Vulnerability map to hydro-geomorphological processes (Romanian Plain)

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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 (Mostistea catchement). For the Romanian Plain, where quasi-horizontal interfluves 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 interfluves and the other one for the river channels.

Keywords: vulnerability, hydrogeomorphological hazard, rivers, flat interfluves, 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; Armaş, 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-Balkanic arch (Vîlsan, 1916). These territories are part of the Mostiştea 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 Mostiştea 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 interfluves and those affecting the channels have distinct genesis and dynamics, hence the necessity to make the respective vulnerability maps based on specific criteria.

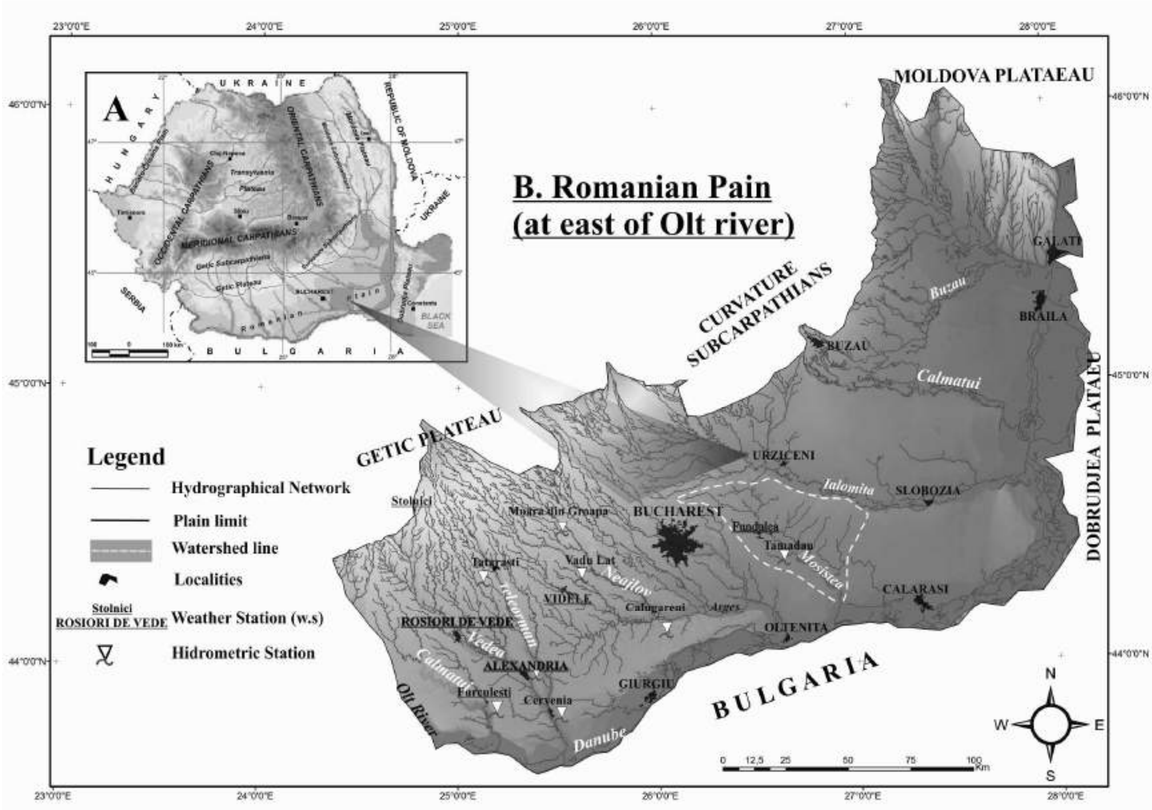

Fig. 1. **Location map** (Mostiștea catchement/Romanian Plain)

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 (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 reclasification	Loess	After reclasification	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 (fluvial vulnerability) = (*D x E*) x (*S x 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 reclasification	Local relief value (m)	Ater reclasification	density X local relief	Vulnerability classes
0-3	2	0-5	7	14-18	stable cources
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 interfluves of the Mostistea 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).

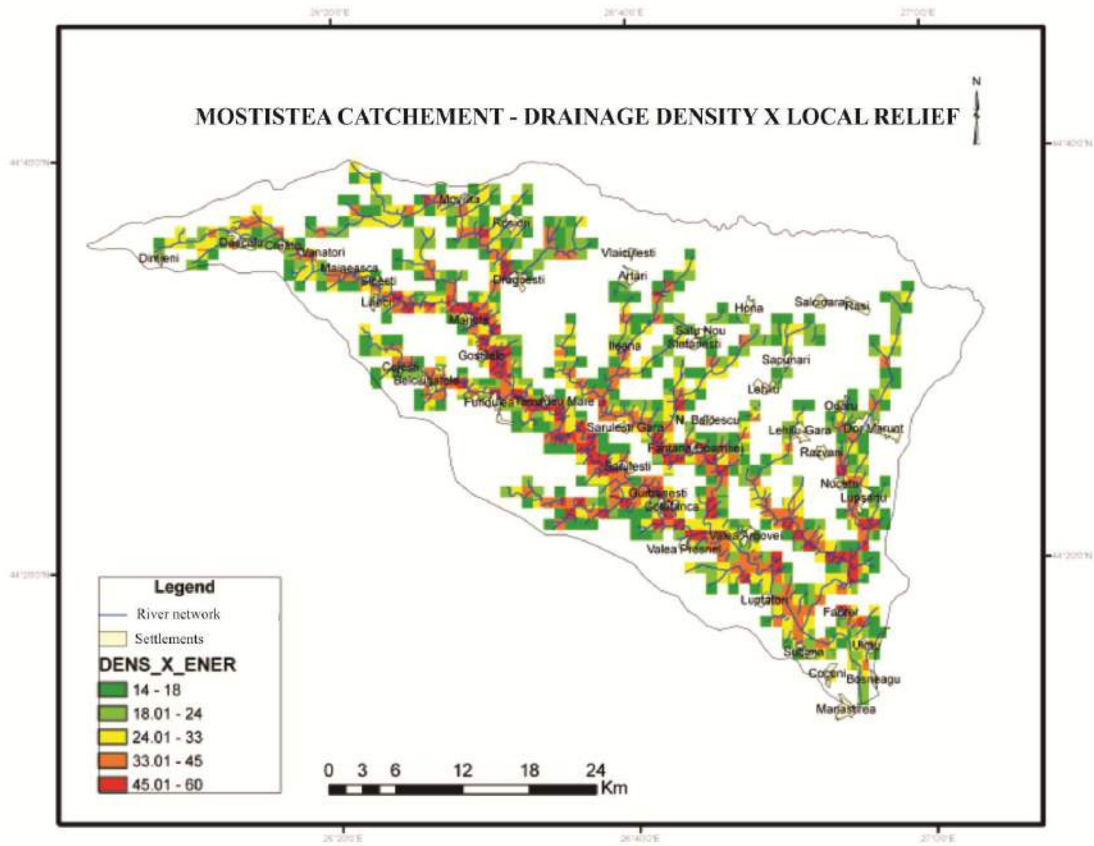

Fig. 2. **Drainage density X local relief**

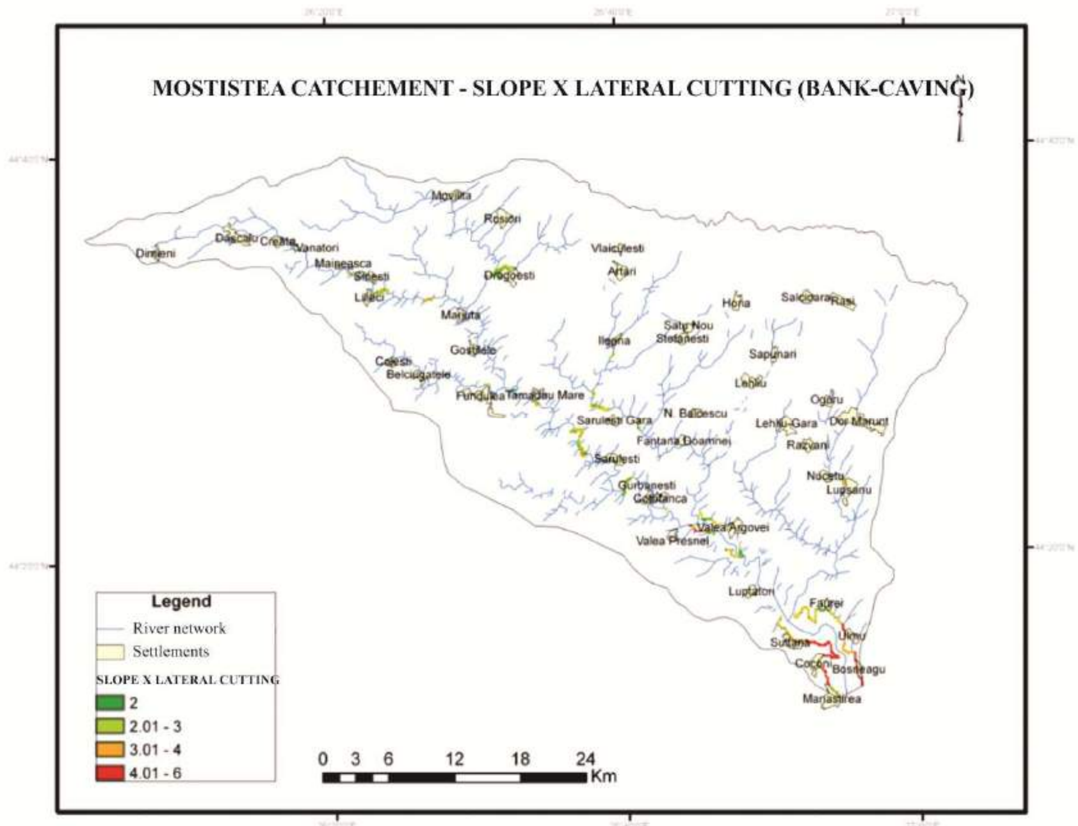

Fig. 3. **Slope X lateral cutting**

Land morphology and geomorphological processes.The geomorphological processes specific for the interfluvial areas lying within the Mostiştea 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 m^2 to 3.3 km^2) and rather circular depressions (low sinuosity coefficient) (Grecu et al. 2006). In the northern part of the catchment and on the Ialomița – Mostiştea interfluve, 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 ortophotoplans were correlated with the distribution of typical phreatic-wet chernozems, levigated chernozems (weakly eluviated) affected by pseudogleyzation phenomena (found in loess sinkholes and sagging areas), phreatic-wet cambic chernozems and phreatic-wet, levigated vertic chernozems, affected by gleyzation.

In the Mostistea 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;
  A_1 – with continuous spread (in the Mostiştea Plain);
  A_2 – 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.
  B_1 – with I_{mg} = 5 – 40 cm
  B_2 – 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 **A_1**) (value 7- the lowest after reclassification); I_{mg} ranging from 5 to 40 cm – value 8 after reclassification) (**collapse B_1**); and I_{mg} > 40 cm (**collapse B_2**) (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 Mostiştea 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 Arges-Mostiştea interfluve (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 B_1). 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 Mostiştea – Ialomița interfluve (accounting for 60% of the area). On these territories, collapsible deposits with supplementary sagging values less than 5 cm (collapse A_1) or less than 40 cm (collapse B_1) 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 (Săruleşti and Valea Argovei) and lower course (Lake Mostiştea) of the Mostiştea 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 Săruleşti, Gurbăneşti, Valea Argovei and around Lake Mostiştea, 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.

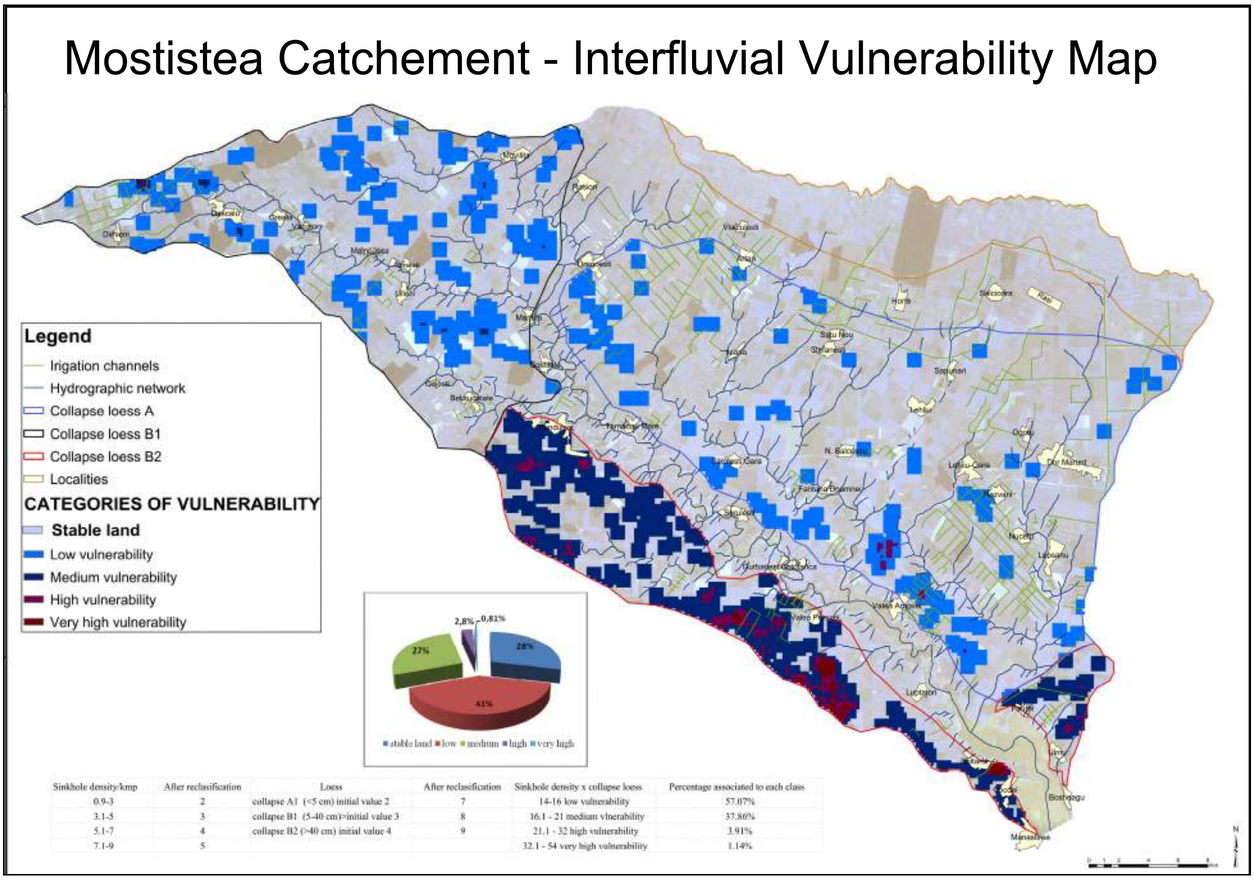

Fig. 4. **Interfluvial vulnerability map**

Table 3. **Categories of vulnerability**

Interfluvial vulnerability	**Fluvial vulnerability** (percentaje caclucated only to affected area)
>14 stable land = 28.6%	> 6 stable cources
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%

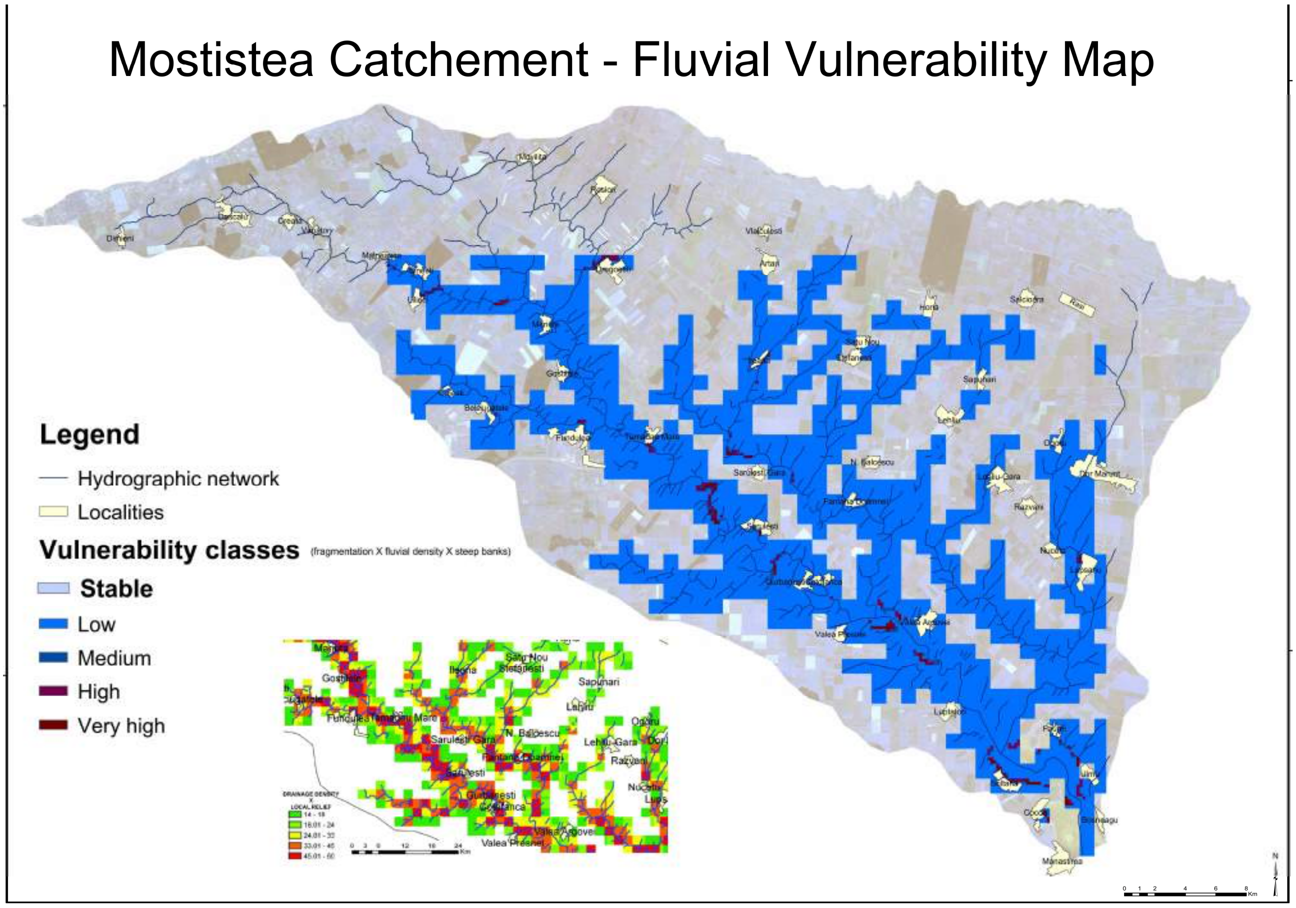

Fig. 5. **Fluvial vulnerability map**

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 interfluves: 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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