ACTIVE LANDSLIDES IN TUTOVA CATCHMENT (EASTERN ROMANIA)

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Abstract. Tutova catchment is situated in the eastern part of Romania, having a surface of about 685937 hectares. The study of active landslides actually took into consideration the analysis of causal factors (geology, morphometry, rainfall), in order to determine the susceptibility of slopes to these processes. Each potential factor of imbalance is divided into several classes of susceptibility, usually based on frequency of landslides. Given the specific of lithology and relative or absolute weight of sliding lands on geological deposits, these ones have been grouped into four classes of susceptibility. The altitude is a control factor of landslides, but only indirectly, through other geomorphometric variables. In relation to slopes, landslides are distributed almost entirely in the gap 5 to 25°, a half being on lands with slopes of 10-15°. Interpreting the distribution of landslides according to the depth of fragmentation, it appears that the maximum frequency is specific to sectors characterized by values of vertical fragmentation between 60-100 m. Gully erosion is an active factor in triggering landslides, with a very close relationship between the two types of processes. Rainfalls play an important role in triggering or reactivation of landslides. Morphodynamic response of the Moldavian Plateau diluvium trigger in the case of long-term rainfalls; fastest dynamics is found for a sequence of at least two years of excess rains, allowing accumulation of sufficient water in diluvium masses.

Keywords: *Tutova catchment, landslides, geological factor, morphometry, rainfall*

1. Introduction

Tutova catchment is situated in the southern part of the Moldavian Plateau (Eastern Romania), having a surface of about 685937 hectares (Fig 1). The natural factors, together with human ones, have permanently favored geomorphologic processes, among these landslides having a great importance, especially in the upper basin. The lithology of region is represented mainly by deposits of sand, sandy clays and rarely clays (Jeanrenaud, 1971), in different successions at the basin level (Khersonian – Meotian – Pontian – Dacian – Romanian). The general monocline structure accounts for the development of the cuesta relief, implicitly for the morphologic, morphodynamic and land use asymmetries. The dominantly sculptural relief, with an accentuated fragmentation (mainly in the middle and upper basin), conditions the dynamics of slope processes through declivity, slope length, energy etc. From a biopedological viewpoint, two aspects are important: the reduced percentage of forested surfaces (20.5%, in comparison to the normal bioclimatic equilibrium conditions, in which forests would occupy 60-70%) and the high percentage of eroded or high erodible soils. The agriculture of the area is characterized by a faulty land use, with an “atomization” of the agricultural exploitations (about 45000 parcels, with an average area of 0.7 ha) and the frequently farming up and down-hill.

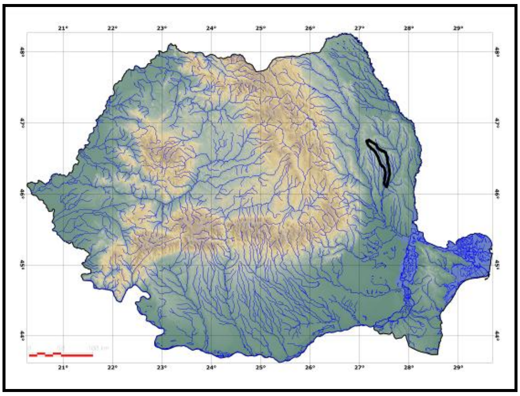

Figure 1. Position of Tutova catchment in Romania

2. Material and methods

The present study approaches the problem of landslides in Tutova catchment, mainly with the help of Geographical Information Systems and remote sensing (using the TNTmips 7.3. software). These data have been accompanied by hydrological and climatic data, so as to establish interactive or causality relationships. For this purpose it was created a GIS that integrates the Digital Elevation Model, geologic and morphometric maps, climatic data, land use information etc. On the basis of topographic maps (1:25000, 1983) and aerial photos (edition 2005, scale 1:5000), in Tutova catchment have been identified 436 active landslides (figure 2). Their total area sums 1775 ha, representing 2.59% of the drainage basin. Morphology of old landslides, currently in morphodynamic equilibrium, can be identified on more extensive areas (≥10%), but this is not of interest in light of current analysis of geomorphological risks.

This study of landslides in the catchment of Tutova River actually took into consideration the analysis of causal factors, in order to determine the susceptibility of slopes to these processes. *This study focuses on the geological factor, morphometry and rainfall.* Each potential factor of imbalance is separated into several classes of susceptibility, usually based on frequency distribution of landslides. The number of classes however varies from one author to another, ranging from three classes of potential or vulnerability (Armas et al., 2003), four classes of susceptibility (Rusu, 2008) or even five classes of susceptibility (Goțiu et al., 2008). Methodological Norms regarding the elaboration and content of the maps of natural risk to landslides, approved by GD no. 447 of 10.04.2003, indicates three classes for potential triggering of landslides (low, medium and high). These ones include six classes of probability, to each one being assign a conventional coefficient (practically zero: 0; low: <0.1; medium: 0.1 to 0.3; medium-high: 0.31 to 0.50; high: 0.51 to 0.80; very high :> 0.80).

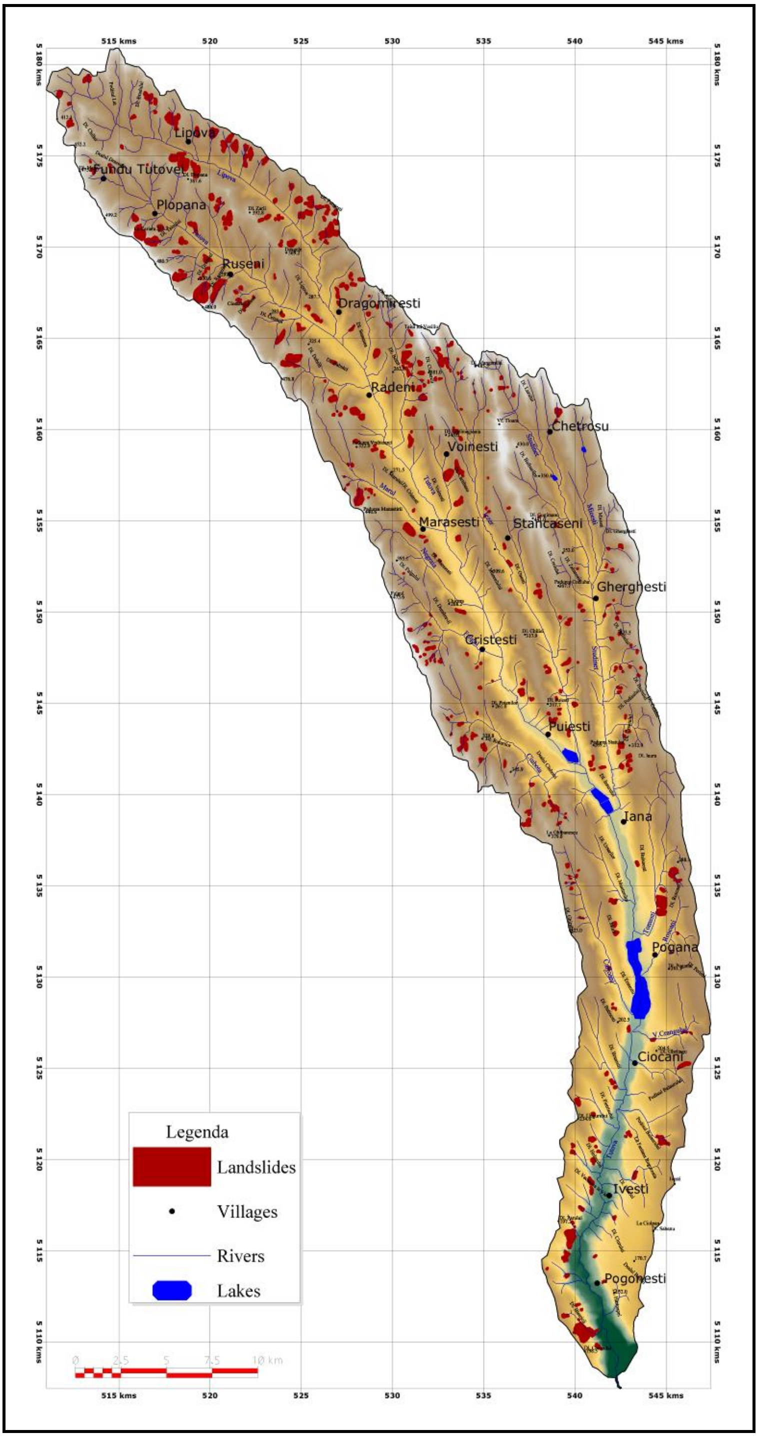

Figure 2. Tutova catchment. Map of active landslides (2005)

3. Results and discussion

Lithology of the region, represented mainly by sandy, sandy-clayey or, more rarely, clayey deposits, is an important factor that has potentiated the rapid development of the present landforms and, nowadays, favors some geomorphological processes (landslides, sheet erosion, gully erosion).

Deposits of Khersonian, represented by clay, sandy clays, clayey sands and sands, with few hard intercalations, occupy almost entirely the upper part of the basin and dominate the middle one, occupying 54.4% of the surface (figure 3), but concentrating 69.7% of sliding bodies and 72.9% of total areas under landslides. This, however, must be put into relation with the specific morphometry (higher altitudes, increased fragmentation etc.).

Meotian deposits, prevalent in the lower basin, are characterized by the presence of a cinerites horizon in base (14.59% of territory) and a clay-sandy horizon at top (19.73%), with some intercalations of sandstones. On this lithological background, there are concentrated 27.29% of landslides, accounting for 24.25% of all sliding lands (figure 4). Yet, Meotian is par excellence an area of gully erosion, which in turn stimulates small delapsive landslides, especially on the banks of gullies.

Deposits of Dacian and Pontian occupy a restraint area in southern catchment (3.71%), being characterized by a predominantly sandy facies, which, with lower values of morphometric parameters, explains the much reduced frequency of landslides (1.43%). Quaternary is not a field of landslides in the analyzed territory (table 1).

Table 1. Statistical indicators of landslides on geologic formations

Indicator \ Stage		Khersonian	Lower Meotian	Upper Meotian	Pontian-Dacian	Quaternary	Total
Total area (ha)		37308,16	10008,66	13537,63	2542,92	5196,32	68593,69
Weight of each stage (%)		54,39	14,59	19,73	3,71	7,58	100
Landslides (hectares)	Total (ha)	1319.16	171,51	259,01	25,41	0	1775,09
	Relative frequency (%)	74,32	9,66	14,59	1,43	0	100
	Absolute frequency (%)	3,54	1,71	1,91	0,07	0	2,59
Landslides (number)	Total (number)	312	58	61	5	0	436
	Mean area (ha)	4,23	2,96	4,25	5,08	0	4,07
	Relative frequency (%)	71,56	13,30	13,99	1,15	0	100
	Absolute frequency (no./km^2)	0,84	0,08	0,45	0,20	0	0,64

Some landslides are developed to the limit between Khersonian and Lower Meotian. In this situation there are some large landslides (with an average area of 8.26 ha), due to sharper slopes as a result of maintaining relatively high altitudes in the presence of the horizon with cinerites of Nuțasca-Ruseni. Almost without exception, these landslides are stabilized, inherited from the Atlantic rainy optimum (Hârjoabă, 1968, Băcăuanu, 1980).

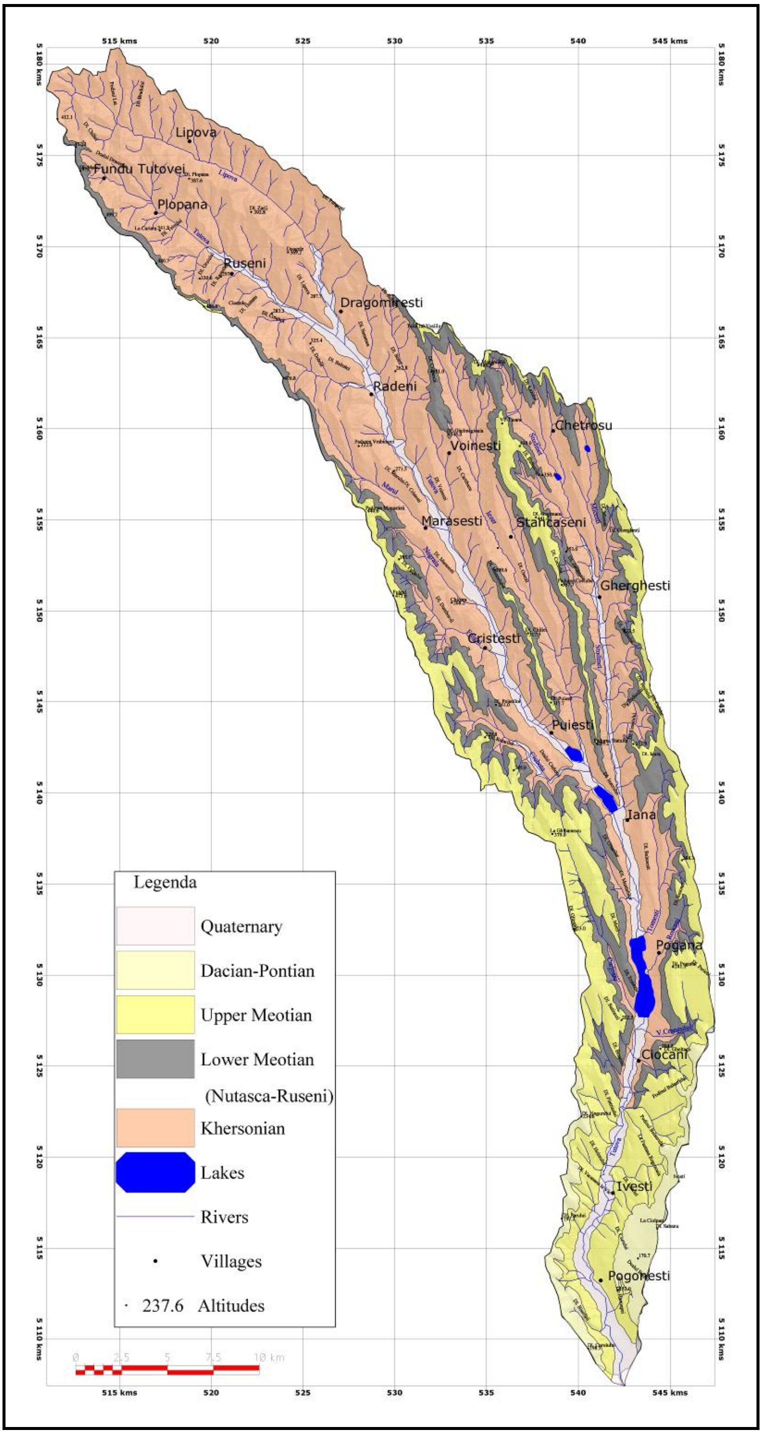

Figure 3. Geological map of Tutova catchment (adapted after Jeanrenaud,1971)

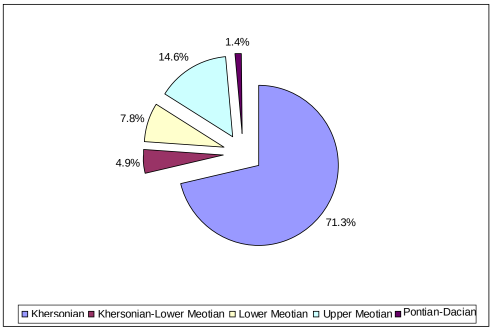

Figure 4. Wieght of landslides on geological deposits in Tutova catchment

Given the specific of lithology and relative or absolute weight of sliding lands on geological deposits (area and number), landslides were grouped into four classes of susceptibility. To each one, an importance factor (IF) was assigned, then equivalent to a risk factor (K), falling in value gap 0-1. The importance factor was obtained as product of absolute frequency of the surfaces, respectively, the number of sliding lands, calculated for each type of deposit (Stângă, 2009):

$$IF = \frac{W_{lsa} \cdot F_{lsn}}{S^2}, \text{ where:}$$

IF – Importance factor;
W_{lsa} – weight of landslides area (%);
F_{lsn} – frequency of landslides/number (%);
S – analyzed area (in this case, the area of each category of geological deposits).

On the basis of IF, a coefficient of susceptibility (K) was calculated according to GT 019-98, which however provides only a few summary benchmarks. According to this standardized technical guide, the value of the coefficient must not exceed the threshold of 0.5 for any deposits in the region.

Table 2. Grouping of geological deposits on classes of susceptibility to landslides

Class number	Class of susceptibility	Geological deposits	Importance factor (IF)	Coefficient of susceptibility (K)
1	Very high	Khersonian	2,974	0,40
2	High	Upper Meotian	0,860	0,25
3	Medium	Lower Meotian	0,137	0,10
4	Low	Pontian-Dacian	0,014	0,05

The relief is an important control factor in triggering landslides, interfering through a large variety of parameters. The altitude is a control factor of landslides, but only indirectly, through other geomorphometric variables (fragmentation, slope etc.) However, the distribution of landslides on altitude steps is quite suggestive (Fig 5). Thus, the highest frequency of landslides is found in the spread of 200-300 m altitude (52.42%), corresponding to most of slopes, while the step of 300-400 m has a weight of only 23.87%, corresponding mostly to interfluvial peaks (except the upper basin). The same situation is found in the spacing of 100-200 m (19.79%), typically assigned to alluvio-colluvial plains, glacis or lower slopes. Completely insignificant frequencies are recorded above 400 m altitude (1.62%) or below 100 m (2.30%).

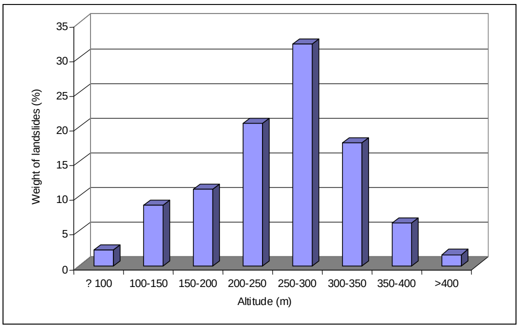

Figure 5. Distribution of landslides on altitude in Tutova catchment

In relation to slopes, landslides are distributed almost entirely in the gap 5 to 25° (98.37%), almost half (47.63%) being on land with slopes of 10-15°, characterized by greater susceptibility to such processes (figure 6). Interpreting the distribution of landslides according to the depth of fragmentation, it appears that the maximum frequency is specific to sectors characterized by values of vertical fragmentation between 80-100 m (32.52%) and 60-80 m (25.86%).

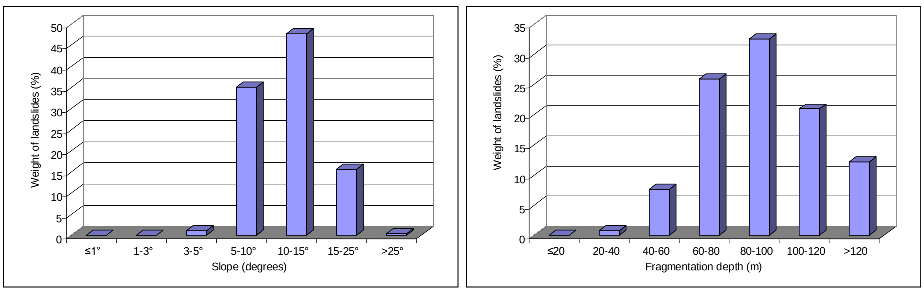

Figure 6. Distribution of landslides on slope and fragmentation classes

Given the general fragmentation of landscape and dominant direction of water courses, associated with asymmetry of the main valleys by developing cuesta relief, it stands the differential distribution of landslides on slope orientation (aspect). Thus, the highest frequency of landslides is recorded on western slopes (29.36%), with typical aspect of cuesta forehead, associated to structural asymmetry of IInd order (Ioniță, 2000). Moreover, the western component (W, NW, SW) has a weight of 44.72%, but lower in the upper basin, as a result of different orientation and development of secondary torrential catchments. To the south, in middle and lower basin, the relative frequency of landslides on western slopes is increasing, which is a characteristic of the entire hilly area (Fig 7).

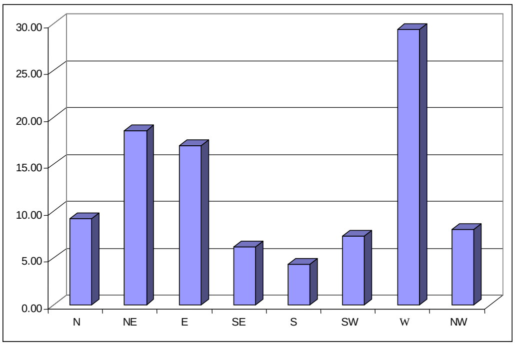

Figure. 7. Distribution of landslides on slope orientation (aspect)

Gully erosion is an active factor in triggering landslides in Tutova catchment, with a very close relationship between the two types of processes. In fact, of 436 landslides, 143 (32.80%) have been directly related to gullies. Of these, 104 landslides (23.85%) developed by undermining the banks (flanks) of gullies and 39 (8.94%) are in the area of sources (gully head).

Moreover, these landslides are most active (83.2%), with very high risk of diluvium mobilization through permanent deepening of gullies. In fact, during 1969-1992, in Tutova catchment were recorded very high rates of denudation by landslides (0.6 to 1.0 $ha/km^2 \cdot yr^{-1}$), just because of coupling of these forces and mechanisms (Pujină, 1997).

Rainfalls play an important role in triggering or reactivation of mass movement processes such as landslides. If for gully erosion, heavy rains are crucial, in this case, lengthy periods of precipitation excess are relevant. Morphodynamic response of the Moldavian Plateau diluvium triggers in case of long-term rainfalls that exceed 50 mm in March, in an excess of moisture and lower water consumption, and 100 mm, in July, due to slightly hydric deficit and a high consumption of water by evapotranspiration (Pujină, 2003). Fastest dynamics of slope processes is found for a sequence of at least two years of excess rains, allowing accumulation of sufficient water in diluvium masses.

The same author (Pujină, 1997) identifies five classes of slope geomorphodynamic activity (A_0-A_4) depending on the rainfall characteristics of warm semester ($Ri_{(IV-IX)}/Rmed_{(IV-IX)}$ - the ratio between rainfall recorded in the warm half/semester of a year and multiannual average rainfall of the same semester). Peculiarities of the classes A_1 and A_2 caused partial reactivation and surface landslides, while high morphodynamic activity (class A_3) determined partial and generalized reactivation but also landslides of mean depth (3-5 m). Very high morphodynamic activity (class A_4) is characterized by profound slides located on old diluvium.

Analyzing climate data from weather stations in the area, it is found that, in accordance with this criterion, most years (83.7%) are characterized by morphodynamic calm (A_0) and only 2.9% of cases recorded high and very high morphodynamic activity (A_3-A_4).

Table 3. Morphodynamic activity according to the rainfalls of warm half of the year (1961-2007)

Class		A_0	A_1	A_2	A_3	A_4
$Ri_{(IV-IX)}/Rmed_{(IV-IX)}$		<1,20	1,20 – 1,40	1,41 – 1,60	1,61 – 1,80	> 1,80
Category		Morphodyn. calmness	Low morphodyn. activity	Medium morphodyn. activity	High morphodyn. activity	Very high morphodyn. activity
Frequency (%)	Bacău	87,2	6,4	6,4	0	0
	Vaslui	87,2	6,4	4,3	2,1	0
	Bârlad	85,1	8,5	4,3	2,1	0
	Onceşti	79,5	12,7	2,6	2,6	2,6
	Plopana	79,5	10,3	5,1	2,6	2,5
	Media	83,7	8,9	4,5	1,9	1,0

Data source: National Meteorological Administration Bucureşti

Major deficiency of this method is that it is not considered the role of cool half of year in creating underground water reserves, otherwise essential in triggering or reactivation of slope processes. Highest frequency of landslides is recorded in at least two consecutive years of excessive precipitations (1964-1966, 1968-1972, 1974-1975, 1978-1980, 1996-1998, 2004-2005), but also in isolated years with rainfall excess recorded in long-term rains (1991). For the period 1969-1992, have been calculated the cumulative landslides, the average annual rate of degradation and the average rate of denudation through landslides (Pujină, 1997).

Table 4. Indicators of denudation through landslides in Tutova catchment (Pujină, 1997)

Parameter	1969-1972	1973-1982	1982-1992
Rainfalls(mm)	679	532	455
Average rate of degradation ($ha/km^2 \cdot yr^{-1}$)	1.18	0.83	0.54
Average rate of denudation ($mm \cdot yr^{-1}$)	32.6	21.1	12.5

4. Landslide risk and conclusions

After this approach, landslide risk was analyzed using buffer method, considering that human structures located at small distances from a landslide are clearly exposed in the situation of reactivation processes. Buffers were applied for distances of 20, 40, 60, 80, 100 m. Since the buffers delimit areas with boundaries equidistant to limit of landslide (in any direction), after automatically creating them, an individual verification and validation was operated. Thus, at least theoretically, we found that human settlements Tutova catchment, landslides are not a major risk, except local landslides, sustained by gullying (Valea Hogei, Stejaru, Lăleşti, Cetăţuia, Tomeşti).

Outside the village, landslides are a risk factor for some important communication routes in the region (e. g. road from Dragomireşti to Vaslui) or, most frequently, for local access ways. Overall, the greatest problems related to landslides are due to degradation of agricultural land. In addition, coupling with gullying processes provides solid material that can be more easily evacuated in torrential flow, contributing to silting of reservoirs and aggradation of floodplains.

Acknowledgements

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