest (repositioning, narrowing, broadening), by overlaying / intersecting the polygons corresponding to different time frames (this type of investigation

allows for prediction analyses of future trends in the spatial dynamics of the channel, such as narrowing/broadening, lateral migration, chute bar development, bar/island dynamics, changes in the riparian land cover); c) analyzing the temporal dynamics of the elements of interest by statistical analysis of the variations in the surface values of the delineated elements (e.g. variations along the river, statistics on the variations of the mean and total values).

To exemplify, we selected an analysis of the evolution of riparian vegetation types along a channel reach on Moldova river between 1960 – 2005 (Chiriloaei, 2012). The available historical maps have enabled us to delineate the boundaries of the vegetation within the channel, as well as outside the channel (marginal vegetation, Rinaldi et al.,

2009; Comiti et al., 2011). Also, we were able to distinguish between herbaceous vegetation with shrubs and arborescent vegetation. Furthermore, orthophotos proved to be even richer in information, allowing for detailed visualisation of the vegetation within the fluvial corridor, and thus enabling us to add other classes of vegetation to our analysis). The result is shown in Fig. 15, which illustrates how the areas with various types of vegetation changed over time. The ArcGIS 9.3 software can assist in obtaining the quantitative data of the element subject to measurement. In this case, we are referring to the area (in hectares) of the terrains covered by certain types of vegetation in successive time frames (Tabel 7). These quantitative elements further allow us to conduct detailed analyses on the evolution of the investigated phenomenon.

Tabel 7. Synthesis of the changes in the vegetation cover in reach 1 on Moldova River (ha)

Year	Total area	Active unvegetated area	Islands with herbaceous vegetation	Islands with arborescent vegetation	Marginal herbaceous vegetation	Marginal arborescent vegetation	Agricultural terrains
1960	620,17	271,69	94,89	36,68	105,1	111,81	-
1980	620,17	190,28	96,02	38,6	254,62	40,79	-
2005	620,17	168,6	38,7	49,39	178,45	30,25	154,78

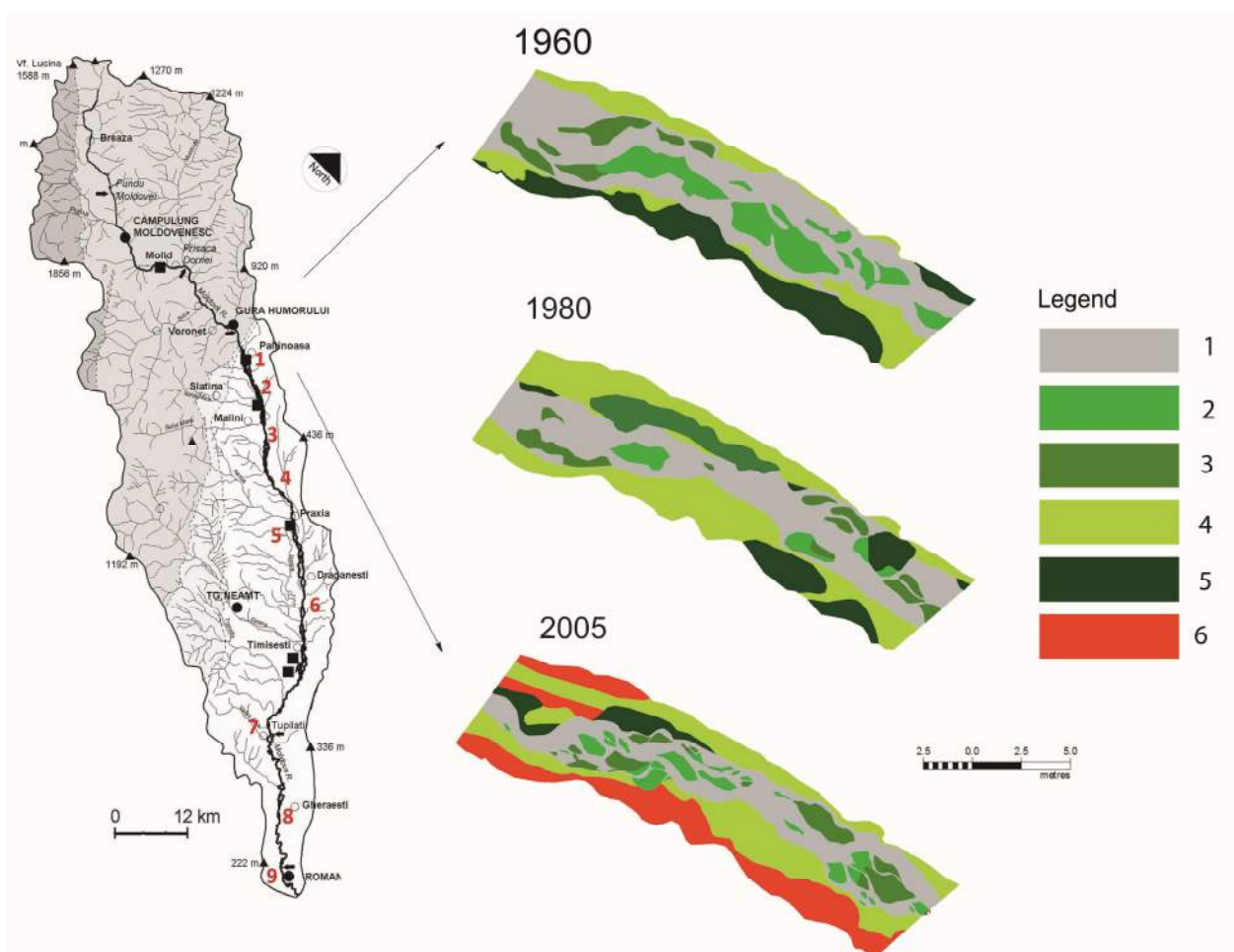


Fig. 15. Vegetation cover changes in reach 1 (Pătinoasa – Berchișești) of the floodplain of Moldova River based on historical maps (Chiriloaei, 2011) 1. Unvegetated active channel; 2. Island with herbaceous vegetation; 3. Island with arboreal and shrubby vegetation ; 4. Herbaceous marginal vegetation; 5. Arboreal and shrubby marginal vegetation; 6. Cultivated areas.

5. Conclusions

The availability of a series of cartographic materials published during the past 250-150 years (depending on the geographical area) enables researchers to conduct analyses on the spatial and temporal variability river channels. This topic of geomorphological research is significant for understanding the natural dynamics and current trends in the behaviour of rivers in the context of high anthropogenic stress and global climate changes. Such investigations have been conducted for at least 4 – 5 decades, but the great difficulty that faced the authors was the lack of comparable data generated by the analysis, due to the fact that the elements of interest (e.g. the morphometric parameters of the river) were represented at different scales and measured/assessed by different methods.

The vigorous development of GIS applications and their massive penetration of geography have generated a tremendous boost for such studies by

allowing the overlay and visualization at the same scale various cartographic and topographic materials which originally had different scales and projections. Modern methods of investigation assimilated classical methods (e.g. measurements along the central axis of the channel on meander loops and meanders) and further diversified (floodplain cross section method, surface measurement method), resulting in the possibility to generate a considerably larger amount of data at much higher resolutions than previously obtained.

Currently, depending on the nature of the study, the level of detail, the quality of available maps and georeferencing errors, the type of investigated channel and mechanisms, the available time and the amount of work required, or the possibility or lack thereof to automatically determine the relevant morphometric parameters, a method or a combination of methods can be chosen, provided that there is unity in the use of working methods in order to be able to generalise the conclusions of the studies.

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Morphometry elements of hydrographic basins with use in the characterization of relief

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Abstract. Since the ground surface has entered under the action of sub-aerial agents, water was the main relief-modelling agent in the temperate zone. Its vectorized action focused on slopes and on the hydrographical network has generated in time the present relief configuration. In this context, it should be normal that for the geomorphologic characterization of any geographical space we also take into account the fluvial morphometry parameters, which can be very useful in quantitative geomorphology studies. We propose, selecting from these parameters, the use of the river segments frequency of successive ascending orders within the Horton-Strahler classification system, as a ratio between their number and the surface of the investigated unit. Another parameter with importance on the dynamics and the intensity of the relief modelling processes is the geodeclivity that ensures the potential energy of any territorial system. This assumes that it is necessary to analyze the slope of the topographic surface, as well as the surface of the river network considered as size orders and the mean value for the entire valley network, divided on relief units under research. The drainage density, expressed as a ratio between the sum of the river segments and the catchment surface or investigated unit surface is similar with the relief fragmentation density already used in classical geomorphology studies. A very important element for the flow processes and flash flood generation is the length of the slope flow calculated with the formula proposed by Horton in 1945 as the inverted value of the drainage density double.

Keywords: river segments frequency, catchment slope, network slope, drainage density, slope flow length.

1. Introduction

The use of morphometry in the field of geomorphology has systematically been used since the middle of the last century, with the work of Strahler (1952) who, by the quantitative analysis of the hypsometric curves, has fundamented the determination of the youth or maturity degree of the hydrographical catchments relief.

Most part of the early classic geomorphology works conducted at the level of different relief units of Romania give little attention to quantitative assessments, but emphasize the qualitative aspects related to relief description based on the performed field researches or on the analysis of the cartographic fund (Roșu, 1967; Badea, 1967; Hârjoabă, 1968; Morariu & Velcea, 1971). The parameter most frequently used in these geomorphology researches was the density of the hydrographical network. The reference parameter used in these geomorphology researches was the density of the hydrographical network (Morariu et al., 1956).

In time, the international as well as the national researches have been developed and intensified introducing into the circuit new elements in

correspondence with the level of development of the discipline (Ichim, 1979; Grecu, 1992; Schreiber, 1994; Grecu & Zăvoianu, 1997; Armaș, 1999; Comănescu, 2004; Filip, 2008; Ionita, 1998; Dimitriu, 2007 ș.a.). For example Hârjoabă (1968), in *Relieful Colinelor Tutovei*, presented the map of the mean density of relief fragmentation and the depth of relief fragmentation. In addition, the information related to the slope analysis are also important, as they are involved in the dynamics of the present relief modelling processes, based on the maps scaled 1:50 000.

In the chapter *Morfosculpture* from the work *Stânișoara Mountains, Geomorphology study* Ichim (1979) briefly presents *The hierarchy and the structure of the valleys system* (after the Horton-Strahler model), considering that this analysis „offers the logical base of the comparative geomorphologic study of the valleys in report to the different factors that determine their evolution” and the present morphography of the study unit. In what concerns the study of the *longitudinal profiles* the main purpose was to discover the connection between the slope changes and the lack of terraces and also the reference significance of the confluences in the process of valleys evolution.

Zăvoianu (1985) applies the newest results from the international literature to the conditions specific to Romania and processes a large volume of data related to the analysis of the hydrographical basins morphometry, in the Horton-Strahler classification system. The synthesis of the performed researches allowed the development of a series of new laws and the finding of quantitative relations and indices, included in the work *The morphometry of hydrographical basins*, which can be very well used for geomorphologic characterizations as well.

The work of Mac (1986) *Elements of dynamic geomorphology* has a chapter referring to the *Fluvial morphodynamics* relevant for accomplishing a relief study that wishes to analyze the temporal evolution of the morphography of a geographic space. This is also based on the Horton-Strahler system due to its implementation in the geographical literature and presents “the order of the river segments, the law of the rivers number, and the law of the rivers length so on.”

Schreiber (1994) analyzes for the morphometry of Harghita Mountains the maximum relief altitude, the mean altitude, the density of the hydrographical network, the depth of the relief fragmentation, slopes declivity and the relief energy. In the case of the mean altitude, it uses very well, as a quantitative expression, the formula used in hydrology form the determination of the mean altitude of the hydrographical basins, and for the density of the network it uses the ratio between the sum of rivers length and the corresponding surface. For the slopes declivity, the values are calculated based on the maps scaled 1:100 000.

Significant contributions to the fundamentation and development of the fluvial geomorphology based on new quantitative data are gathered in the work of Ichim et al., (1989), *The morphology and dynamics of riverbeds*. The special contribution of the work resides in the approach of theoretical problems of novelty for the Romanian geomorphologic literature, based on the newest researches in the field and it offers a special methodological basis for the practical studies of fluvial geomorphology. Nevertheless, sustaining the idea that for geomorphology development the quantitative analysis is necessary, he determines, in another work, numerous variables, such as: the number of 1st order rivers, the number of 2nd order rivers, basin surface, mean basin altitude, mean basin slope so on. Thus, he has strengthened the necessity of using these parameters in a relief study (Ichim et al., 1998).

In a regional study of environmental geomorphology Filip (2008) presents in the 3rd part

the analysis of a classical geomorphology study and the analysis of a geomorphology study that includes the antropic component, giving the practical utility of the relief studies. In the work *Models of functional geomorphology of the valley-slope system in the Transilvanian Depression*, Roșian (2011) highlights the novelty of the interfluves order (the law of the interfluves number), established in a similar way as the hydrographical network order. The author calculates the *knot report* (R_n) or the intersection knot (analogous to the confluence report) and he presents the hierarchy on size orders and the graphical representation of the law of the interfluves number for a significant amount of interfluves.

In correspondence with the increase in number of the followers of these new approaches, we can say that at the national level few research nucleus appeared.

Thus, at the Geography Institute of the Romanian Academy, the classification system of the hydrographical network proposed by Horton was first applied in Romania by Platagea and Popa (1962). Afterwards, the researches continued by moving and applying these methods to the detailed study of the hydrographical basins situated in different geographic conditions (Zăvoianu, 1985; Sandu 1998; Jurchescu, 2007 ș.a.).

Along with the individual investigations, it is necessary to mention the special contributions of the Stejarul Research Centre in Piatra Neamț and of the research team in Suceava, conducted by Maria Rădoane, with contributions to the theoretical and practical fundamentation (Rădoane et al., 1991; Rădoane, et al. 1996; Rădoane et al., 1999; Rădoane, Rădoane, 2002-2003).

At the Faculty of Geography within the Bucharest University there is to be noticed the interest in using morphometrical parameters in studying the relief of the hydrographical basins (Grecu, 1992; Grecu & Comănescu, 1998; Armaș, 1999, Bogdan & Șandric, 2002-2003; Grecu et al., 2005; Grecu & Palmentola 2003; Grecu et al., 2012). In *The study of relief. Workbook for practical studies* (Grecu, Comănescu 1998), a series of morphometrical analyses are presented within the hydrographical basins, with use for the study of relief in both a morphographic and a dynamic way. In 2003 the work *Dynamic Geomorphology* appears (Grecu & Palmentola), where we can also find a chapter entitled *The morphohydrographic basin – elements of dynamic geomorphometry*.

At the Faculty of Geography within Babeș-Bolyai University in Cluj, both regional and local approaches are in view (Mac, 1986; Haidu, 1993; Pandi, 1997; Filip, 2008; Roșian, 2011 ș.o.).

At the Faculty of Geography and Geology of A. I. Cuza University a series of theoretical and practical works are notable, of whom we recall Ungureanu, 1978, Bojoi, I. et al., 1998 s.o.

The characterization of the geomorphologic units and subunits with the aid of fluvial morphometry parameters, also accomplished within the PhD thesis from the last decade, is useful for the theoretical studies as well as for the practical activity of organization and improvement of the geographical space, of the hydrology, erosion and environment conservation studies, etc.

2. Methodology

The data needed for the determination of the analyzed morphometrical parameters have been obtained starting from the processing of the cartographic fund scaled 1:25 000, using the GIS and DTM methodology. Thus, the level differences between the maximum and minimum altitudes for all the basins, on size orders. The summed individual values and the sums reported to the number of used basins allowed the determination of average values of the relief of successive ascending orders basins. The slope of the hydrographical basins was determined for each basin separately using the length of the main contours, their equidistance, and the surfaces of the basins or the investigated geomorphologic units. In what concerns the segment slope of the rivers of successive ascending orders, we had in view the altitudes of the initial and final points of each river segment, and the corresponding length. From the subtraction of the two values, the level differences for each segment was obtained, which, summed on size orders, have offered a values range with the sums of level differences on size orders. By reporting these values to the number of river segments taken into account for each order, the mean values of the level differences on size orders were obtained. The same procedure was used for the mean lengths resulted from the river segments lengths summed on orders, reported to the number of segments corresponding to each order. This way, two data ranges were obtained for mean differences and average lengths. From the report between the two value ranges a third row is obtained, containing the average slope of the river segments of successive ascending orders.

The declivity, as a tangent of the tilt angle is an adimensional parameter that can be determined both for the basins and the hydrographical network as the ratio between the fall (ΔH) between two points and the length of the horizontal distance between them (L).

$$\text{tg } \alpha = \Delta H/L$$

On the field, this can be established with the clinometers, the theodolite, or the total station. In the cabinet, for measuring declivity, the work supports are the topographic maps, the plans with contour lines and the methods are the classic ones, the diapason or the slope graphic, respectively.

3. Results and discussions

In the temperate zone, regardless the genetic type of relief (fluvial, glacial, periglacial), relief modelling, and the genesis of the present morphography was conducted by the hydric agent this fact motivating us to support the necessity of using some parameters of fluvial morphometry in the characterization of the existent landforms.

3.1. Relief

In the international geomorphologic literature, the term relief is generally used with two senses. On one hand, it stands for the absolute relief, which represents the height of a point above sea level. In the Romanian geographical literature, this type of relief is known as *the altitude*. On the other hand, the second meaning is that of relative relief, defined by the level difference between the local maximum and minimum altitude of a hydrographical basin or a geomorphologic unit (Selvan et al., 2011). In the Romanian geomorphology, the notion of relief has a more complex significance, but with a generalized aspect included in the term morphography.

If we consider a hydrographical basin or a relief unit, the relative relief of the hydrographical basins can be determined, because, being summed on size orders, it tends to form a descending geometric progression. The obtained data row reported to the number of identified basins generates a third geometric progression, which establishes that *the medium relief of the basins of successive ascending orders tends to form an ascending geometric progression in which the first term is the medium relief of the first order basin and the ratio is the report of the successive values* (Fig. 1 a, b). The distribution of the values and the existent relations between the medium relief and the size order of the hydrographical basins prove an exponential growth function of the order, with higher ratios for the basins in the mountain area and lower in the subcarpathian and plain areas.

The relief of the basins or of the relief units is essential for geomorphology, because it gives dimension to the potential energy existent in the respective entities, energy that induces the modelling and the intensity of the actual processes

that, in time, modify the general morphography of the topographic surface (ex. Grecu, 1980, 1981; Sandu, 1980; Grecu & Zăvoianu, 1997; Grecu et al., 2012 s.a.).

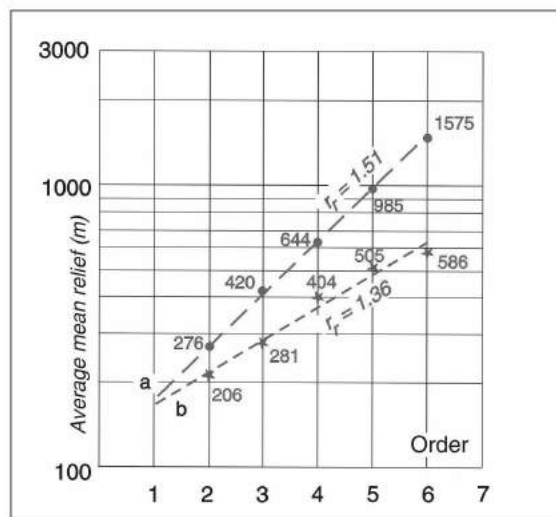


Fig. 1. The medium relief of the basins of successive ascending orders in the hydrographical system:

- a) Doftana upriver of the confluence with Prahova
b) Cricovul Sărat upriver of the confluence with Lopatna

3.2. River segments frequency

As a report between the total number of river segments (in the Horton-Strahler classification system) and the surface of the basin or of the corresponding geomorphologic unit, the frequency of the river segments is an important parameter that offers information upon the basins reaction to the action of precipitation and erosion processes (Selvan et al., 2011). Considering the fragmentation degree of the relief, a high value of the river segments frequency implies an accentuated incision of the relief with all the consequences that derive for the dynamics of the processes that occur within hydrographical basins. An increased fragmentation degree assumes a shortening of the interval between the flow arteries and, consequently, a reduction of the length of slope flow. As a following, the response of the hydrographical basins to rain action will be shorter, because the accentuated fragmentation enfavors the rapid formation of flash floods with a significantly higher erosion and transport force.

In the Romanian geomorphology, stands the work of Grecu (1980, 1992, 2008) has been analyzing the number of the river segments (N) and the frequency of the elementary thalwegs (f_1) for the Hârtibaciu basin, while Comănescu (2004) did the same for the Casimcea morphohydrographic basin.

In 2012 Grecu et. al use a great number of morphometric parameters in a work dedicated to the Romanian Plain and highlights the necessity of these parameters in geomorphological studies. The obtained data are used to highligh the critical values, to define the risk triggering thresholds and, also, to establish the different classes of relief vulnerability to geomorphological processes.

The analysis of a high number of cases of river segments frequency in the Horton-Strahler classification system proves the fact that this frequency is strongly influenced by the resistance degree of the rock types from the hydrographical basins (Zăvoianu et al., 2004). If we take into account large relief units, it is noticeable that the highest frequency of the river segments is encountered in the subcarpathian area, followed by the mountain area and the plain area, the latter showing the smallest values.

3.3. The surface declivity of the basins and of the hydrographical network

The present slope of the relief, defined as tangent of the bent angle of a line or of a plan of the terrain is the result of the complex and continuous interaction between the internal and the external forces that act at the surface of the terrestrial land. The size of the slope depends on the rock, but also on the thickness, texture, and mobility of the deposit of debris, which, on their turn, depend on the climate (Baulig, 1959). Within a drainage the slopes and channel declivity is directly connected with the quantity of potential energy that determines the intensity of the flow, erosion and transport processes that lead to the establishment of an equilibrium state of the declivities in relation to the ensemble of the local geographical conditions. The role of the declivity is also very important for the fluvial processes. The flow, the formation and propagation of floods, the hydro energetic potential of the water courses, the formation and evolution of the river channels, the processes of relief modelling, erosion and accumulation through channels etc. cannot be approached without knowledge about basins and river network declivity.

The mean declivity of the drainage basins surface (S_b) or of a relief unit can be determined using the expression:

$$S_b = \Delta h(l_0 + l_n)/2 + l_1 + l_2 + \dots + l_{n-1} + l_n/A$$

where Δh (constant) is the equidistance, l_0 , l_1 , l_n the length of the utilised contour lines and A the surface of the basin. In a shortened form, the expression is currently used in the speciality literature (Diaconu & Lăzărescu, 1965;

Vladimirescu, 1978). In a shortened form, the expression is:

$$S_b = \Delta h \Sigma L / A$$

where S_b is the declivity of the basin, Δh the equidistance of the contour lines utilised, ΣL the length of the contour lines, and A the surface of the basin or of the investigated unit.

The law of the average basins declivity. The values of the mean basins declivity can be summed on size orders. The obtained sums reported to the number of basins involved are the mean values of the mean declivity for each order. The obtained values row graphically represented in semi logarithmic coordinates emphasize a very good relation between the averages of the mean declivities and the size orders of the basins. The relation highlights a geometric progression in which *the averages of the mean declivities of the basins of successive ascending orders tend to form a geometric progression in which the first term is given by the average of the mean declivities of the first order basins s_{b1} and the ratio is expressed by the report of the mean declivities of successive ascending orders r_{sb}* (Zăvoianu, 1985). The ratio of the new row can be obtained also from the report of the ratios for row of number of successive ascending basins and the one of the sums of mean declivities for the basins taken into account, resulting that $r_{sb} = R_c / R_{sb}$ and the general term of the relation is:

$$sb_u = sb_1 r_{sb}^{u-1}$$

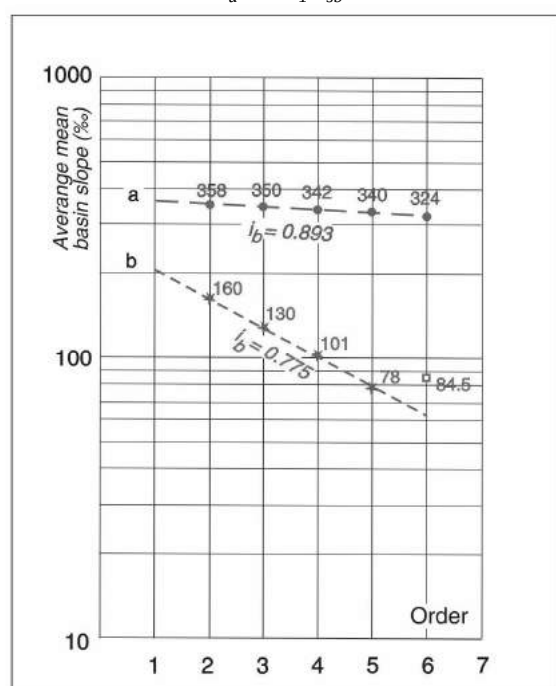


Fig. 2. Average slope of the successive ascending orders basins for the hydrographical system:

- a) Doftana upriver of the confluence with Prahova
- b) Bucovel upriver of the confluence with Teleajenul

The values determined for a large number of basins from the Ialomița hydrographical system, basins situated in different geographic conditions, prove an exponential decrease function of the order and the fact that the highest slope values belong to the basins situated in the mountain area, followed by the ones in the hill and plain areas, respectively. The basins that are completely or partially situated in the mountain and subcarpathian areas present high slope values, with small differences between the orders, as we can see from the value of the ratio, close to the unit ($i_b = 0.893$) which assumes a small slope of the regression line (Fig. 2). Nevertheless, in the case of the subcarpathian area, where the basins are sculpted in poorly or unconsolidated rocks, with small resistance to erosion, the differences between the declivities of the successive orders are higher and, subsequently, the ratio has a smaller value ($i_b = 0.775$) (Fig. 2 b).

The average slope of the drainage network. In the lower part of the slopes, the slope flow enters the channel network, as the waters pass by in the same time to a flow regime determined by the hydraulics of the channels, in which the slope has a very important role. The factors that determine the slope of the riverbeds are very numerous. Among these factors we can distinguish the geomorphologic evolution, the structure and the tectonics of the geological formations, the degree of vegetation cover and not last the surface of the basin, which determines the water debits and implicit the grain size of the materials found in the channel. Ever since 1877, Gilbert noticed the fact that the declivity of rivers is inversely with the flown water debit, as it is found in an inverse relation with the determined basin surface and in a direct relation with the size of the material within the riverbed (Hack, 1957). He also highlights the relations between slopes, lithology, and tectonics.

From all the morphometrical elements of a channel network, the slope is a very dynamic element, which rapidly adapts to the physical-geographical local conditions, with control of the base level and the resistance imposed the ground to the action exerted by the water volume of the respective watercourse. The slope regime controls most of the morphohydrographic processes that take place in channels, the intensity of the erosion, transport and accumulation processes, the degree of alluvial loading of the river, continuously imposing the manifestation of a tendency towards a dynamic equilibrium. In a lithologically homogenous space the sizing of the slopes is made considering the water debit, which, in his turn, depends on the basins surface.

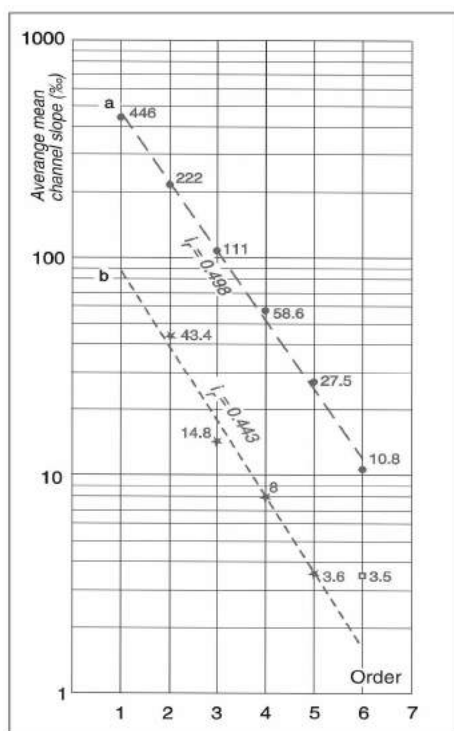


Fig. 3. Mean slopes of river segments of successive ascending orders for the following hydrographical systems:

- a) Doftana upriver of the confluence with Prahova
- b) Bucovel upriver of the confluence with Teleajen

The slope of river channels. Being a representative element of a watercourse, the slope has been defined and used for a long time in practical purposes. In many cases, the focus is on the slope of the river from its source until the discharge or on a certain sector, but there were no studies to appreciate the average slope for the entire rivers network in a given hydrographical basin. A first step in this sense was made ever since 1945 by R. E. Horton who came with the concept of the law of the average slope for the rivers with successive ascending orders. The problem has been later on re-evaluated by Strahler (1952), Schumm (1956), Hack (1957) who have used this law, verifying it in many cases. Hack, for example, has established an equation by which the slope of the channel is directly proportional with the power 0.6 of the ratio between the size of the particles and the drainage surface of the basin. In 1962, Morisawa formulated the law of the slopes and expressed it both in an exponential form as well as in a geometric progression form.

The law of the average slopes of riverbeds. In order to know the average values of the slopes of the courses of successive ascending orders the row of values defining the law of average falls will be reported to the row of values defining the law of average lengths. A new row of values is obtained, which, if represented in semi logarithmic

coordinates function of the order of the courses proves that *the average slopes of the courses of successive ascending orders tend to form a descending geometric progression having as the first term the mean slope of the first order courses s_1 and as a ratio the report between these slopes r_s or the result of the report between the average heights and the average lengths* (Zăvoianu, 1985). The following relation gives the general term of the progression:

$$S_u = S_1 r_s^{u-1}$$

The exponential connection between the average slopes and the size order of the segments show that the highest slopes correspond to the first order segments and the smaller belong to the segments with the highest order. In comparison with other laws previously analyzed, this law is very well verified, fact that proves that the slopes of the drainage network tend faster to an equilibrium state imposed by the mass and energy transfer through the drainage ways in report to the specific conditions of the basin.

Following the connection between the values of the average slopes corresponding to the courses of successive ascending orders from the fifth and sixth order basins from the hydrographical system of Ialomița river, it is visible that the slope of the determinate lines varies from a basin to another function of the physical-geographical conditions specific to each basin. In comparison to the slope of basins surface, the slope of river segments of successive ascending orders create geometric progressions with much higher differences between the slopes of neighbouring orders, this being shown by the low values of the ratios (Fig. 3).

The average slope of the entire drainage network within a hydrographical basin or a given relief unit. The determination of the average slope of a river sector or of a rivercourse from the source until a certain point is not difficult when we know the level difference and the length of the route. Nevertheless, most of the works that take into account this element always use the slope of the main river as a resultant of the processes that take place in that basin.

If between the debit and the slope there is an inverse relation that means that the main artery with the highest debits has also the lower slopes in the basin. This implies that the mean slope of the main river does not reflect the situation of the collected affluent, their slopes being constantly higher, as observed from the analyzed laws. Even so, the entire rivers network with its characteristics contributes to the formation and evolution of many hydrological and geomorphologic processes, this

fact imposing the necessity to determine a mean slope of the entire rivers network in a given basin. In addition, from the investigated situations results that the average slopes of the thalwegs of a hydrographical basin also imposes a certain slope of the basin surface. Between these two elements, there always is the tendency to create an equilibrium function of the local physical-geographical factors and, first of all, function of the geological resistance coefficient.

In the conditions of the Horton-Strahler classification system, the mean slope of the entire drainage network from a given hydrographical basin can be easily calculated as a report between the sum of the level differences and the summed lengths at the basin level. As these values are already known from the progressions determined by the level differences and the lengths summed on size orders, calculating the mean slope of the entire network is not difficult any longer.

3.4. Drainage density

Defined as the length of the river segments on the surface unit, the drainage density is connected to rock strength to erosion, to the climatic conditions, soil permeability and so on. In geomorphology the term *density of fragmentation* is utilised and it is given by the report between the length of the valleys and the investigated surface, evaluated in the same measurement units (km/kmp) (Filip, 2008).

$$Dd = \Sigma L / A, \text{ where:}$$

Dd is the drainage density, ΣL the summed length of the drainage network and A the surface of the investigated unit or of the hydrographical basin. From the hydrological point of view, high values of this parameter imply a high degree of relief fragmentation, with an important role on the erosion processes and formation and propagation of the flood waves (Abrahams, 1972; Bauer, 1980).

The evaluation of this parameter, although it is very important, it has subjective values regarding the determination methodology and the map scale that is being used. For the determination the grid method or the module squares are utilised, for a reference surface of one km². Another used method is that of counter lines that uses as a base the previous method, interpolating the results obtained. The results obtained with the method on hydrographical basins, sometimes hierarchal, are similar with the results obtained with the modules method. There is also the profiles method, used more rarely due to the generalisation of the obtained results. In order to obtain values more closely to the

reality we propose the use of the information existent on the maps scaled 1:25 000 and the length of the network evaluated in correspondence with the principles enunciated by Horton in 1945.

In order to determine the drainage density it is necessary to calculate the sum of the river segments length from a hydrographical basin or a relief unit with a known surface, on size orders. By cumulating the sums for all the size orders we obtain the sum of the length of the river segments network, which reported to the investigated surface gives the mean value of the drainage density. At the same time, *the drainage density on size orders forms a descending geometric progression in which the first term is the drainage density for the first order (D_1), and the ratio is given by the report between densities (R_D)* (Armaş, 1999).

3.5. The length of slope flow Σ

The length of the slope flow, defined by Horton ever since 1945 as being the distance of water flow on the slope before it concentrates into channels, is synonymous with the length of the surface flow as it is called in some works in this domain. As a basis element of flow formation, it is used in many formulas of hydrologic prognosis to calculate the maximum flow, the duration of water flow concentration, being one of the most important variables directly involved in the evolution of hydrographical basins. The concentration duration of the maximum flow depends on it, being involved in the formation of flood waves, because as lower the values of this variable get the shorter is the concentration time and the opposite.

In 1945, Horton calculated the length of the flow slope (L_v) as being approximately half the mean distance between the river channels, respectively the opposite of the double of the drainage density (D_d) using the formula:

$$L_v = 1/(2D_d)$$

Although it is very simple to determine, the formula has not been used in the scientific research that continued to use, even in detailed cases, other formulas to determine this variable. The inconvenient that made the formula proposed by Horton not to be used, although it is logical and easy to apply we consider that are due to the way of determining the drainage density.

First, we have to mention that there is in the literature two terms expressing the network density. It is the *density of the hydrographical network* (D_r) as a report between the length of the watercourses (ΣL) and the surface of the corresponding basin (S_b).

$$D_r = \Sigma L / S_b.$$

In order to determine the dimensions involved, in most cases we take into account those watercourses that are marked on the map with blue lines, which means that at the time of map construction the rivers had water flow. This is estimated on maps at small scales that do not allow considering the detail morphology (Zăvoianu, 1978, 1985).

Except for this notion, in the last decades the *drainage density* (D_d) has been used more often expressing the result of the report between the lengths of all the negative forms that have the capacity to direct and organize the flowing (ΣL_r) and the surface of the corresponding basin (S_b).

$$D_d = \Sigma L_r / S_b$$

Thus, the formula remains the same, but the difference is made by the detail and precision degree of the measuring manner of the flow paths lengths. In conclusion, the method of obtaining the drainage density depends on the analyse purpose, the choice being determined by the precision of the maps and by scale (Zăvoianu, 2006).

Of course that for having data as close to field reality as possible large scale maps are necessary, the best being those scaled 1:25 000, because they offer the necessary information to correctly estimate the drainage density and it is requisite that all parameters be analyzed at the same scale.

The determination of the drainage density in the Horton-Strahler classification system is easy to determine with the condition to determine the law of the summed lengths of the successive ascending orders rivers network. Clearly that the thoroughgoing study can take into consideration the fact that in the real length of the slope flow the cartographic projection is not included, but there is a value determined by the hypotenuse of a rectangular triangle in which one of the cathetus is the horizontal projection of the slope flow length and the second is given by the average height of the watershed above the horizontal plan that crosses the flow channel. Thus, knowing the horizontal projection of the slope flow length (L_v) and the cosine of the angle given by the mean slope of the first order basins ($\cos \alpha$) we can also calculate the real length of the slope flow (L_p) within a given hydrographic basin.

$$L_v = L_p / \cos \alpha$$

4. Conclusions

The analyzed parameters and not only can be used for the characterisation of the hydrographical basins as well for the geomorphologic units and subunits. Using the Horton-Strahler classification system, these parameters can be studied and evaluated quantitatively on successive ascending size orders or globally, using the properties of the geometric progressions. The fact that between the mean slope of terrain surface and the one of the drainage network there is a direct connection proves that between these variables there are interdependence relations that can be discovered and efficiently used in the purpose of a future sustainable development.

The mean slope of the basins surface does not replace or exclude the slope or geodeclivity maps that evidenciate numerically and cartographically (if GIS program have been used) some areas at the slopes level with higher potential energy that can favourites a more accentuated dynamics of the present morphodynamic processes. The mean slope of the (drainage) network on size orders is useful in the studies of fluvial geomorphology because the slope is the most dynamic element that evidenciate the adaptation of the hydrographical network to the local physical-geographic conditions, function of the base level, rock properties, water volume and so on.

The drainage density, known in the geomorphologic literature under the name of relief fragmentation density or the density of the hydrographical network or the relief horizontal erosion also presents an image of the spatial repartition of this variable that highly depends on the degree of resistance of the rocks from the geomorphologic units and subunits.

The average length of the slope flow is a very important element for the dynamics of the present relief modelling processes, controlling in a very strong way the intensity of the present relief modelling processes.

All these justify the necessity of using the presented parameters in the study of relief morphography and dynamics, for the quantitative evaluation of the present state of the physical environment. Numerous software used within GIS can facilitate fast results and can evidenciate morphography and morphometry aspects that can emphasize the state or the dynamics of the geomorphologic processes and phenomena.

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Signification des formes et des formations fluviatiles du Quaternaire supérieur dans la vallée de l'Ouerrha, Rif méridional – Maroc septentrional

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Résumé. Nul ne conteste qu'une terrasse fluviatile soit l'expression des tendances morphoclimatiques qui ont régné dans un bassin-versant. Plusieurs théories de genèse des terrasses ont été avancées (isostasie, eustatisme, tectonique et climatique) pour expliquer la périodicité des phases d'accumulation et d'incision des alluvions. Chacune de ces théories prévoit une phase de colmatage des vallées, suivie d'une phase d'incision qui détermine le dégagement des terrasses. Aucune de ces théories ne suffit pour expliquer la genèse et la disposition des terrasses (étagées, emboîtées ou semi-emboîtées). Nos investigations dans la vallée de l'Ouerrha, comparées à d'autres secteurs du Maroc septentrional, sur la morphogenèse actuelle et sur la paléodynamique du Quaternaire récent, nous ont permis de nuancer les théories préexistantes. Ces recherches nous ont permis de proposer un nouveau schéma de genèse et de disposition des terrasses. Ce modèle est basé sur le synchronisme de l'incision et de l'accumulation dans les vallées. Ces conclusions remettent en cause la signification climatique des étages Soltanien (Pléistocène supérieur) et Rharbien (Holocène) de la chronologie du Quaternaire continental marocain.

Mots-clés : Terrasses fluviatiles, théorie de genèse, étagement, semi-emboîtement, dynamique fluviale, Quaternaire.

1. Introduction

Il est communément admis qu'une terrasse fluviatile est l'expression des tendances morphoclimatiques qui ont régné dans un bassin-versant. L'accumulation d'une nappe alluviale prévoit une phase de remblaiement des vallées, alors que son individualisation en terrasse nécessite une phase d'incision. J. Tricart (1947) conclue que « *le facteur déterminant dans la formation des terrasses est le facteur morphoclimatique* ».

Plusieurs théories de genèse des terrasses ont été proposées ; elles permettent d'expliquer la périodicité des phases d'accumulation et d'incision des alluvions. Néanmoins elles ne permettent pas d'expliquer la disposition étagée, emboîtée ou intermédiaire des nappes alluviales en relation avec les variations hydrodynamiques des cours d'eau.

Nos investigations sur les nappes du Quaternaire récent et sur la paléodynamique de l'Ouerrha concluent que la mise en place des nappes et le dégagement des terrasses ne peuvent être expliqués par la succession des processus de remblaiement et de creusement d'origine climatique.

2. Formes et formations fluviatiles

2.1. Historique des définitions des terrasses fluviatiles

Le terme de « *terrasse fluviatile* » est souvent associé aux dépôts fluviatiles. Cette expression a été employée pour des formes topographiques particulières et pour des alluvions surplombant les vallées actuelles. La signification de ces formes a évolué :

E. Chaput (1924) considère une terrasse comme une accumulation alluviale. Elle représente une « *surface sensiblement horizontale, comparable à une plaine alluviale du lit majeur, d'une nappe d'alluvions anciennes ...* ». Il ajoute qu'une terrasse apparaît en pente douce, recouverte d'alluvions et limitée par un talus à pente forte permettant l'affleurement de son substratum.

J. Tricart (1947) ajoute que « *la surface d'une terrasse doit être plane et ses dépôts épais pour éviter toute confusion avec un replat d'érosion* ».

M. Derruau (1956) précise qu'« *une terrasse alluviale présente un sommet plat – un témoin de lit d'inondation – et un rebord abrupt* ». Il ajoute que « *le sommet plat est le plus souvent une surface de remblaiement, mais il peut parfois être une surface* ».

d'érosion taillée dans l'épaisseur d'une nappe alluviale ».

Selon G. Viers (1967), in J. P. Texier (1979), « une terrasse fluviale est un lit abandonné, non par divagation mais par incision : le cours d'eau coule en contrebas de la terrasse qui reste, contrairement au lit majeur, hors de portée des crues. ... ».

J. P. Texier (1979) considère la terrasse « un replat topographique d'origine fluviale qui domine le lit d'un cours d'eau ». Il fait la distinction entre des terrasses de remblaiement et des terrasses d'érosion.

Pour F. Joly (1997), « une terrasse fluviale est une partie d'un lit fluvial ancien, rocheux ou alluvial, à surface plane ou peu inclinée, abandonné et perché au-dessus du lit majeur actuel ».

2.2. Formes et formations des plaines alluviales actuelles

L'étude de la dynamique actuelle dans les plaines alluviales a beaucoup contribué à la connaissance des conditions de genèse des nappes alluviales anciennes. Les études qui traitent de cette problématique couvrent des bassins versants soumis aujourd'hui à des conditions morphoclimatiques distinctes. Cette variabilité pourrait expliquer les particularités des régimes hydrologiques, les modalités morphodynamiques des cours d'eau et les spécificités remarquées dans la genèse et la disposition de ces formes et formations.

Les formes actuelles dans les plaines alluviales correspondent aux différentes banquettes, représentant les lits mineur, majeur et exceptionnel. Ces replats présentent une disposition étagée entre le chenal et la première terrasse non inondable.

Quant aux formations actuelles, elles correspondent aux différentes nappes qui forment les différents lits de la plaine actuelle. Ces nappes présentent une succession de faciès, similaire à celle qui forme les terrasses (*sensu stricto*) : un ensemble inférieur, formé par des alluvions grossières, est surmonté par un ensemble supérieur, formé par des alluvions sablo-limoneuses.

2.3. Les nappes et les terrasses fluviales de l'Ouerrha

La vallée de l'Ouerrha présente une toposéquence des nappes alluviales attribuées au Quaternaire (Arif, 1994). Ces nappes se présentent sous forme de terrasses qui montrent des dispositions distinctes sur le même versant. En effet, les terrasses anciennes, attribuées au Quaternaire inférieur et moyen sont étagées ; alors que celles attribuées au Quaternaire récent sont semi-emboîtées (Fig. 2).

Les nappes des terrasses du Quaternaire récent de l'Ouerrha ont fait l'objet d'une étude sédimentologique (Gartet, 2001). L'analyse des faciès qui constituent les ensembles de ces formations (T0, T1 et T2) rappelle les éléments de la plaine actuelle qui se mettent en place actuellement en surface.

Une terrasse fluviale se définit comme un lambeau d'une ancienne plaine d'inondation, lit majeur abandonné. Son replat présente une surface sensiblement horizontale et un talus en falaise ; la planéité de sa surface est souvent modifiée par des apports latéraux postérieurs. Quant à la formation fluviale, elle correspond à une nappe alluviale présentant des structures internes et des lithofaciès de type fluviale.

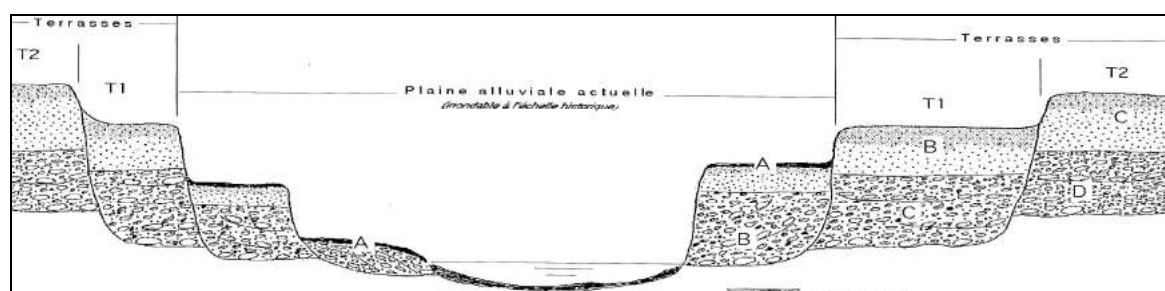


Fig. 1. Étagement des replats dans la plaine alluviale actuelle

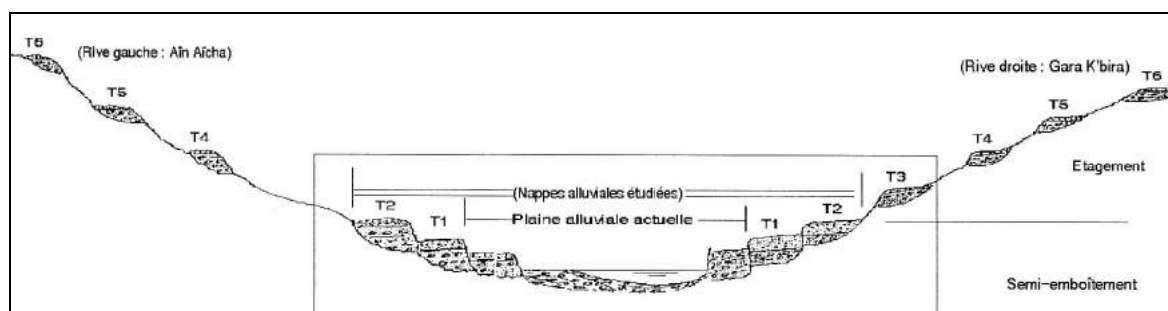


Fig. 2. Disposition des terrasses fluviales dans la vallée de l'Ouerrha

3. Analyse des théories de genèse des terrasses fluviatiles

Les premières recherches sur les dépôts fluviatiles notent que depuis l'aube du Quaternaire, les cours d'eau œuvraient dans l'incision de leurs vallées. En effet, dans les vallées, les niveaux les plus anciens ont des altitudes plus élevées, de même que sur les littoraux. Ainsi se dégage une tendance générale au creusement dans les continents et une régression sur les littoraux, que J. Bourcart (1945) et plus tard G. Beaudet et al. (1967) avaient déjà avancée concernant le cycle quaternaire marocain.

Les premières études sur les dépôts fluviatiles remontent au début du XX^e siècle. Elles permettent de connaître leur mode de dépôt et leur genèse, en relation avec le dernier mégacycle climatique quaternaire (Haq et al, 1987). Cependant, avec l'approfondissement de ces recherches, on a vu jaillir un désaccord sur les théories proposées pour l'édification de ces terrasses. Nous exposons les principales théories qui ont été proposées pour expliquer leur genèse et leur disposition.

3.1. La théorie isostasique (mouvements verticaux)

Elle propose que, lorsque le secteur est en soulèvement (mouvement épirogénique positif), les rivières incisent leur vallée afin d'établir leur profil d'équilibre ; alors que lors de la stabilisation isostasique ou d'un abaissement continental (mouvement épirogénique négatif), le niveau de base des cours d'eau s'élève et les rivières déposent les matériaux pour remblayer leurs vallées ; il en résulte la formation d'une plaine alluviale de remblaiement (Macaire, 1984). De ce jeu isostasique, de soulèvement et d'abaissement

continental, peut en résulter soit le remblaiement, soit le creusement. La théorie isostasique considère que la répétition cyclique de ces oscillations conditionne la genèse des terrasses fluviatiles ; alors que l'ampleur de ces mouvements conditionne leur disposition.

Le rôle de l'isostasie, dans l'édification des terrasses fluviatiles, pourrait être important dans les domaines en soulèvement. Or les terrasses, certes emboîtées, existent dans des secteurs en subsidence : c'est le cas du Rharb, ainsi que des secteurs réputés stables, où plusieurs niveaux de terrasses bordent la vallée actuelle. Par conséquent, l'effet de l'isostasie est loin d'être un facteur principal dans l'édification des terrasses.

3.2. La théorie eustatique

De Lamothe, en s'inspirant des théories de E. Suess (in Mulder et al, 1996), énonce que « *la succession des plages étagées correspondrait à autant d'abaissements du niveau marin* ». Il s'est inspiré également de W. M. Davis (1913) pour qui « *chaque variation du niveau des océans entraînerait les fleuves à se creuser un lit parallèle au précédent* ». De Lamothe élabore sa théorie eustatique de la formation des terrasses (in Texier, 1979). Il considère que « *Chaque remontée marine ou transgression correspondrait à une phase d'alluvionnement et chaque descente ou régression correspondrait à une phase d'incision* ». Ainsi, pour une altitude donnée, chaque terrasse fluviatile correspondrait à un niveau marin.

Au Maroc et en Afrique du nord, on distingue un système de terrasses fluviatiles qui correspondent à autant de niveaux marins (Tableau 1).

Tableau 1. Correspondance et intercalation des étages marins et continentaux quaternaires marocains (d'après Beaudet et al., 1967 complété et modifié)

Chronologie du Quaternaire			
Chronologie marocaine		Chronologie méditerranéenne	
Marin	Continental		Marin
	Rharbien	Holocène	
Mellahien			Versilien
	Soltanien	Riss	
Ouljien			Tyrrhénien
	Tensiftien	Riss	
Anfatien			Sicilien
	Amirien	Mindel	
Messaoudien			Calabrien
	Moulouyen	Günz	
Moghrebien			Plaisancien

La théorie eustatique connaît son succès auprès de C. Deperet (1926) dans la région lyonnaise et auprès d'E. Chaput (1924) et G. Denizot (1923) dans le bassin de la Loire (in Texier, 1979). Les travaux de H. Baulig ont montré que les terrasses correspondaient aux hauts niveaux marins d'âge interglaciaire et que les transgressions résultaient de la fonte des glaciers continentaux. Cette hypothèse a pour conséquence de faire correspondre, indépendamment des mouvements tectoniques, les glaciations aux régressions marines et les interglaciaires aux transgressions. C. Deperet énonce les principes de coordination : « *chaque terrasse (ou cycle) sédimentaire fluviale doit se raccorder à l'aval à un niveau marin transgressif* », d'où la triple équivalence : « Glaciaire (Pluvial) = Régression = Creusement » ; et « Interglaciaire (Interpluvial) = Transgression = Remblaiement ». Ainsi, selon cette théorie, les rivières creusent leurs lits afin de rétablir leurs niveaux de base par rapport au nouveau niveau de base marin. En effet, en période interglaciaire, la fonte des glaciers provoque

une élévation du niveau marin : c'est la transgression. Et les rivières remblaient leurs vallées pour établir le nouveau niveau de base, (Beudet, 1971 ; Clozon, 1982 ; Blum et al, 1994 et 2000).

Le raccord entre les niveaux littoraux et continentaux pose des problèmes. La grande diversité régionale, la proximité du littoral, des régions de montagnes et la différenciation des environnements bioclimatiques font que les phases de creusement et de remblaiement peuvent ne pas être synchrones, de l'amont à l'aval des cours d'eau. J. P. Raynal (1986), Beudet et al. (1971), J. P. Texier et J. P. Raynal (1985) concluent en le chevauchent partiellement des cycles marins et continentaux (Tableau 2). Dans cette optique, si le remblaiement s'effectuait pendant un interpluvial, il se pourrait que ces formations continentales se raccordent vers l'aval aux dépôts transgressifs, alors que, si le remblaiement s'effectuait lors d'un pluvial, il devrait y avoir une alternance (au moins approximative des formations continentales) avec les transgressions marines quaternaires.

Tableau 2. Schéma du chevauchement des cycles marin et continental (Texier et al, 1986)

Variations du niveau marin		Variations climatiques continentales	
	Régression		
Cycle marin = étage marin	Maximum transgression	Biostasie-pluvial-interglaciaire	
	Transgression	Rhéxistasie-interpluvial- glaciaire	Cycle continental = étage continental
	Régression		

3.3. La théorie de point neutre

Cette théorie (Trevisan, 1949) repose sur un schéma théorique prévoyant pour chaque cours d'eau deux zones. La première est une zone d'alluvionnement et la seconde est d'érosion. L'auteur distingue deux types de terrasses : climatiques *sensus stricto* et eustatique déterminées indirectement par des oscillations climatiques.

- **Terrasse climatique.** L. Trevisan (1949) prévoit qu'« *une terrasse est l'expression d'un cycle climatique, elle résulte d'une oscillation de l'aval vers l'amont puis de l'amont vers l'aval du point neutre* ». L'alluvionnement se produit lorsque la pente est suffisamment faible. Il commence à partir du niveau de base et gagne vers l'amont au fur et à mesure du vieillissement de la vallée. La hauteur des talus de la formation décroît vers l'aval (en relation avec la durée de creusement) et les alluvions sommitales sont de plus en plus récentes vers l'aval.

- **Terrasse eustatique.** Une régression marine détermine un creusement qui part de l'embouchure et gagne peu à peu vers l'amont. Le point qui sépare la zone d'érosion aval et la zone d'alluvionnement à l'amont est appelée point neutre inverse. Ce dernier remonte le chenal jusqu'à ce que la rupture de pente soit effacée. La hauteur des talus augmente vers l'aval. Les alluvions sommitales sont de plus en plus récentes vers l'amont.

La théorie du point neutre ayant été critiquée, a été rapidement abandonnée. Elle ne peut expliquer l'enfoncement des cours d'eau, ni la disposition relative des nappes alluviales ; d'autre part les observations de terrains contredisent les postulats et les déductions de cette théorie.

3.4. La théorie bio-rhéxistasique (climatique)

La mise en place des dépôts dans un milieu fluviale résulte des modifications dans la compétence des cours d'eau. Les études sur les

modèles actuels montrent le rôle du climat, par le biais des précipitations et du couvert végétal, dans la morphodynamique fluviatile (Collinson, 1986).

F. Bourdier (1943) et J. Tricart (1947) démontrent que la plupart des terrasses avaient une origine climatique. Plus tard les travaux de G. Beaudet et al. (1967), G. Beaudet (1971), J. P. Texier et J. P. Raynal (1985) et autres viennent appuyer cette théorie. En effet, pendant les périodes sèches interpluviales (froides et glaciaires d'Europe), le couvert végétal se réduit et les processus de ruissellement s'accroissent (phases rhéxistatiques). Le transport sur les versants augmente et le rapport charge solide/débit se modifie, augmente, en provoquant l'alluvionnement et le colmatage des talwegs, (Erhart, 1956). En revanche, pendant les phases humides pluviales (tempérées et interglaciaires d'Europe), les versants se stabilisent et les apports en éléments détritiques se réduisent (phases biostatiques d'Erhart). Les sédiments produits antérieurement (lors de la phase interpluviale) sont entraînés et l'érosion fluviatile, qui reprend son cours en s'enfonçant progressivement, détermine la formation de terrasses alluviales.

Les dépôts de terrasses sont attribués à l'existence à la fois des périodes sèches des interpluviaux (rhéxistatiques) et des périodes humides des pluviaux (biostatiques). La théorie bio-rhéxistatique, dite aussi climatique, semble la plus vraisemblable pour expliquer la genèse des formes et des formations fluviatiles ; mais, elle ne peut pas être retenue pour expliquer leur disposition.

4. Disposition géométriques des terrasses fluviatiles

La signification de la disposition morphologique des terrasses a souvent posé un problème. Les terrasses sont généralement emboîtées dans les secteurs subsidents et proches du littoral et étagées dans les domaines en soulèvement. Dans d'autres secteurs réputés stables, elles peuvent être tantôt emboîtées, tantôt étagées.

Dans la vallée de l'Ouerrha, les terrasses attribuées au Quaternaire inférieur et moyen sont étagées alors que celles du Quaternaire supérieur sont semi-emboîtées (Fig. 2). Ailleurs, les travaux sur les

nappes alluviales mettent en évidence des dispositions de type étagement ou emboîtement.

4.1. Disposition étagée des terrasses

F. Joly (1997) considère des terrasses étagées lorsque « les nappes alluviales sont perchées les unes par rapport aux autres et séparées par des talus laissant apparaître leur substratum rocheux ». Cette disposition s'observe lorsque l'ampleur de l'incision est plus forte que celle du remblaiement qui la précède ; le cours d'eau déblaie en laissant des témoins des alluvions antérieures ou du substratum. Dans l'optique de la théorie eustatique, les abaissements successifs du niveau de base sont plus forts que les relèvements marins qui les ont précédés.

4.2. Disposition emboîtée des terrasses

F. Joly (1997) considère l'emboîtement tel que « chaque terrasse est entièrement taillée dans le matériel alluvial de la terrasse antérieure ». Cette disposition est obtenue lorsque l'ampleur des incisions est inférieure à celle des remblaiements qui les précèdent, (Texier, 1979). Les alluvions se déposent les unes sur les autres sans reprise de l'érosion du substratum. Dans l'optique de la théorie eustatique, ainsi que celle des pulsations climatiques, l'amplitude des fluctuations successives du niveau de base marin est de plus en plus faible.

4.3. Disposition semi-emboîtée des terrasses récentes de l'Ouerrha

Cette disposition a été décrite dans les terrasses du Quaternaire récent de l'Ouerrha (Gartet, 2001 et 2003). C'est une disposition morphologique intermédiaire entre l'étagement et l'emboîtement, dont les critères de reconnaissance morphologiques sur le terrain ne sont ni ceux de l'étagement, ni ceux de l'emboîtement. En effet, lorsque la toposéquence est complète, elle ne montre pas l'affleurement du substratum entre la surface de la terrasse et le talus de celle qui la précède ; de même, les affleurements des surfaces basales des nappes montrent le ravinement de la roche en place (Fig. 5).

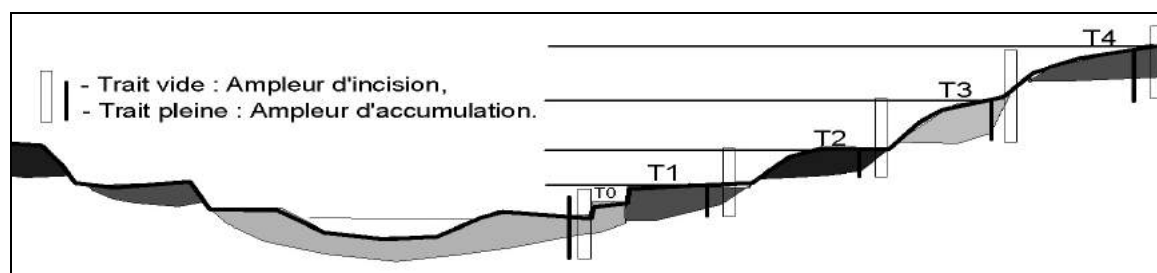


Fig. 3. Disposition étagée des terrasses

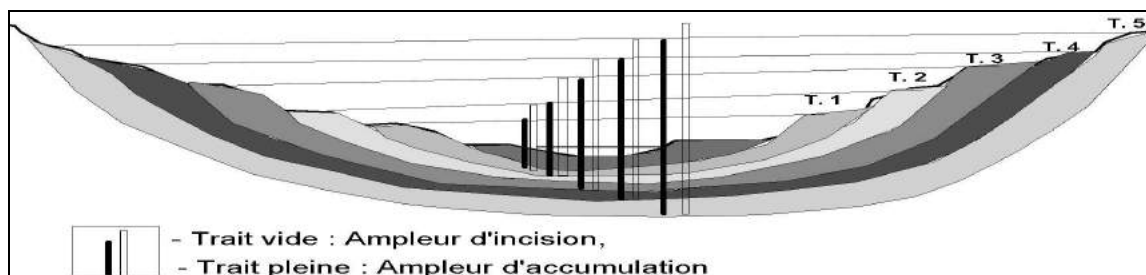


Fig. 4. Disposition emboîtée des terrasses

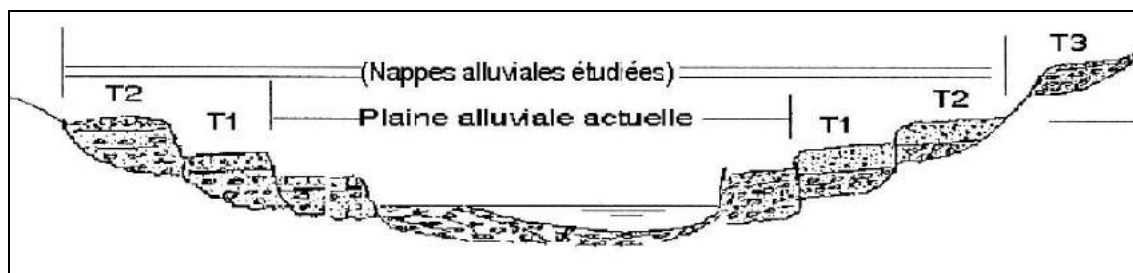


Fig. 5. Disposition semi-emboîtée des nappes du Quaternaire récent dans la vallée de l'Ouerrha

5. Modelé morphodynamique de genèse et de disposition des terrasses dans la vallée de l'Ouerrha

5.1. Arguments en faveur du modèle morphodynamique de genèse des nappes

L'interprétation dynamique et climatique des nappes et des terrasses fluviales quaternaires a souvent été faite par trois phases climato-sédimentaires. Les dépôts grossiers ont été attribués à la phase rhéxistatique (interpluvial d'Afrique du nord) et les dépôts fins à la phase biosatistique (pluvial). Quant à la phase d'incision de la formation, elle a été rapportée à l'optimum pluvial (Texier et Raynal, 1984 ; Raynal et al., 1986 et Coudé-Gaussen, 1984). Cette interprétation corrobore l'hypothèse climatique des terrasses fluviales. Selon ce schéma, dans un premier lieu les fonds des vallées connaissent une phase de remblaiement : c'est la phase d'accumulation de la nappe alluviale dans le lit de la rivière ; ensuite, les vallées s'incisent : c'est la phase de creusement des alluvions déposées (Sommé, 1984 ; Campy, 1984 ; Macaire, 1984 ; Mandier, 1984 ; Rognon, 1984 ; Ballais, 1981, 1996 ; Choubert, 1946 ; Choubert et al., 1956 ; Gigout, 1957 ; Raynal et al., 1986 ; Texier, 1979 ; Tricart, 1947 ; Klein, 1993 ; Weisrock, 1984 et Weisrock et al., 1994).

Nos investigations sur les nappes alluviales récentes de l'Ouerrha (Gartet, 2001, 2003) nous ont permis de nuancer ce modèle dit *climatique* et de proposer un nouveau modèle qui, au contraire, se base sur le synchronisme de l'incision et de l'accumulation dans les vallées. Ces deux processus

sont l'œuvre de la dynamique fluviale (*sensus stricto*). Ce modèle nie l'existence de phase d'accumulation suivie de phase d'incision dans la vallée et considère que l'alluvionnement, mis en place des nappes, est synchrone à l'incision. Ce modèle dit « morphodynamique » considère que la dynamique fluviale est le moteur principal, par divagation de l'axe du chenal et instabilité des milieux de dépôt, dans la genèse et la disposition des nappes alluviales. Il prévoit une morphogenèse fluviale à double composante, l'approfondissement et l'élargissement de la vallée. Cette dynamique contrôle l'ampleur de l'incision par rapport à celle du sapement en adaptant le régime hydrologique au contexte du bassin-versant. L'approfondissement serait commandé par le cycle d'érosion continental, d'obédience isostasique, eustatique ou climatique. Tandis que l'élargissement est régit par la tendance de la rivière à établir son profil d'équilibre en contrôlant le rapport charge/débit. Ces deux processus (sapement latéral et incision) seraient à l'origine de l'enfoncement progressif des vallées, de la disposition semi-emboîtée et étagée des nappes alluviales et du rétrécissement progressif de l'extension latérale de la plaine alluviale au cours du Quaternaire.

Ce modèle considère que la migration latérale de l'axe du paléo-chenal est à l'origine de la multiplication des replats des lits et de la superposition des environnements de dépôts. L'abandon progressif de l'inondation des surfaces des replats, de plus en plus élevées, par accentuation de l'incision verticale aboutit à la formation des terrasses hétérochrones. L'alluvionnement serait ainsi synchrone dans le lit mineur (ensemble

inférieur de la future terrasse T03) ; dans le lit majeur (ensemble supérieur de la future terrasse T02) et dans le lit majeur (ensemble supérieur des terrasses T01 ou T0) (Fig. 1). En conséquence, les formations fluviatiles ne peuvent pas renseigner sur la compétence hydrodynamique ancienne, et ne peuvent non plus être interprétées en termes de cycles climatiques. Ces nappes traduisent uniquement l'aggradation des environnements de dépôt, par l'enfoncement progressif et la migration de l'axe du chenal.

5.2. Arguments en faveur de la disposition semi-emboîtée des terrasses

Le modèle morphodynamique permet également d'expliquer la disposition semi-emboîtée et étagée des nappes. En effet, si le jeu de la divagation latérale de l'axe du chenal d'une rive à l'autre conditionne la mise en place des alluvions et des replats de la plaine alluviale, l'ampleur du sapement des berges par le chenal conditionne le type de la disposition des nappes (Fig. 6). La disposition semi-emboîtée résulterait lorsque le chenal, en divagant, érode et laisse sur ces berges les témoins de ces alluvions formant un de ces lits ; dans le cas contraire, la disposition obtenue serait l'étagement.

Le modèle morphodynamique considère qu'en contexte stable des bassins versants, la disposition

qui en résulte serait le semi-emboîtement. En revanche, lorsque les conditions locales des bassins versants (eustatisme, isostasie et climat) changent, elles engendrent l'accentuation du sapement des berges détruisant les alluvions des banquettes jusqu'à lors épargnées ; la disposition qui en résulterait serait l'étagement (Photo 1). La disposition étagée résulte lorsque l'élargissement de la plaine alluviale et l'incision du chenal deviennent importants. Cette dynamique serait favorisée lors des régressions (eustatisme) ou des phases de soulèvements accélérés (isostasie) ; alors que la disposition emboîtée serait le résultat lors des transgressions (eustatisme) ou des affaissements (isostasie).



Photo 1. Étagement et semi-emboîtement des terrasses dans la vallée de l'Ouerrha, au contrebas du Gara K'bira

Morphodynamique de la plaine alluviale	Divagation latérale (évolution de l'extension maximale du chenal en rive droite)	Disposition résultante des terrasses
Rétrécissement progressif de la plaine alluviale		Semi-emboîtement
Elargissement brutal de la plaine alluviale		Étagement
Rétrécissement progressif de la plaine alluviale		Semi- emboîtement

Fig. 6. Schéma morphodynamique de la mise en place et de la disposition des terrasses fluviatiles

6. Conclusion

Si la définition d'une terrasse fluviale est acquise, le processus de sa formation ne fait pas l'unanimité des chercheurs. Différentes théories de genèse ont été proposées : isostasique (tectonique), eustatique (ou climato-eustatique), points neutres et climatique (bio-rhexistasique). Chacune de ces théories prévoit une phase de colmatage des vallées, lors de la mise en place des alluvions, suivie d'une phase d'incision déterminant l'édification des terrasses. Aucune de ces théories ne semble expliquer la genèse et la disposition des terrasses du Quaternaire récent dans la vallée de l'Ouerrha.

L'étude de la morphogenèse actuelle et des nappes des basses et très basses terrasses de l'Ouerrha nous ont permis de proposer un nouveau modèle. Ce dernier considère que les formes et les formations fluviales sont l'œuvre de la dynamique fluviale. Il prévoit un rôle majeur de la dynamique fluviale ; la conjonction des événements climatiques, isostasiques ou eustatiques intervient pour nuancer cette dynamique.

Le modèle morphodynamique se base sur le synchronisme de l'incision et de l'alluvionnement.

Par conséquent, il nie l'existence d'une phase d'alluvionnement généralisée de la vallée (conditions rhexistasiques), suivie d'une phase d'incision (conditions biostasiques). Ce modèle prévoit une morphogenèse à deux composantes : l'approfondissement et l'élargissement des plaines alluviales. Cette dynamique induit une tendance générale à la réduction latérale des plaines alluviales. En effet, lorsque les bassins versants enregistrent les pulsions des événements climatiques, eustatiques et isostasiques, elles se répercutent sur l'accentuation de la divagation latérale des chenaux (intense sapement des berges) ou sur l'incision (intense enfoncement des chenaux). Dans ces conditions, la dynamique intervient de nouveau pour contrôler le rapport charge solide/liquide et le profil longitudinal.

Ces propos se distinguent de ceux des théories avancées précédemment et considèrent que les formes et les formations fluviales ont une signification morphoclimatique. Elles remettent en cause la signification climatique des terrasses qui caractérisent les étages de la chronologie du Quaternaire continental marocain.

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Geomorphological processes susceptibility assessment using GIS analysis in Ilwis software.

Case study: Ialomița Upper Valley (Romania)

Mădălina TEODOR

Abstract. From a morphological point of view, the Ialomița Upper Valley represents a typical mountain valley. This feature frequently determines the appearance of torrential geomorphological processes (runoff, gulling, and torrent). The goal of this article is to highlight the occurrence of soil erosion using a bivariate analysis in the Ilwis 3.4 software.

Statistical approaches are indirect methods for assessing susceptibility, involving statistical determinations by combining variables that determined the known processes. The weights of evidence modeling for torrential erosion is based on overlapping the erosion map with parameter maps (slope, aspect, geology, land use, soil, etc.), which aims at obtaining the susceptibility map and the final prediction map (success rate map)¹.

Keywords: erosion, susceptibility, maps, statistical analysis, Ialomița Upper Valley.

1. Introduction

The uses of GIS softwares bring many advantages and multiple possibilities of obtaining a complex cartographic material in comparison with the conventional mapping techniques. Through the multiple options to represent the information on a map and the variety of the methods in which the map can be delivered (overlapping several thematic layers, mathematical operations between multiple layers or with digital elevation models, databases connections), maps expressing the cause and the effect are obtained by linking the geology (rock type, structure) with land use, slope with aspect, elevation with geomorphological processes or linking all together (Grecu, 2002, 2009).

Susceptibility to landslides and its mapping are statistically or deterministically evaluated in several studies by international authors (Okimura & Kawatani, 1987; Soeters & van Westen, 1996; Gökceoglu & Aksoy 1996; Tobin & Montzy 1996; Westen et al., 2002; Guzzetti, 2005, Dahal et al., 2008, 2012; Pradhan & Lee, 2010; Regmi et al., 2010; Chauhan et al., 2010) and Romanian authors (Armaș & Damian, 2006; Armaș, 2008², 2010; Mihai & Șandric, 2004, Mihai et al., 2008; Chițu &

Șandric, 2009; Grecu, 1998, 2002, 2009; Grecu et al., 2010; Șandric, 2010; Dobre, 2011a, 2011b; Dobre et al., 2011).

The bivariate statistical approach is used by many authors to achieve landslide susceptibility map (Bonham-Carter et al., 1990; Agterberg, 1990; Van Westen et al., 2003; Dahal et al., 2008a, b; Armaș, 2010; Regmi et al., 2010). This method has been also applied in order to achieve other types of maps such as a mineral potential map (Emmanuel et al., 2000; Harris et al., 2000; Tangestani and Moore, 2001; Carranza & Hale, 2002), or a map of water accumulation areas (Zahiri et al., 2011). In this study the method is applied for the determination and analysis of torrential erosion processes.

The goal is to establish the susceptibility to erosion using a statistical method, taking into account several morphometric parameters, including morphodynamics and morphogenetic factors like hypsometry, slopes, aspect, geology, land use, soil and geomorphological processes (Grecu et al., 1998).

There are several publications in the international and national literature regarding hazard maps achievement by using statistical analysis. Most of the studies aimed to achieve the landslide

¹ TEODOR, M., ARMAȘ, I., (2012), "Tutorial: Metoda bivariată în evaluarea susceptibilității terenurilor la procese geomorfologice actuale", Available Online URL: http://www.geodinamic.ro/upload/fck/Madalina_Teodor-Tutorial_analiza_bivariata.pdf.

² ARMAȘ, IULIANA, (2008). „Riscuri naturale (Cultura riscului), Suport de curs http://www.geodinamic.ro/curs/Sinteze_curs.pdf.

susceptibility maps. Having these studies as a model, in this paper the method was applied on erosion susceptibility determination in an area belonging to the Romanian Carpathians Mountains (Bucegi Mountains are very representative for the occurrence of geomorphological processes (Velcea, 1961).

The bivariate statistical approach of torrential erosion processes for obtaining the susceptibility erosion map is based on the intersection between erosion map and parameter maps, containing data which leads to determinate the density of complex erosion in the area (van Westen, 2002). A standardization of these values (density) may be obtained by relating them to the overall density (for the entire area studied). Linking can be done using mathematical operations (Exercise L1 - after UNU-ITC School for Disaster Geo-information Management, 2009).

Natural logarithm is used to give negative values when erosion density is lower than normal and provides positive values when erosion density is higher than normal. By gathering the values of the density weight, the final susceptibility map results. It can be analyzed by determining the success rate or the predictive power. (Armaş, 2010; Şandric, 2009).

2. Study area

The studied area is located close to the center of the Bucegi Massif in Carpathians Mountains. It has a horseshoe shape opened to the south. From its center springs the Ialomița River. The Ialomița Upper basin covers an area of 4.5519 square kilometers and has a perimeter of 9.4 kilometers.



Photo 1. The Ialomița Valley

The Bucegi Massif is a large synclinal consisting of Mesozoic sedimentary deposits (Jurassic limestone, conglomerates and micaceous sandstones) placed in a transgression process above crystalline schists. It formed at the same time with the entire Carpathians Mountains chain during the Alpine Orogenesis and reaches its maximum altitude in the Omu Peak: 2505 m (Velcea, 1961).

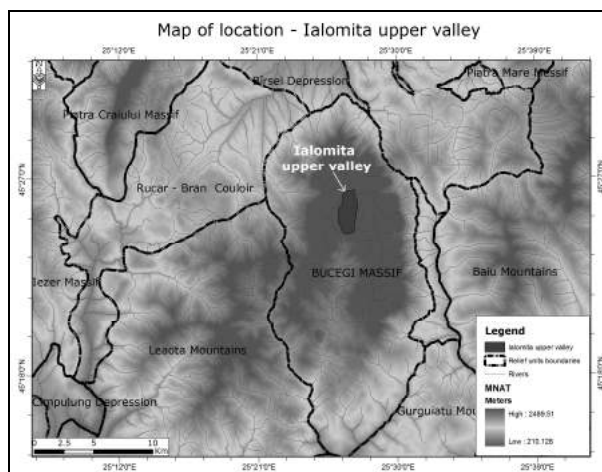


Fig. 1. Location of the study area

The horseshoe shape of the Bucegi Massif determines the arrangement and flow direction of the rivers and the torrential bodies (Grecu et al., 2000).

3. Methodology and research stages

To achieve a map of the susceptibility to erosion a statistically-based method was used in the Ilwis 3.4 software (Grecu, 2002). This method uses a limited number of thematic maps (slope, orientation, land use, soil map etc., Grecu et al., 1998) and the map showing one type of erosion (in this study, the torrential erosion map).

Torrential erosion occurs on steep slopes where the water is set quickly in linear drains. The absence or poor vegetation development, heavy rain falls, soft rocks and deposits or anthropogenic activities stimulate the occurrence of geomorphological processes (Ielenicz, 2004).

Working steps:

- *Documentation and field research stages* were started by studying similar analysis from international literature. This stage involved methodology assimilation and bibliographic documentation.

- *Geospatial data collection:* the data held were insufficient; they require updates from mapping, analysis and field observations. Databases are very important because they are a great starting point for a study and they are also an end of it (through the development and updating data).

This study began by collecting, managing and analyzing large volumes of geographic data. After data standardization, the essential elements needed for the analysis were extracted. To carry out the study topographic maps at a 1:25 000 (1982) and a 1:100 000 scale (1982), geological maps at a scale

of 1:50 000 (Braşov sheet 1971) and 1:200 000 (Braşov sheet 1969) were used. For the identification and digitalizing of geomorphological processes ortofotoplans 1:5 000 in scale (2005, 2009) and data from numerous field research campaigns were used.

Corine Land Cover vector data (EEA, 2010) were used for the mapping of land use and for the susceptibility determination.

- *Using of GIS techniques* is one of the most important steps, having the purpose to obtain the primary, intermediate and final maps that led to the conclusions sought.

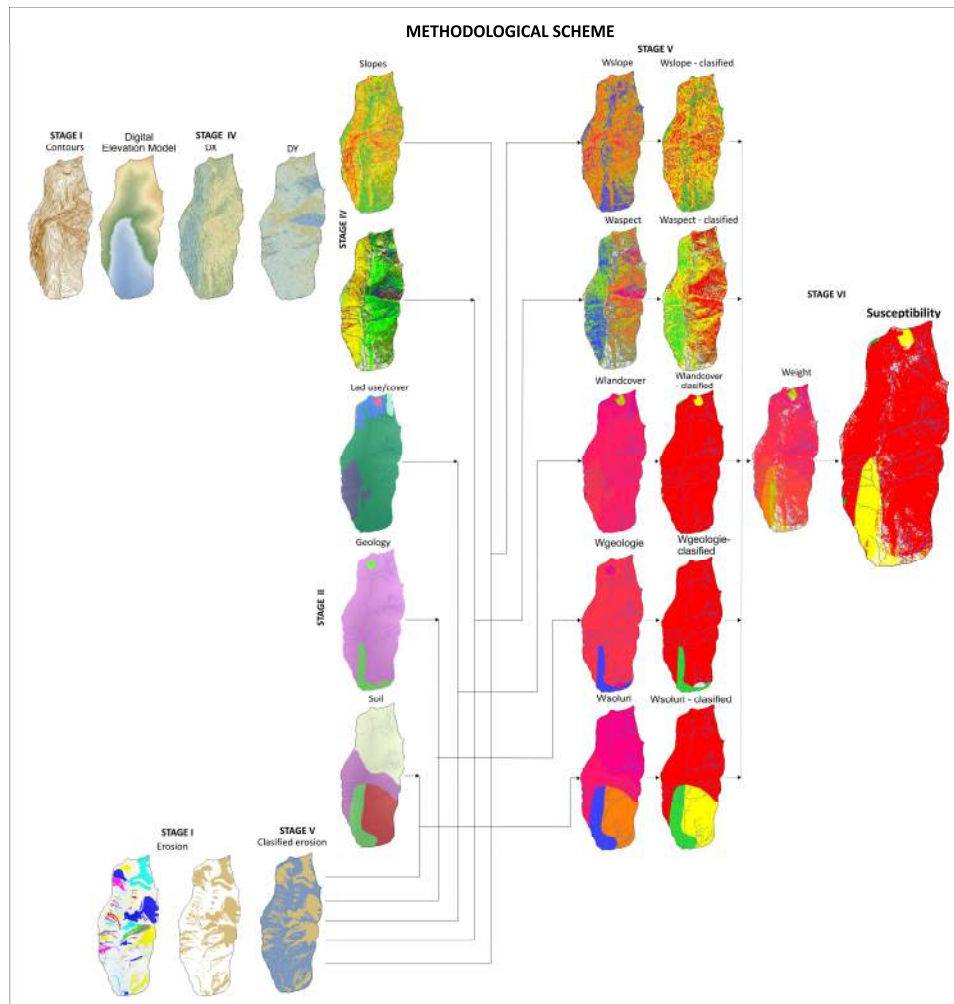


Fig. 2. Methodological scheme of achieving the susceptibility to erosion

The graphic material was achieved using specialized GIS software: ILWIS 3.4., ArcGIS 10.1. By the beginning of this stage our purpose was to achieve a *Digital Elevation Model – DEM* (obtained by using elevation contours from the topographic map at a 1:25000 scale (1982) and the ortofotoplan at 1:5000, (2005 and 2009) by applying the *Topo to Raster* interpolation function in ArcGIS 10.1), to identify and to digitize the areas affected by torrential erosion. The next step was to import in the Ilwis 3.4 software, all the data needed for the analysis (contours, geology, hydrography, the valley boundaries) and to define the *coordinate system* (Fig. 3). The next step was to realize the parameter maps (hypsoetry, slope map, geological map, land use map, soil map, erosion processes map), the

torrential erosion susceptibility map and the final susceptibility map.

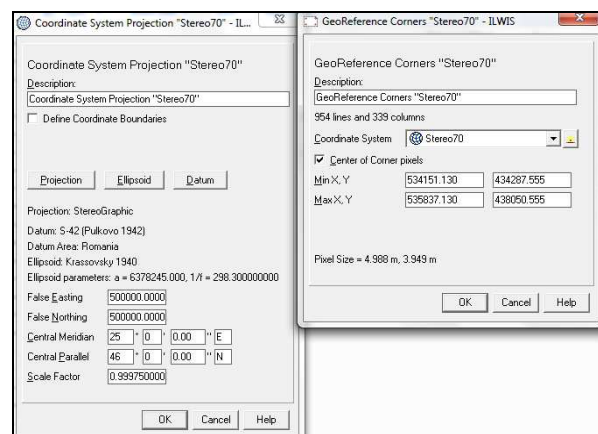


Fig. 3. Defining the projection and the coordinate system

Creating parameter maps:

- *Slope map* in Ilwis 3.4 software is achieved by applying on the created DEM, two directional filters: on DX and DY direction. DFDX filter calculates the first derivative in the X direction (dx/dy) per pixel; DFDY filter calculates the first derivative in the Y direction (df/dy) per pixel. (Exercise L1 – after UNU-ITC School for Disaster Geo-information Management, 2009).

The slope map is expressed in degrees and it is achieved by tapping in the main program window the next formula:

„Slopedeg=RADDEG(ATAN(HYP(DX,DY)/PIXSIZE(DEM)))”.

The resulting raster map requires reclassification into relevant slope intervals (by creating a new domain, linked with the map).

- *Aspect map*: is achieved by tapping in the main program window the next formula:

„Aspectdeg=RADDEG(ATAN2(DX,DY)+PI”.

The initial result is reclassified into relevant degrees intervals (0-45° and 315-361° – North, 45-135° – East, 135-225° – South, 225-315° – West).

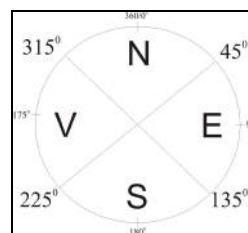


Fig. 4. Orientation

Standardization of erosion data into two classes is the next step. “0” is the class represented by areas where the erosion is absent and “1” is the class where torrential erosion occurs. For this standardization the next formulas have to be introduced in the main window of the program:

(„eroziune=:iff(torrentialitate='eroziune',1,0”),

(„eroziune=:iff(siroire='eroziune',1,0”).

They will create a raster map which requires removing unknown values. The next formula will be used:

(„eroziunecl=:iff(isundef(eroziune),0,eroziune”).

This is a base map (Fig. 6) which will be intersected with the parameter maps by comparing the pixels of the same position. These intersections will lead to create new maps and combined tables.

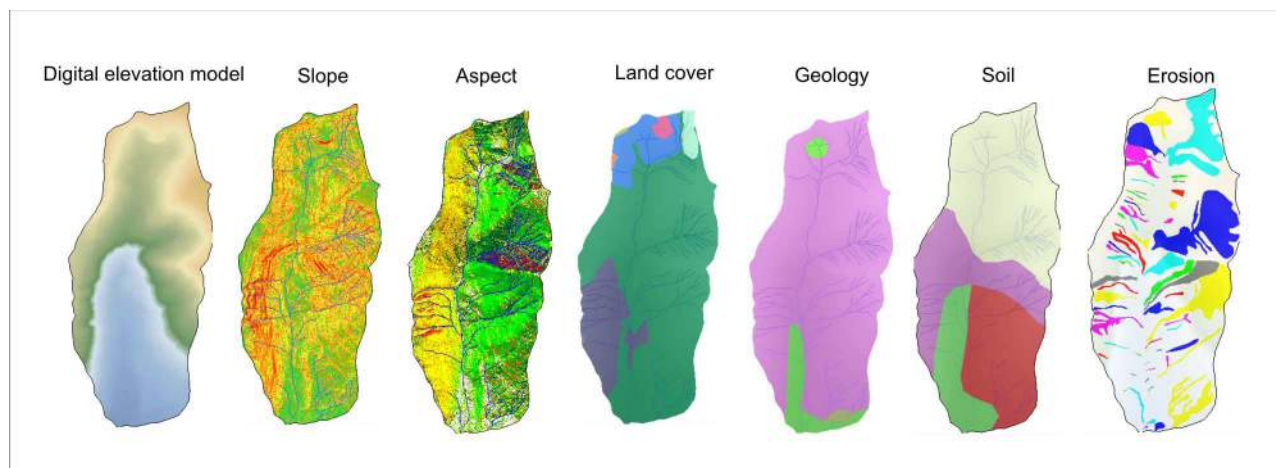


Fig. 5. Parameter maps

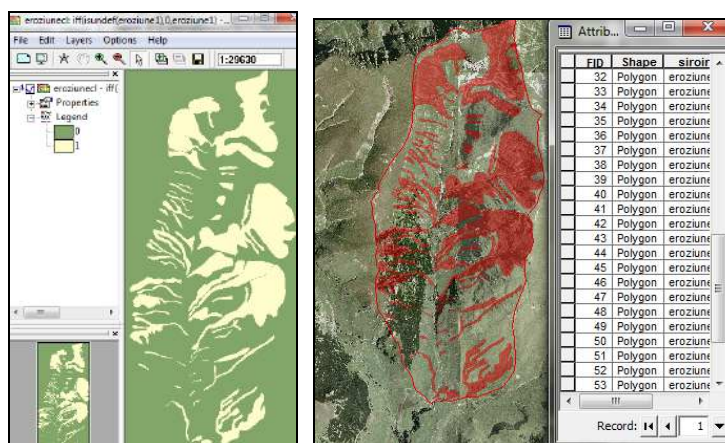


Fig. 6. Torrential erosion map

For each parameter the erosion density is calculated. For each parameter interval the active erosion surface is set by applying the formula: „ $AreaAct=iff(eroziunecl=1,area,0)$ ”, then it is required to calculate the total area occupied by each interval (using *Aggregation* and *Sum* functions). The next step is to calculate the area of active erosion of each interval of the parameters (using *Aggregation* function, selecting to sum the values of the column that contains the area and grouping results by parameter range) and to calculate the total area of the map and the total area affected by erosion in order to determine the erosion density on

each slope class (or aspect, geology, land use, soil classes). This will be done by applying the following function:

$$„Densclas=Areaslopeact/Areslopetot”.$$

Also the density of the erosion on the entire map is calculated by applying the formula:

$$„Densmap = Areamapact/ Areamaptot”.$$

In order to avoid "0" density appearance, the next function will be applied:

$$„Dclas:=iff(Densclas=00.0001,Densclas)”.$$

For each parameter will result a table containing quantitative information.

Interval	slopecl3	eroziunecl	NPix	Area	AreaAct	Areaslopetot	Areaslopeact	Areamaptot	Areamapact	Densclas	Densmap
0-10 * 0	0-10	0	597372	597372	0	771685	174313	4534286	1563373	0.2259	0.3448
0-10 * 1	0-10	1	174313	174313	174313	771685	174313	4534286	1563373	0.2259	0.3448
10-20 * 0	10-20	0	235733	235733	0	341726	105993	4534286	1563373	0.3102	0.3448
10-20 * 1	10-20	1	105993	105993	105993	341726	105993	4534286	1563373	0.3102	0.3448
20-30 * 0	20-30	0	550501	550501	0	863332	312831	4534286	1563373	0.3624	0.3448
20-30 * 1	20-30	1	312831	312831	312831	863332	312831	4534286	1563373	0.3624	0.3448
30-40 * 0	30-40	0	737229	737229	0	1195009	457780	4534286	1563373	0.3831	0.3448
30-40 * 1	30-40	1	457780	457780	457780	1195009	457780	4534286	1563373	0.3831	0.3448
40-50 * 0	40-50	0	660875	660875	0	990622	329747	4534286	1563373	0.3329	0.3448
40-50 * 1	40-50	1	329747	329747	329747	990622	329747	4534286	1563373	0.3329	0.3448
50-60 * 0	50-60	0	173456	173456	0	336044	162588	4534286	1563373	0.4838	0.3448
50-60 * 1	50-60	1	162588	162588	162588	336044	162588	4534286	1563373	0.4838	0.3448
60-70 * 0	60-70	0	15584	15584	0	35332	19748	4534286	1563373	0.5589	0.3448
60-70 * 1	60-70	1	19748	19748	19748	35332	19748	4534286	1563373	0.5589	0.3448
70-80 * 0	70-80	0	163	163	0	536	373	4534286	1563373	0.6959	0.3448
70-80 * 1	70-80	1	373	373	373	536	373	4534286	1563373	0.6959	0.3448

Fig. 7. Table containing quantitative information

Interval	Areaslopetot	AreaSlopeAct	Densclas	Dclass	Weight
0-10	771685	174313	0.2259	0.2259	-0.4229
10-20	341726	105993	0.3102	0.3102	-0.1057
20-30	863332	312831	0.3624	0.3624	0.0498
30-40	1195009	457780	0.3831	0.3831	0.1053
40-50	990622	329747	0.3329	0.3329	-0.0351
50-60	336044	162588	0.4838	0.4838	0.3387
60-70	35332	19748	0.5589	0.5589	0.4830
70-80	536	373	0.6959	0.6959	0.7022

Fig. 8. Simplified table (for each parameter)

These tables will be simplified for achieving susceptibility maps (Fig. 8).

Using the erosion density depending on the parameter's interval one can calculate the weight by extracting the natural logarithm taking into account that the density of erosion in the map is equal to 0.3448 (areamapact: 1563371/Areamaptot: 4535286):

$$„Weight:=ln(Dclas/0.3448)”.$$

To achieve the susceptibility maps we will use the „Weight” column (Fig. 8) which will be classified into three main classes of susceptibility (by analyzing the results and creating a new domain. We will choose three intervals according to the data previously obtained. The map called “Wslope_cl” results³.

The last step is to achieve the torrential erosion susceptibility map. In order to achieve this map we will gather all other previous data by applying the formula:

$$„Weight:=WAspect_cl+Wgeologica+WLand_cl+W Slope_cl+WSoluri_cl”.$$

4. Results and discussion

Slope map (Fig. 9a) indicates the presence of higher slopes (60-80°) on the Eastern side of the valley. By analyzing the graph and the associated table the predominance of 30-40 degrees slopes (on 5.84 km² – representing 26%) is observed, followed by slopes in the 40-50 degrees interval (4,84 km² – 22%). Lower values are recorded along the main riverbed and on the side valleys. *The aspect map* (Fig. 9b) shows the predominance of East oriented slopes (4.36 km² – 14%), West oriented slopes (4 km² + 13%) and South-West oriented slopes (3.6 km²). *The land cover map* (Fig. 9c) shows the predominance of

³ RiskCity exercise 3L1, „Hayard Landslides statistical method”. http://eusols.jrc.ec.europa.eu/esdb_archive/eusols_docs/other/eur22904en.pdf (Armaş Iuliana, Gheorghe Diana, (2009), Exercițiul L1. Evaluarea susceptibilității la alunecare prin metode statistice (exercițiu preluat după UNU-ITC School for Disaster Geo-information Management, 2009).

natural pastures – 54%, subalpine vegetation in the North-West of the map and rock areas in the North. The *geological map* (Fig. 9d) highlights the presence of conglomerates and sandstones 66%, deposits - 5%. The *soil map* (Fig. 9e) shows the predominant presence of acid brown criptosodic soils and feriluvial podzols in the North, podzols, litosols and rocks in the center of the map's area.

The medium susceptibility is indicated by intersecting the torrential erosion map with slopes map. The high susceptibility appears on 20-50 degrees slopes. The potential of torrential erosion is influenced by slope inclination.

After intersecting the erosion map with aspect map (Fig. 9) it is observed that the medium susceptibility appears on East and Southeast oriented slopes and high susceptibility on West oriented slopes. South and South-East slopes receive the most powerful solar radiation thus they are the warmest and driest slopes, being the most favorable for occurrence and development of geomorphological processes. Greater significance has the heating in the winter because of fast snow melt and a longer period for processes to appear. West and South-West oriented slopes are half warm and half dry and present mostly a higher susceptibility in the analyzed area. Half wet and half cold slopes are represented by East and North-West slopes which have a low potential for erosion process. The less favorable slopes are the cold and

wet ones. They are protected by snow cover over a long period of the year because of the North and North-East orientation.

Susceptibility to erosion map intersected with the land use map indicates a higher susceptibility on natural pasture and on 70% of the entire map. Susceptibility map intersected with geological map indicates the appearance of high values corresponding to limestones and sandstones (90% of the total surface). Low susceptibility appears on 7 % in the south of the area, because of the gravels, sands and glacial deposits. Susceptibility map intersected with the soil map indicates the occurrence of high values of susceptibility in the North on the map corresponding to high altitudes, where brown acid criptosodic soils and podzol soils have developed. Low susceptibility corresponds to areas situated on the riverbed.

According to the final results (Figs. 11 and 12) the high susceptibility to erosion is registered on 87% from total analyzed area. Moderate susceptibility is registered on 8.67% corresponding to the 10-40 degree East orientated slopes represented by natural pastures developed on conglomerates and brown acid soils. Low susceptibility is registered in the North-East on 0.14% of the map corresponding to lower Eastern slopes with sparse vegetation on conglomerates, sandstones and brown acid and criptosodic soils (Figs. 9 and 11).

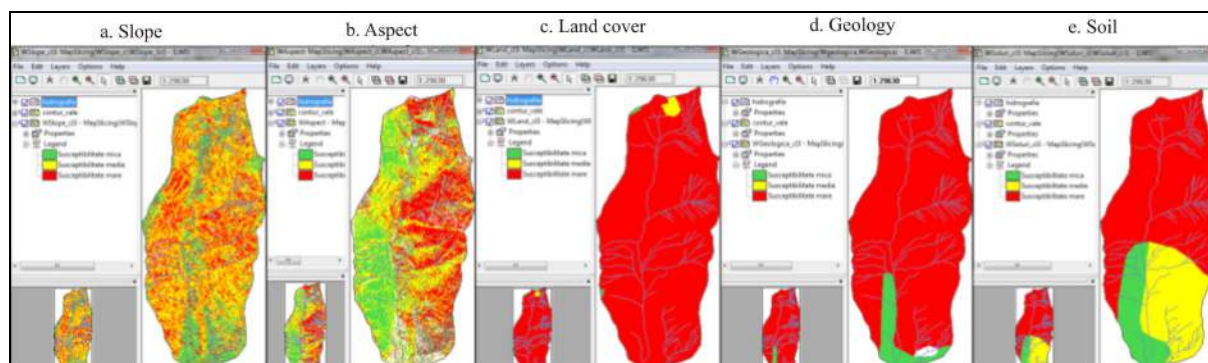


Fig. 9. Map susceptibility classified into three classes based on the initial parameters

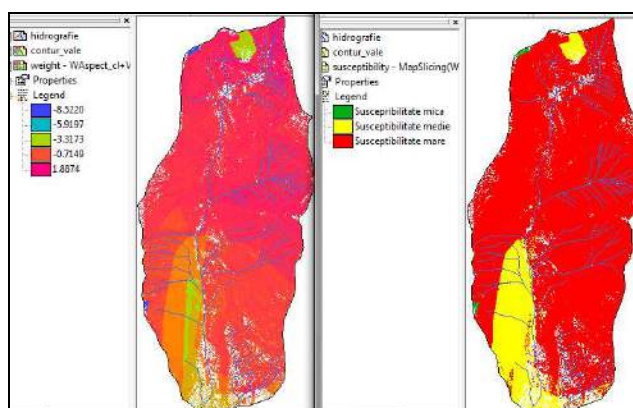


Fig. 10. Torrential erosion susceptibility map

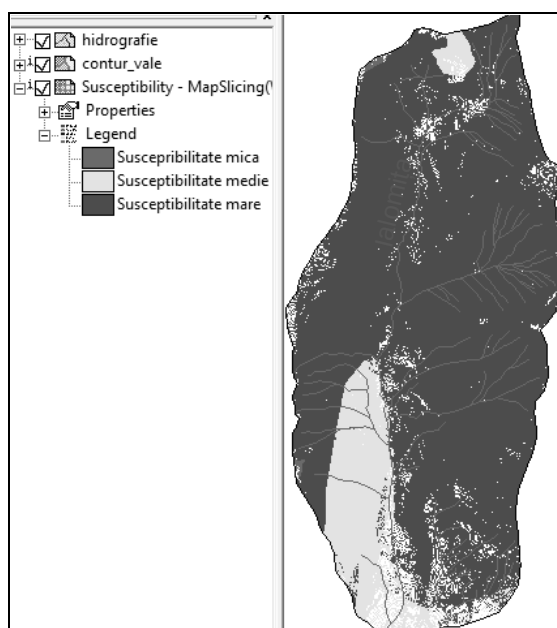


Fig. 11. Torrential erosion susceptibility map

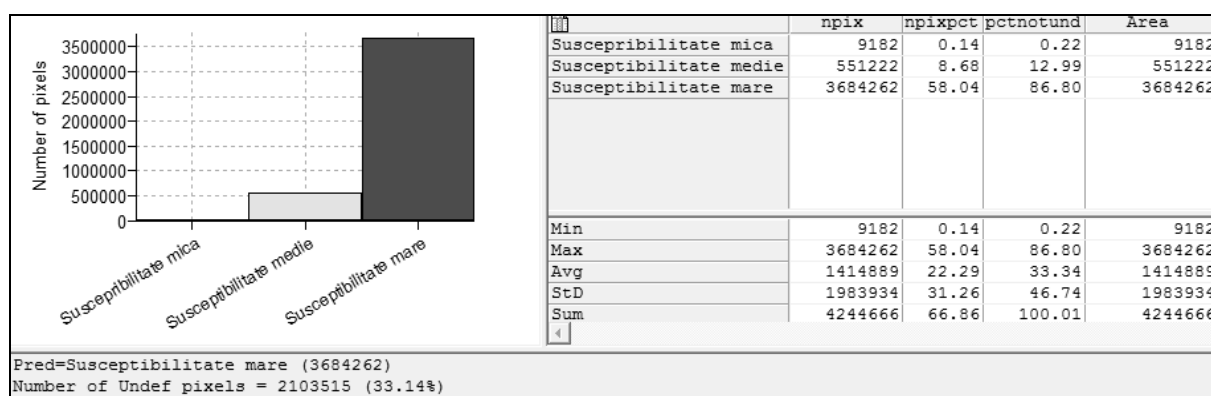


Fig. 12. The graph and statistical data

Dependent Table "WEroziune" - TableCross(Weight.mpr,eroziune1.mpr,IgnoreUndefs) - ILWIS													
	Weight	eroziune1	NPix	Area	npixact	Npsumactiw	totaleroz	totalarea	percentage	Percenteroz	Npixcumul	reverse	percentmap
-8.5220 * 0	-8.5220	0	398	398	0	0	1504187	4244666	0.00	100.00	398	4244268	99.99
-8.4239 * 0	-8.4239	0	120	120	0	0	1504187	4244666	0.00	100.00	518	4244148	99.99
-8.3228 * 0	-8.3228	0	275	275	0	0	1504187	4244666	0.00	100.00	793	4243873	99.98
-8.2939 * 0	-8.2939	0	184	184	0	0	1504187	4244666	0.00	100.00	977	4243689	99.98
-8.2807 * 0	-8.2807	0	18	18	0	0	1504187	4244666	0.00	100.00	995	4243671	99.98
-8.2384 * 0	-8.2384	0	296	296	0	0	1504187	4244666	0.00	100.00	1291	4243375	99.97
-8.2247 * 0	-8.2247	0	822	822	0	0	1504187	4244666	0.00	100.00	2113	4242553	99.95
-8.2048 * 0	-8.2048	0	106	106	0	0	1504187	4244666	0.00	100.00	2219	4242447	99.95
-8.1958 * 0	-8.1958	0	472	472	0	0	1504187	4244666	0.00	100.00	2691	4241975	99.94
-8.1403 * 0	-8.1403	0	930	930	0	0	1504187	4244666	0.00	100.00	3621	4241045	99.91
-8.0947 * 0	-8.0947	0	237	237	0	0	1504187	4244666	0.00	100.00	3858	4240808	99.91
-8.0605 * 0	-8.0605	0	2	2	0	0	1504187	4244666	0.00	100.00	3860	4240806	99.91
-8.0131 * 0	-8.0131	0	1190	1190	0	0	1504187	4244666	0.00	100.00	5050	4239616	99.88
-8.0061 * 0	-8.0061	0	237	237	0	0	1504187	4244666	0.00	100.00	5287	4239379	99.88
-8.0056 * 0	-8.0056	0	132	132	0	0	1504187	4244666	0.00	100.00	5419	4239247	99.87
-8.0050 * 0	-8.0050	0	3	3	0	0	1504187	4244666	0.00	100.00	5422	4239244	99.87
-7.9624 * 0	-7.9624	0	790	790	0	0	1504187	4244666	0.00	100.00	6212	4238454	99.85
-7.9512 * 0	-7.9512	0	14	14	0	0	1504187	4244666	0.00	100.00	6226	4238440	99.85
-7.9194 * 0	-7.9194	0	415	415	0	0	1504187	4244666	0.00	100.00	6641	4238025	99.84
-7.9150 * 0	-7.9150	0	325	325	0	0	1504187	4244666	0.00	100.00	6966	4237700	99.84
-7.9075 * 0	-7.9075	0	283	283	0	0	1504187	4244666	0.00	100.00	7249	4237417	99.83
-7.9069 * 0	-7.9069	0	40	40	0	0	1504187	4244666	0.00	100.00	7289	4237377	99.83
-7.8957 * 0	-7.8957	0	47	47	0	0	1504187	4244666	0.00	100.00	7336	4237330	99.83
-7.8775 * 0	-7.8775	0	1	1	0	0	1504187	4244666	0.00	100.00	7337	4237329	99.83
-7.8727 * 0	-7.8727	0	293	293	0	0	1504187	4244666	0.00	100.00	7630	4237036	99.82
-7.8220 * 0	-7.8220	0	282	282	0	0	1504187	4244666	0.00	100.00	7912	4236754	99.81

Fig. 13. Table containing information from the final susceptibility map

High susceptibility is determined by physical and geographical favorable conditions for the occurrence of erosion processes. Steep slopes (specific to mountain area) determine rainfalls or snowmelt water to concentrate along gutters..

The **predictive power** analyses whether this method is useful by calculating the success rate by ordering decreasingly the pixels of the final susceptibility map using the frequency from the histogram (Fig. 15). This is overlapped with the actual erosion map and the common frequency is calculated. The success rate indicates the percentage from the total number of pixels corresponding to actual erosion, which occurs in the areas with the highest values of final susceptibility to erosion.

To calculate the success rate we applied a script (with several statistical operations shown in the Figure below) that will combine the Weight columns from tables that contain erosion. (Exercise L1 – after UNU-ITC School for Disaster Geo-information Management, 2009).

The final step is the creation of the success rate graph. It can be created by selecting on the OX axis the percentage from the total map area and on OY

axis the percentage from the total area with observed erosion.

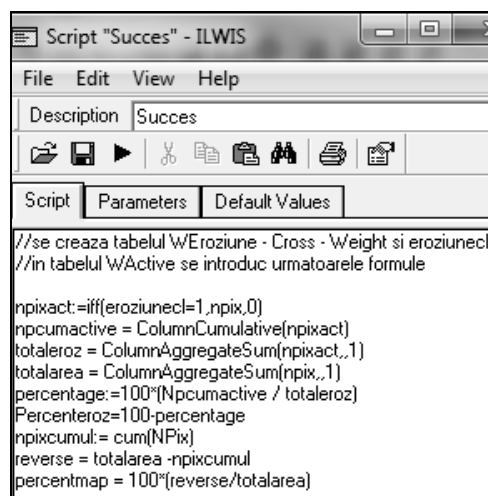


Fig. 14. Script applied to determine the success rate

Analyzing the final graph (Fig. 15) it is noted that 80% of the total erosion is predicted over 60% of the total area, corresponding to the highest values of susceptibility.

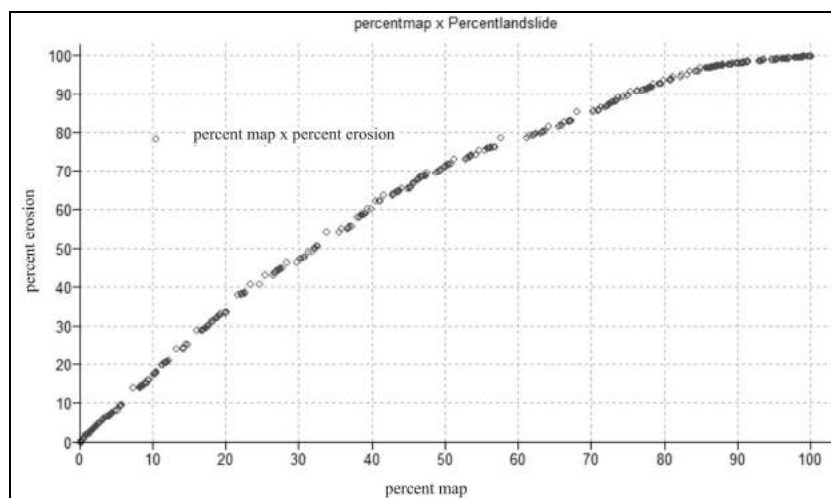


Fig. 15. Success rate graph

5. Conclusions

Torrential and other forms of erosion produce soil degradation, land fragmentation and many other damages (destruction of roads, houses, crops cover with materials etc.) for human activities (Ielenicz, 2004). The proposed method is very useful in determining the susceptibility to erosion because it provides quantitative accurate data related to occurrence of slope processes.

This methodology can be applied to any region in order to obtain results for different complex

problems. The wide applicability of this method makes it useful both for suitability analysis, impact, and development of areas (mountains, hills, depressions areas) but also to analyze possibility of extending the built area, taking into account all the factors that may be favorable or restrictive.

Such an analysis can capture in the future the environmental influences on human activities and also the human intervention on the dynamic and destabilization of slopes by deforestation, inappropriate use or improper building.

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Miscellanea

Professor Grigore POSEA at the age of 85 years

Our professor, **Grigore POSEA**, is celebrating, in 2013, 85 years of age. An age that finds him in full scientific creation, approaching, with the same known spiritual force, current and new knowledge areas about The Earth. It is very difficult to realize a summary of a life and scientific activities with outstanding results *the Professor* reached after a continuous and very carefully organized work, touching a unique level in the geographic literature.

The particular valences of the scientist and Professor Grigore Posea are circumscribed to the renewing ideas in Romania's regional geomorphology, the contribution to the development of the geomorphological school in Bucharest (and other universities), as well as an intellectual model proposed for contemporary and for the other generations. In other words, the Professor is a model not only by what he has written, but also by training scientists, because of the accuracy and objectivity of reality in life and profession. All this is due to the love and respect for profession and family which stayed on first, not being neglected regardless the implications requested by the career at the University of Bucharest, yet started at the University of Cluj-Napoca under the careful guidance of Professor Tiberiu Morariu.

Born **85 years** ago (15/12 October 1928) at Nehoiu, somewhere at the contact between the Carpathian Mountains and the Buzau Subcarpathians, he began his studies in his native town, then continued at the Military High School (known for the rigor and discipline required to students), which he graduated in 1948. Higher education was received at the University of Bucharest, as student of the Faculty of History and Geography and then of the new Faculty of Geology and Geography, which he graduated in 1952.

Professor Posea began his career in science at the Institute of Geography, as an assistant, and after only one year he was admitted as full time PhD student at the only doctoral supervisor at the time,

academician Professor Tiberiu Morariu, at the University of Cluj, with a thesis called on "The Lăpuș Country - Geomorphological Study" finished in 1958 and published after four years. Thanks to the results achieved in the doctoral internship and the problems demonstrated with valid arguments, his tutor offers him a job. In 1960 he reaches the position of lecturer and becomes one of the most appreciated teachers – a fact supported by stories of former students (some of them, his future colleagues) – at the seminar, tutorials or lectures, but especially during the many field applications he coordinated.

In 1960, Professor Posea returned to the University of Bucharest, Faculty of Geology and Geography, as a senior lecturer, position occupied as result of a contest. Here, he manages to create an exceptional academic environment, thanks to the experience gained at Cluj, an environment conducive to achieving a prestigious higher education. Subsequently, he becomes Dean (1961-1963) and also General Director in the Ministry of Education (1962-1966), Dean (1972-1976), Director of the Institute of Geography of the Romanian Academy (1975-1976), Head of Department, Chairman of the Romanian Society of Geography, President of the Romanian Geomorphology Association, member of numerous editorial boards etc. During this period, due to his well-known tenacity, he had many recognized scientific and academic achievements and also created a well organized geographic school, with many young people trained especially in the many field trips that he organized. We can say, beyond any doubt, that most of the teachers of the Faculty of Geography at the University of Bucharest went through the classrooms and seminars where the professor disseminated geographic knowledge.

One must also remember the training session that Professor Posea attended in Paris (1967). Remarkable teachers, among which N. Al. Rădulescu, I. Conea, V. Mihăilescu, N. Popp, M.

Peahă etc. focused and directed the Professor's scientific future by discourses which were held in lecture halls, laboratories and discussion during the field trips (things that professor Posea tells us from time to time, especially during field trips that were quite numerous in the recent years).

Since 1990, Professor Posea has also created a new geographical school in Bucharest, being one of the founding members of the Spiru Haret University. The Professor works in two universities the with the same tenacity, starting at 8 am and ending ... do not know what time (most of us leaving before he leaves the office).

Many at the sometime Professor's eminent students became geography teachers of the University and also doctors. We mention a few names who have made their mark in the Romanian higher education and research, as I. Ilie, A. Nastase, S. Ciulache, M. Ielenicz, N. Smith, M. Geanana, Florina Grecu, Maria Pătroescu, E. Vespremeanu, Gh. Măhăra, I. Povară, Al. Badea, C. Goran, M. Cârciumar, Iuliana Armaș, N. Cruceru and others, people showing some thinking abilities and skills induced by Professor Posea. Many faculty colleagues, lately colleagues at the University (in Bucharest and Cluj-Napoca), happily tell about their work along with *the Professor*.

The hard work in the office and in the field has generated many valuable studies, which were a key pillar of support in deciphering and explaining theoretical and practical problems of Romania's relief, both on large spaces (e.g. the Danube's Gorges, the glaciations in the Carpathians, regionalization of Romanian Carpathians etc.) as well as confined, local spaces (e.g. contact of Vlăsiei and Târgoviște-Ploiești Plains, Săliște Depression etc.). Do not omit, but we do not have the required space to present the master's works, many of them scientifically marking many of the geographers, teachers or researchers, works that were awarded the highest ranking academic distinctions.

The Professor's scientific heritage has become an important educational and scientific support: over 30 books, 350 articles, nearly 50 contracts, over 10 maps, many undergraduate textbooks, creator of scientific laboratories, research station, organizer of symposia and national and international congresses, etc., are just some of the many scientific references. Being given the opportunity and the chance to spend many years close to *the Professor*, we have noticed how accurately and thoroughly he works, regardless of the situation or circumstances. The resulting works have suffered a long time thinking, rethinking, proofreading, editing, etc., so almost all

remained and will remain true scientific works. The geomorphological imprint of the Professor is to be found in the development of general and regional geomorphology, things that are even today support points in deciphering some theories and concepts. Thus, the issues discussed by the Professor such as the terraces (important as landforms and as cutting, age, relative altitude, etc.), leveling surfaces (not necessarily preserved as old forms, but especially as stages in the evolution of landscape over time), pediments and glacises, piedmonts (as shapes and relationships with erosion landforms), morpho-chronological scale (over Romanian territory, in relation to systemic genetic), geomorphological regionalization, the Carpathian glaciations etc., all can be found in the theoretical and practical Romanian geographical education. We can also notice some courses/papers (not to mention many textbooks and teaching aids for schools), published alone or in collaboration, currently recommended to undergraduate, postgraduate and PhD students. All these gives us the belief that Professor Grigore POSEA is one of the most representative scientists in the country, creator of schools, prestigious specialist and also a teacher who has never forgotten the geography in secondary education.

We must not overlook the family at home: his wife Assoc. Prof. Dr. Aurora Posea, who followed him with honesty both in life and profession, understanding the sacrifice and devotion to the profession, and his son, Cristian Posea, a doctor by profession, who is a real ongoing support of the teacher.

We quote our colleague and friend from Cluj, Professor Dr. Ion Mac who called him, on the anniversary of 75 years, "...*the first magistrate of the second great generation* ...".

We are glad that we had the chance to work together with the Professor, who has given us, as part of his reign, attitude towards work and respect for geographical academic world, but most of all the guidance that we had for accomplishing our PhD thesis.

We hardly try to complete this brief overview of our Professor wishing him good health, long life and fulfillment.

Many Happy Returns of the Day, Professor Posea!!!

List of main works:

- *Geomorfologie generală* (1970), Edit. Didactică și Pedagogică, București;

- *Relieful României* (1974), Edit. Științifică, București;
- *Geomorfologie* (1976), Edit. Didactică și Pedagogică, București;
- *Enciclopedia Geografică a României* (1982), Edit. Științifică și Enciclopedică, București;
- *Geografia de la A la Z* (1986), Edit. Științifică și Enciclopedică, București;
- *Câmpia de Vest a României* (1997), Edit. Fundației România de Mâine;
- *Geografia fizică. Terra cămin al omenirii și sistemul solar* (1998), Edit. Enciclopedică, București;
- *România Geografie și Geopolitică* (1999), Edit. Fundației România de Mâine;

- *Vulcanismul și relieful vulcanic (hazarde, riscuri, dezastre, relieful vulcanic din România)* (2001), Edit. Fundației România de Mâine;
- *Geografia Fizică a României*, vol. I (2003), vol. II (2004), Edit. Fundației România de Mâine;
- *Geomorfologia României* (2002, 2005), Edit. Fundației România de Mâine;
- *Relieful resursa de bază a turismului. Geodiversitate și geomorfosituri* (2012), Edit. Fundației România de Mâine;
- *Geografia României* (tratatul de geografie, vol. V) (2005), Edit. Academiei Române, București;
- *Harta geomorfologică a României*, 1:400000 (1980), Edit. Didactică și Pedagogică, București;
- *România – unitățile de relief*, 1:750000 (1984), Edit. Științifică și Enciclopedică, București.



In the Parâng Mountains – 2012



Near “bray” Lechința – 2013

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Florina GRECU, Nicolae CRUCERU

Academician George Vâlsan – a peerless master in deciphering the mysteries of Romania's landform evolution*

I met the savant and University Professor PhD George Vâlsan indirectly, by studying his work, what was written about him, narratives of his former students (high school teachers, or the Prof. N. Popp), or lectures of my former professors. All of these formed the image of a devotional and constructive example in geography and that of a remarkable pedagogue.

Though his life was extremely short, he asserted himself by an elaborate work based on flawless theoretical knowledge, deep field research (especially on key sectors) that led to distinct information, a peerless intuition that allowed multiple correlations, concise and well argued language, and rich illustrations in context and variety (complex profiles, maps, drafts, suggestive block diagrams, photographs, etc.). He was also the only professor solicited by the three important Romanian universities (Iași, Cluj, București) to teach, research and manage. His results in the “university aura” were so remarkable that he became a creator of geographic school, making his own way towards the Academy (he became a titular member of the Academy in 1920) and to his final acknowledgement in shaping the modern geography in our country, as the main scholar of the savant and academician Simion Mehedinți. Simultaneously, he can be found in the activities of the Royal Romanian Society of Geography, through conferences, scientific material in its publications (especially in the Bulletin) whose thematics involved purely geomorphologic and also other regional, historical geography, demography issues etc., all these written with undeniable arguments reflecting the field research results and the truth resulted from history or the geographical interpretation of the naturalistic information. He received European recognition through active participation in international meetings (Geography Congresses in London, Cambridge and Warsaw) or through materials published in various prestigious journals. Add to this the pure didactical contributions (advice to students, textbooks, relevant opinions regarding the teaching methods

and methodology or to improvement of the content of education, either secondary or university etc.) or the understanding of the need to develop the Carpathian tourism (he was the first president of the National Tourism Office).

A few elements reflect other qualities completing the scientist's complex profile, engaged in a multiple system of preoccupations which reflect the combination of genius struggling with the suffering caused by health problems which had deprived him in the latter part of life of many of the sides which are priorities (firstly, the field research in large spaces). He is the author of manifold poems and vivid descriptions of many beautiful places located within the Carpathian Mountains, which mirrors both sensibility resulted from his communion with nature, and his desire to make known the beautiful and interesting features of the nature, playing with words so cunningly chosen, through metaphors, comparisons and a distinct verification. In the fund of manuscripts, there are also letters to the few loved ones, whose analysis can provide many answers concerning the complexity of his life and his creation. But just as well, these features are understood by studying images, photographs representing him at different times. Following his facial features and especially the forehead, the eyes, the chin, we distinguish a determined and ambitious man whose beliefs are strong, a way of thinking in which the structure and the objective laws prevail, a thin smile that shows kindness and understanding. From one photograph to the other we can see the differences depicting changes over time occurring in the plane of his inner life (sadness, rigor, disappointment, dullness, anger etc.).

George Vâlsan was a distinct personality who, though he died young, gave valuable creations in the Romanian geography and science, contributions that aimed major problems in geomorphology, physical geography, ethnography (German school influence, also the influence of Simion Mehedinți and his belief in the need to restore traditional values of popular culture), geopolitics, human

* This paper was presented at the session of scientific communications of the Romanian Academy from December 17th, 2011, dedicated to the 125 year commemoration of this great geographer's birth.

geography (also, the importance of studying the Romanians abroad), geographical didactics etc.

His "**Geomorphology**" contains the most numerous achievements starting from an excellent PhD thesis prepared under Professor's Emm. de Martonne guidance followed by many communications and articles dedicated to regional areas which required special genetic and evolution complexities, and for which he issued original and very well argued ideas, lithology courses and lectures with content based on his experience but also based on a deep knowledge of French, English and German geography concepts. Views developed in various geography textbooks or popular works should not be overlooked, nor the maps he prepared in which the relief is perceived as the central element of the geographical system. These accomplishments were gradually developed in time. Until 1920, they were achieved through field-based study evaluations, geographical and historical data interpretation, all these combined into the complex system based on analysis from nodal point to regional conclusions, and demonstrative onto genesis – evolution – chronology – immediate and time effects axis. Between 1920 and 1929 he strived to systematize the education and geographical research at the University of Cluj – supporting the basic geography forms and all related areas of knowledge. He organized the geographical expeditions and conferences of Emm. de Martonne in Transylvania, supervised the publishing of these expeditions' results in *Geographic Magazine of Cluj*; he also structured The Ethnographical Society in Cluj, whose president he was. It was a period he contributed to the development of theoretical and practical geography through writings and conferences on various topics in which the links between the relief and other components of the environment were permanently at the very basis of understanding the unity of the whole regardless of its extent. He always relied on results of his previous researches, the vast pool of theoretical knowledge and his manager skills. In the third stage – the last six years – at the Bucharest University, G. Vâlsan continues his assets with emphasis on the didactical side (with more lectures in land morphology), with writings on regional geomorphological synthesis (Danube Delta, coastal platform, morphology of Prahova's Carpathian basin) in which the field observations over time were enriched with map analysis and lots of intuition.

Among these works, four of them created at different times, fully reflect the working system he followed his whole scientific life on the one hand

(thorough documentation with selection of the essential geological elements, detailed field research – observations, schematics, drillings, profiling –, permanent analysis of topographic and geologic maps, truth extrapolation from pilot points to larger areas, completions through evidence of essential and specific genetical-evolutionary elements reflected in a rich-content illustration leading to a better understanding of theoretical concepts), and on the other hand the perennial value regardless of any followers' subsequent addition.

The Romanian Plain – is his master work, a corollary of his geomorphologic research started even since he was a student (Bucharest and surroundings) guided by Simion Mehedinți. His geographic training continued in Berlin and Paris (R.R.S.G. scholarships) where his masters were A. Penck and Emm. de Martonne. This is definitely the best and most comprehensive work of its kind, unequalled in ideas, demonstrations and truths by any later works. This is his PhD thesis (the first geographic work of this type presented in Romania, in 1915; it was published by the Library of R.R.S.G., in 1916), assigning him as the first Romanian creator of geomorphologic school – a titan of Romanian geography, and supporting his exquisite university career and Academy membership (correspondent member in 1919 and titular member since 1920). Within this paper we can only point out some of George Vâlsan's most significant contributions:

- *this is a genuine model to approach, acknowledge and present completely a vast regional area*, also valuable considering that it is a plain unit where the morphogenetic "mysteries" are more difficult to identify, correlate and demonstrate (this approach should be considered by those who have researched lately smaller geographic units, limiting to area situations and neglecting the depth of systemic presentations);

- *it represents an eloquent model of multidisciplinary approach*, since the naturalistic (especially geologic) or human pressure on environment data and information are treated as a whole within the geomorphologic documentation, resulting a unitary, functional and chronologic understanding (while some actual researchers take statistical data, information, or definitions from different works and insert them in their studies as simple additions, not as defining elements within the analysis system);

- *it proves his mastery and appreciation of the informative fund* through opportune quotations (a fact neglected now by those seeking recognition by all means) and *harmonious combination of texts and*

illustrations (he is the first Romanian geographer who appreciated correctly this approach, opening the door to use it not only in geomorphology, but also in other directions);

- a few *achievements* should be detailed, as they were significant, new and complex a century ago:

- setting the geomorphologic contact of the Romanian Plain with the adjacent units, according to the various genetic factors and time interferences;
- analyzing a rich theoretical fund and pointing out especially the geologic elements necessary for the geomorphologic approach or the palaeo-geographic evolution reconstruction;
- differentiating and characterizing the genetic types of plains;
- identifying and describing the morphostructural plain steps, especially the terraces, watersides, and flood plains;
- presenting morphogenetic agents, dynamics of actual processes and resulted landforms;
- presenting landform genesis and evolution on loess, loess and sand rocks;
- presenting river network evolution with detailed analyses on representative sectors;
- concluding that the Romanian Plain is a complex morphologic system resulted from the association of different landforms created in different stages of the Quaternary, as the lake retreated toward the East and North-East and the hydrographic network generated steps;
- highlighting that the influence of the tectonic factors and other agents generated specific landforms locally, concluding in a Quaternary evolution differentiated by sectors.

Other remarkable achievements are: the concordance between statements and illustrations (accurate representations); the text, abundant in information, made up of clearly expressed phrases, many of them becoming axioms for those who resumed the research later, so that the news belong to George Vâlsan, while the additions to his followers.

On the Danube crossing the Iron Gates – represents George Vâlsan's contribution to clearing up the evolution of one of the largest gorges in Europe and the most important within the basin of this river. His approach reflects the sequence of problems, a solving technique based on studying former geomorphologic and geologic papers combined with his own observations, map analysis and excellent intuition.

He considered all possibilities of gorge evolution and indirectly of Danube formation between the Pannonian and the Getic basins in upper Pliocene –

Quaternary. These variants were argued differently by the researchers quoted by the professor, depending on the acceptance of river capture or lake overflow. But George Vâlsan focused on the critical analysis of the Serbian professor J. Cvijic, the first one who mapped in detail the landforms and deposits within the Danube gorges. He paid attention to the following aspects: the extent of the Pontian level, the upper terraces and the better developed terraces within the gorges; interpreting the characteristics of the deposits in Severin-Timoc basin in terms of structure, aspect, and age; the valley network characteristics in the gorges compared to the Danube; the valley network formed in the western Getic basin in the Quaternary, as the lake was filled and retreated eastward, etc. He considered necessary to observe the evolution in time of the Pannonian and Getic basins, including the gorges within a complex system generated by the regional tectonics, with different stages of intensity and directions correlated with the evolution of the adjacent lakes (in the upper Pliocene – lower Pleistocene). These led him to the *hypothesis of the Danube formation in the gorges* (made initially by tectonic fragmentation in the Sarmatian) *by capture* (Greben sector) in the lower Quaternary. The arguments are mainly morpho-hydrographic. The palaeo-geographic evolution of the Getic basin in the lower Quaternary favored the capture process due the low base level that provided a stronger penetration force westward. G. Vâlsan considered that from the *chronologic and evolutionary* points of view, this area evolved as a tectonic gorge (graben) in the upper Miocene (there was a lacustrine connection between the Pannonian and the Getic basins), drained in the upper Pliocene by two rivers towards the adjacent lakes (the watershed was located at Greben), and finally the river completed by capturing the western river at the beginning of the Quaternary.

The morphology of the upper Prahova valley and of adjacent areas. This writing was published posthumously (1939) and it was, unfortunately, the last large work of regional geomorphology, considered a valuable morphogenetic synthesis of the area connecting the units studied by Emm. de Martonne and A. Nordon. It is also an excellent model of combining observations with geological data, maps, profiles and enviable intuition, reflected in the morphologic sequences, genetic and evolutionary correlations, or chronological results on landforms. Other important contributions were: the manner of analysis, the gradual sequence of problems (from the erosion steps to the valley network, or the actual morphogenetic processes

reflection on the landscape), or the scientific and artistic geomorphologic representations (profiles, maps, block diagrams, panoramic drafts).

The starting point was to present the morphologic evolution of the Carpathian area between the rivers Ialomița and Buzău (considered a relatively unitary region from the morphostructural point of view), based on the landforms resulted in different stages. They have morphometric, physiognomic and morphostructural characteristics that differ on sectors and belong to two stages:

- *The stage of old evolution cycles* corresponds to those in the Southern Carpathians, considered pre-Quaternary (the level of ± 2000 m peaks and plateaus belonging to the Borăscu erosion surface, the levels belonging to the Râu Șes erosion surface in Ialomița basin and Clăbucete, Predeal level that extends on Bran area correlated with the Gornovița erosion surface, and ± 800 m and ± 700 m low levels on the edge of Brașov Depression).
- *The stage of new Quaternary cycles* (terraces, steep slopes, valley steps, capture gorges at Posada and Timiș, etc.).

Other important contributions were:

- *the extent of the erosion steps* that emphasizes regional differences determined by the tectonic movements, different in intensity and direction, and by the local litho-structural influences (represented outstandingly in profiles);
- *the attempt to correlate* all existing erosion steps with the adjacent Carpathian area, as well as the manner they join regionally or locally;
- *the description of the modified valley sectors by captures* and their reflection on the orographic characteristics.

A new hypothesis of the Danube Delta – is the last paper presented by this great geographer within an international reunion – the Geography Congress in Warsaw (1934). The novelty and arguments aroused interest and distinct appreciations. The bases of this paper were the map of Vidrașcu (1913), the two genetic and evolution maps of Gr. Antipa and C. Brătescu, and many foreign and Romanian references (especially those referring to the Black Sea). The deep analysis of each defining landform or lithologic element led the author to a new hypothesis on the Delta's evolution. The entirely marine formations (sand banks) from the Eastern Delta, the outward convergent offshore bars

(presumed toward the Isle of Snakes), the way the shore line cuts them, the East-West regressive shore evolution during the last millennium, were some of the arguments that determined G. Vâlsan to state that the Danube Delta is now during a retreat stage, while the sea forwards toward the land, cutting the marine bank sands. This process is connected with the effects of the descending movements that would occur in the western Black Sea and with the sea level oscillations (favored by climate variations in upper Quaternary). G. Vâlsan considered that the Danube Delta is post-glacial, and the large sand banks that extended more eastward had formed during a dry climate with a lower sea level; the shore retreat and offshore bar cutting (from East to West) to the actual shape belong to a wet climate (Subatlantic). Some of these specifications resulted from some papers published posthumously.

In conclusion, a few viable arguments were enough to achieve a new evolution system with a precise chronologic development, a fact that denotes an excellent intuition and a model of rapid explanation.

These arguments along with others that may be added show a life full of scientific achievements. Throughout his didactic career, Professor George Vâlsan was an *exquisite geographer, a genial geomorphologist, a pillar of modern geography imagined and accomplished with his mentor, Professor Simion Mehedinți. His contributions to culture, research, teaching and Academy were completed by his managerial abilities. He supported youth education in general, but especially the implementation of modern geographic research. He was a board member of many scientific, cultural, and tourism societies, he founded geographic magazines, he wrote poems and geographic readings passionately, and he respected and praised his forerunners and few friends.*

If his fate had not been so cruel, the road he climbed so gloriously would have certainly led him among the most important geographers of the 20th century worldwide, and Geography would have got more prestigious works.

He was a savant, an excellent didact, a renowned geographer, a poet geographer, but first of all, he was a great MAN.

Mihai IELENICZ

6th International Symposium on Gully Erosion in a Changing World (6th ISGE)

Iași, Romania, 06-12 May 2013

Gully erosion has been recognized as an important environmental threat throughout the world affecting several soil and land functions. There is ample physical evidence of intense gully erosion occurring at various times in the past in different parts of the world. Gullies are one of the few sources of morphological evidence in the landscape of past phases of erosion reflecting the impact of environmental change (land use, extreme climatic events). The development of gullies increases runoff and sediment connectivity in the landscape, hence increasing the risk of flooding and reservoir sedimentation.

Assessing the interactions between environmental change (land use, climate) and land degradation remains a key issue for environmental scientists, land managers and policy makers. Over the last decades, significant progress has been made in understanding gully erosion and its controlling factors.

The 6th International Symposium on Gully Erosion (6th ISGE) deployed in the city of Iași, Romania between 06-12 May 2013, continued the sequence of successful meetings held in Leuven (Belgium, 2000), Chengdu (China, 2002), Oxford (USA, 2004), Pamplona (Spain, 2007) and Lublin (Poland, 2010). This important scientific meeting was organized by the "Alexandru Ioan Cuza" University of Iași, Faculty of Geography and Geology, under the high patronage of the International Association of Geomorphologists (IAG), the European Society for Soil Conservation

(ESSC), the Romanian Association of Geomorphology (AGR) and the Romanian Academy.

The scientific meeting was chaired by Prof. Dr. Ion Ionita with the Department of Geography, Faculty of Geography and Geology, "Alexandru Ioan Cuza" University of Iași, Romania and co-chaired by Prof. Dr. DSc. Jean Poesen, Head Division of Geography, Department of Earth and Environmental Sciences, KU Leuven, Belgium.

Almost 50 scientists from 21 countries attended and actively participated in the 6th ISGE by very interesting 34 oral presentations and 20 posters on the 07th and 09th of May 2013. The main focus in these presentations has been oriented on: Gully erosion and associated processes; Gully development and rates; Advances in measuring techniques; Gully erosion models and Gully erosion control.

Two scientific field trips have been carried out on the 08th and 10th of May 2013 in the Falcu Hills of the Barlad Plateau and the Jijia Rolling Plain of the Moldavian Plain. The meeting was closed by one day post-conference field excursion in the Moldavian Subcarpathians and the Eastern Carpathians of Romania.

Throughout the event, the organizing committee, coordinated by Prof. Dr. Ion Ionita and his "right and left hands", Dr. Lilian Niacsu and Dr. Mihai Niculita, hoped that the undoubted high quality scientific expertise of the participants and the Romanian hospitality joined in a very successful symposium.



The scientific field trip in the Valcioaia catchment, Fălcu Hills, Moldavian Plateau of Eastern Romania
(Photo: Mihai Niculita, 08 May 2013)

Lilian NIACSU, Ion IONITA

**The Carpatho-Balkan-Dinaric Conference on Geomorphology held on the occasion
of the 50th anniversary of the foundation of the Carpatho-Balkan Geomorphological Commission**
Stará Lesná, Tatranská Lomnica, Slovakia, June 24–28, 2013

In 2013, 50 years are completed since the Carpatho-Balkan Geomorphological Commission (CBGC) was founded. Back in 1963, an International Symposium on the geomorphology of the Carpathians was organized by the Institute of Geography of the Polish Academy of Sciences and the Institute of Geography of the Slovak Academy of Sciences. The symposium was held both in Poland and in Slovakia.

Therefore, this year's Carpatho-Balkan-Dinaric Conference on Geomorphology, held in Stará Lesná between the 24th and the 28th of June 2013, was a jubilee edition celebrating 50 years since the founding of the CBGC. It was organized, as half-a-century ago, by both Slovak and Polish geomorphologists. More precisely, this year's Conference – belonging to the Carpatho-Balkan Geomorphological Commission (CBGC) and the IAG/AIG Carpatho-Balkan-Dinaric Regional Working Group (CBDRWG) – was organized by the Association of Slovak Geomorphologists, the Association of Polish Geomorphologists, the Institute of Geography of the Slovak Academy of Sciences (Dr. Milan Lehotský, Dr. Ján Novotný, MSc. Miloš Rusnák), the Institute of Geography and Spatial Organisation of the Polish Academy of Sciences (Assoc. Prof. Zofia Rączkowska, Dr Michał Długosz), the Institute of Geography and Spatial Management of the Jagiellonian University (Prof. Kazimierz Krzemień, Dr. Elżbieta Gorczyca, Dr Dominika Wałach-Wrońska) and the Faculty of Natural Sciences of the Comenius University in Bratislava (Dr. Zora Machová).

Among the honorary members of the International Committee of the Conference two Romanian geomorphologists were also listed: Prof. Lucian Badea and Prof. Dan Bălteanu from the Institute of Geography of the Romanian Academy.

The conference venue has been the Congress Center Academia of the Slovak Academy of Sciences, in Stará Lesná, Tatranská Lomnica, Slovakia. This center is located in the Eastern part of the Vysoké Tatry Mountains in Slovakia, in the near vicinity of the Tatra National Park.

Key note lectures were given by: Prof. Leszek Starkel (Main regularities of mountain relief evolution), Prof. Jaromír Demek (Pleistocene

cryopediments and cryopediplains of the Moravian-Silesian Carpathians (Czech Republic)), Prof. Dénes Lóczy (Landforms, water availability and land use in floodplains), Prof. Petru Urdea (Geophysical investigation in the periglacial belt of the central area of the Făgăraș Mountains) and Prof. Milan Lehotský (Response of a mountain bedrock-alluvial river in flysh geological setting to contemporary environmental conditions (case study the Topľa River, Slovakia)).

The conference was further structured in several successive oral and poster sessions which brought together presentations on *fluvial geomorphology and palaeo-hydrology, slope processes*, as well as on other topics. The conference was attended by a large number of participants coming from Carpathian, Balkan and Dinaric countries: Poland, Slovakia, Czech Republic, Hungary, Romania, Slovenia, Austria and Croatia.

Two excursions were provided during the conference program: one half-day excursion in the Liptovská kotlina Basin and one-day post-conference excursion in the Polish part of the High Tatra Mountains (the Morskie Oko Lake) and the Western Tatra Mountains. (the Chochołowska dolina Valley).

On the evening of the first day a Joint Council Meeting of the IAG/AIG CBDRWG (the last meeting of the working group) and of the CBGC took place. The meeting approved the main issues to be submitted to elections within the Plenary Session of the CBGC, at the end of the actual conference. This latter one was, as expected, mainly devoted to the anniversary of the Carpatho-Balkan Geomorphological Commission. The programme included several speeches: Prof. Leszek Starkel shared some of his memories from the early beginning of the Commission's existence and explained the first steps taken by the Carpathian colleagues in cooperating with each other (the founders of the Commission who are no longer among us were remembered on this occasion, among which also the Romanian ones - Prof. Vintila Mihăilescu, Prof. Tiberiu Morariu, Prof. Gheorghe Niculescu); Prof. Miloš Stankoviansky summarized the 50 years of activity of the CBGC (1963-2013) – presidents, meetings, working groups, publications –,

as well as the briefer history of the IAG Working Group on the CBD Region; Prof. *Dénes Lóczy*, before ending his Presidency of the CBGC, gave his Report on the past two years since the last meeting in Ostravice; Prof. *Zofia Rączkowska* presented a Report on the journal *Studia Geomorphologica Carpatho-Balcanica*.

The officially nominated candidate for the Presidency of the Commission, Prof. *Petru Urdea* from Romania, was elected by the Plenary Session, and the position of a Secretary, to be occupied by a person from the same country as the President, was also approved. In his new quality, that of President of the CBGC, Prof. *Petru Urdea* presented the plan of activities for the next years, which includes, among other things, conferences, thematic workshops and summer schools, editing a new

volume in the Springer Geography series and a special issue of the *Studia Geomorphologica Carpatho-Balcanica* and constructing a website. The date and venue for the next conference were also voted in the Plenary Session. Based on a slight change suggested in the name of the Commission from Carpatho-Balkan to Carpatho-Balkan-Dinaric – following the example of the IAG Working Group, a proposition came from the President of the Geomorphological Society of Slovenia, Dr. *Irena Mrak*, which would place the next Geomorphological meeting in September 2016 in Postojna, Slovenia. Prof. *Karel Natek* offered to be the contact person in this respect. With this occasion an increase in the frequency of meetings was made, i.e. from four to three years.



The 50th anniversary of the Carpatho-Balkan Geomorphological Commission celebrated during the Plenary Session; from left to right: Prof. Dénes Lóczy, Prof. Leszek Starkel and Prof. Miloš Stankoviansky
(Photo: Laurențiu Niculescu, June 27th 2013)

Marta JURCHESCU

National Geomorphology Symposium **29th Edition, Suceava, 30th May - 1st June 2013**

Romanian geomorphologists are proud to be forming a professional scientific community shaped by the following attributes: illustrious predecessors, exceptional scientific results, real competition among generations and especially strength and focusing power, year by year, in organising the national symposiums.

The year 2013 offered the opportunity for the geomorphologists from Suceava to be the host of the annual manifestation of the Romanian geomorphology, under the patronage of the Romanian Association of Geomorphology (AGR). The honour was even greater as 20 years have passed since the 16th edition of the same symposium, which was also organized in Suceava.

As organizers we considered a debate theme, which we announced early, entitled: "Natural vs. anthropic in controlling the geomorphologic processes and landforms". Consequently, there were 57 papers from which more than 90% answered to our debate on subjects of dynamic and applied geomorphology.

Friday, the 31st of May, was dedicated to the debates in plenary and in the two sections (one dedicated to the geomorphological system of the slopes, the other one to the fluvial and coastal geomorphological systems). I could make the observation that this year's edition was one dominated by young researchers (30-40 years old), with remarkable results in the new orientation of the Romanian geomorphology (which gained considerable attention after the year 2000): the

emergence from the local horizon and attacking the most important problems scientific research. Some of the subjects that caught my attention were: the progress done in the geomorphologic cartography domain, the morphogenetic role of climate change in the Late Quaternary, how natural and how anthropic is the evolution of the Danube's river mouths and uncertainties associated to the risk evaluation of landslides. I have equally noticed, the numerous innovations in the methodology of research (ex. for avalanches, for the identification of permafrost), impressive databases (for the morphogenetic role of flush floods, for river bed dynamics in the last century) and in solving some practical issues regarding the land use (geomorphosits, ski domain, urban space evolution). The discussions, the questions, the information exchange animated constantly the entire atmosphere of the symposium, until the evening.

Saturday, 1st of June, was dedicated to a thematic field trip, focused on *Methods and techniques for the reconstruction of the paleoenvironmental conditions of the fluvial and lacustrine domains*. It provided the occasion for the geomorphologists from Suceava to insist on the results of the last 10 years in the fluvial geomorphology and the reconstruction methods of the fluvial and lacustrine paleoenvironments.

It has to be mentioned an important fact of the symposium, the confirmation of Prof. Dr. *Petru Urdea* as the head of the AGR, in conformity with the status and elections.



The scientific field trip in Bucovina - National Geomorphology Symposium

8^e Conférence Internationale de Géomorphologie de l'AIG
« Géomorphologie : des processus naturels au développement durable »
Paris (France), 27 – 31 août 2013

L'Association Internationale des Géomorphologues (AIG) organise une conférence internationale tous les quatre ans. En 2013, la réunion a eu lieu à Paris, du 27 au 31 août, au Centre des Sciences de La Villette. L'organisation de la conférence a été possible grâce au travail en équipe de plusieurs centres universitaires et de recherche de France, sous la direction des professeurs Stéphane Costa et Monique Fort.

La conférence a réuni environ 1400 participants de cinq continents. L'Association des Géomorphologues Roumains a été représentée par son président, professeur Petru Urdea, et plusieurs membres du Comité. Au total, nous avons compté une vingtaine de participants roumains des centres universitaires de Bucarest (Florina Grecu, Liliana Zaharia, Alfred Vespremeanu-Stroe, Ionuț Șandric, Anca Munteniu, Gabriela Ioana-Toroimac, Luminița Preoteasa, Florin Tătui, Daniel Iosif, Zenaida Chițu), Cluj-Napoca (Aurel Irimuș, Titu Anghel, Olimpiu Pop, Sanda Roșca, Luana Maguț, Cătălina Roșu), Timișoara (Petru Urdea, Mircea Voiculescu), Iași, Suceava (Ioana Perșoiu) et de Institut de Géographie d'Académie roumaine (Dan Bălțeanu, Mihai Micu, Marta Jurchescu). Les communications orales et les posters ont porté sur la dynamique des versants, géomorphologie fluviale, géomorphologie côtière, Quaternaire, aléas et risques, glaciologie, géomorphosites, géomatique. Trois jeunes géomorphologues roumains ont reçu des bourses de participation à la conférence de la part de l'AIG (Titu Anghel, Gabriela Ioana-Toroimac, Daniel Iosif).

De point de vue scientifique, le congrès s'est déroulée sous le thème généreux de « Géomorphologie : des processus naturels au développement durable ». Il a réuni :

- cinq conférences invitées (Denys Brunsdén, Vic Baker, Ana Luiza Coelho Netto, Asfawossen Asrat et Xiaoping Yang) ;

- vingt-sept sessions de communications orales et de posters (Histoire et épistémologie de la géomorphologie ; Géomorphologie et Science du Système Terre ; Géomorphologie planétaire ; Méga-géomorphologie ; Tectonique et géomorphologie ;

Géomorphologie volcanique ; Magnitude et fréquence en géomorphologie ; Evolution à long terme des paysages et processus géomorphologiques ; Contrôle lithologique des processus et des formes ; Géomorphologie du Quaternaire ; Géomorphologie et changement global ; Géoarchéologie ; Impact de l'Homme sur les paysages ; Aléas géomorphologiques, gestion des risques et impact du changement climatique ; Géoconservation, géotourisme et éducation ; Géomorphologie et « Zone critique » ; Dynamique des versants et mouvements de masse ; Géomorphologie fluviale et gestion des cours d'eau ; Budgets sédimentaires ; Géomorphologie littorale et aménagement ; Géomorphologie sous-marine ; Systèmes éoliens et géomorphologie des domaines arides ; Géomorphologie tropicale ; Géomorphologie des domaines froids ; Les méthodes en géomorphologie ; la Session des jeunes géomorphologues et le Forum francophone) ;

- une vingtaine d'excursions scientifiques pré-, inter- et post-congrès (en France, en Belgique et en Suisse) ;

- l'apparition des deux livres (*Géomorphologie de la France* sous la direction de Denis Mercier et *Landscapes and Landforms of France* sous la direction de Monique Fort et Marie-Françoise André).

De point de vue socio-culturel, les organisateurs ont proposé aux participants :

- un cocktail de Bienvenue à l'Hotel de Ville de Paris ;
- une soirée Vin et fromage au Centre des Sciences de La Villette ;

- une soirée de gala sur une péniche, en remonant la Seine et admirant les monuments de Paris, à la découverte de la cuisine française, à la fois traditionnelle et innovante; champagne à volonté !

Nous rajouterons deux autres événements qui ont eu lieu lors de la conférence. Les collègues français ont organisé un pot de départ à la retraite de professeur Monique Fort ; à cette occasion, un numéro de la revue italienne *Geographia physica et dinamica quaternaria* (volume 36, numéro 1, 2013) lui a été dédié. Le congrès a été aussi l'occasion d'élire le nouveau comité exécutif de l'AIG ; le

professeur Eric Fouache est le nouveau président élu de l'AIG.

Pour conclure, la variété des domaines réunis sous le thème de « Géomorphologie : des processus naturels au développement durable », ainsi que le nombre élevé de participants issus de différents domaines montrent l'intérêt de la société pour une des plus anciennes et pragmatiques sciences – la géomorphologie. D'une manière générale, la conférence a été une nouvelle occasion de montrer le rôle de la géomorphologie dans le développement durable. Pour chaque participant, la conférence a été une opportunité d'apprendre, de se tenir au courant

des tendances en géomorphologie et de prendre des contacts dans différents coins du monde entier. Nous tenons à remercier les organisateurs pour ce moment d'échange scientifique et de convivialité à la française et l'équipe des tee-shirts oranges pour l'assistance technique.

Rendez-vous à la 9^e Conférence Internationale de Géomorphologie de l'AIG à Calcutta, en 2017 ! Jusqu'à la prochaine rencontre, reflétez aux mots de Denis Brunsden : « Respirez profondément / Marchez doucement / Pensez outrageusement / Soyez non-contraint / Soyez libre ».

Gabriela IOANA-TOROIMAC

Recenzii / Reviews

Florina GRECU (coordonateur), Liliana ZAHARIA, Cristina GHIȚĂ, Laura COMĂNESCU, Emil CÎRCIUMARU, Maria ALBU (DINU) – **Sisteme hidrogeomorfologice din Câmpia Română. Hazard – Vulnerabilitate – Risc**, Edit. Universității din București, 2012, 308 pages, 189 figures, 96 tableaux, 14 planches.

La Plaine roumaine représente la plus vaste unité majeure de relief du pays, qui, en apparence, par sa monotonie et inexpressivité de l'ensemble du paysage, ne pose aucun problème géomorphologique majeure. Pourtant c'est cette subtilité qui a incité le collectif d'auteurs et les a poussé à aborder la problématique variée du relief « caché » de cette plaine, aussi bien de point de vue théorique que pratico-applicatif. Le caractère complexe et interdisciplinaire de cette recherche dérive de l'analyse de la géomorphométrie des systèmes hydrogéomorphologiques, de l'application des théories morphologiques pour la compréhension du relief, de l'étude de la dynamique des chenaux fluviaux, de l'analyse géographique des aléas, des risques et des facteurs de contrôle de la dynamique des chenaux fluviaux et des éléments socio-économiques du risque.

L'ouvrage est structuré en trois parties et sept chapitres, précédés d'une introduction. Chaque chapitre est accompagné de bibliographie, figures, tableaux et conclusions. A la fin de l'ouvrage, se retrouve une liste de travaux sur la Plaine roumaine publiés par les auteurs, puis les annexes regroupant 14 planches.

La **première partie** porte sur les **Facteurs de vulnérabilité. Aléas hydrogéomorphologiques. Valeurs critiques** et regroupe 5 chapitres sur les *caractéristiques géologiques* (l'analyse complexe des dépôts), les *caractéristiques géomorphologiques* (la présentation générale du relief de la Plaine roumaine et des bassins morphohydrographiques étudiés, l'analyse morphométrique du relief, des profils longitudinaux des cours d'eau, de la morphométrie du réseau de drainage et des

méandres, l'identification des seuils et des valeurs critiques et l'analyse des dépressions en lœss), les *caractéristiques climatologiques* et l'identification des valeurs et des seuils critiques de certains paramètres climatiques, les *caractéristiques hydrologiques* et les *caractéristiques du lœss, des dépôts lœssiques et des sols*.

La **deuxième partie** se réfère aux **Éléments socio-économiques du risque** et inclut un seul chapitre sur l'analyse de l'occupation des sols et de la pression anthropique en tant que facteurs de la vulnérabilité aux processus hydrogéomorphologiques.

La **troisième partie** est intitulée **Vulnérabilité socio-économique aux aléas hydrogéomorphologiques** et contient un seul chapitre et plusieurs sous-chapitres. Après la présentation du cadre théorique conceptuel, des objectifs, des méthodes, des données et des outils utilisés, sont expliquées les étapes de l'élaboration et de la réalisation de la carte de la vulnérabilité aux aléas hydrogéomorphologiques dans le bassin morphohydrographique de Mostiștea et les bassins du Secteur central de la Plaine roumaine. Cette approche se matérialise par une carte synthétique de la vulnérabilité aux processus hydrogéomorphologiques qui montre les communes soumises au risque inondation, résultats comparés aux endommagements des inondations de 2005.

Nous considérons que cet ouvrage est précieux, original, enrichit la littérature géographique roumaine et souligne le caractère unique de cet espace, en apparence monotone et inexpressif. L'ouvrage inclut de nombreuses cartes, graphiques et photos, complémentaires au texte, qui augmentent son authenticité et montrent le dialogue permanent des auteurs avec le terrain.

Iulian SÂNDULACHE

Ștefan CONSTANTINESCU – *Geomorphological analysis of cliff shore between Cape Midia and Vama Veche*, Edit. Universitară, București, 2012, 172 p., 123 fig., 16 foto.

The present book represents Ștefan Constantinescu PhD thesis. It has 171 pages and is structured in two parts:

- 1st part (corresponding to the first two chapters) presents the theoretical framework of cliff shores geomorphology and of the main factors influencing their morphology and dynamics;
- 2nd part (corresponding to the other three chapters) consists in the creation and analysis of digital elevation models and in extracting main specific morphometric indices (*Plan Curvature*, *Profile Curvature*, *LS Factor* etc.).

Some of the proposed working techniques may look common nowadays, being used in many PhD thesis, bachelor degree studies and master dissertations. But, this book should be judged in the context of the 2003-2004 period (when the thesis was written), when producing especially digital terrain models based on own measurements or on navigation maps was scarce. A necessary task was represented by the terminological clarifications, the Romanian cliff shore being studied in the context of the international nomenclature. Advancing new notions or translating others from English gives surplus value to the book, these notions completing the Romanian geomorphological vocabulary (*shore platforms*, *potholes*, *ramps*, *furrows*, etc.).

Chapter four, presenting the geomorphological analysis of cliff shore, is the densest in the whole book. The author succeeds here to offer for the first time a unitary image of the entire cliff shore evolution between Cape Midia and Vama Veche. The evolution rates, computed by compared

analysis of various cartographical products, are very useful for integrated coastal zone management studies. In this chapter we can also find a new surprising approach in the geomorphological literature, which combines historical cartography with deltiology elements. The author is convincing us that a history of Constanța and Eforie beaches or some reconstitutions of the first touristic activities in Techirghiol represent not only easily accessible elements for every geographer, but information which offers delightful moments for all the lovers of the Romanian coast. This way, we get knowledge of the first hotel, the treatment period at *cold or hot baths* (*băile reci sau calde*) or we can reconstitute an estimative budget for a tourist in holiday at the beginning of the XXth century.

The author is asking himself, from the very beginning of the book, if this cliff shore is still fascinating as it was more than a century ago. The pro and against arguments are found all over the book and we do not want to divulge all, letting you the pleasure to discover them. It seems like all his answers take shape when he integrates the whole cliff shore in a higher geographical context, the fascinating dobrogean space. Keeping the mirage of this dobrogean presence, which Mircea Eliade calls a *prologue to One thousand and one nights*, the author finds his answers through the final affirmation from the end of the book, fully acceding to George Vâlsan words: *Who knows Dobrogea, loves it forever / Cine cunoaște Dobrogea o iubește pentru totdeauna!*

Florin TĂȚUI

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