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SOME ASPECTS CONCERNING GULLY EROSION PROCESS IN SMALL TORRENTIAL WATERSHEDS AND ITS IMPACT ON ENVIRONMENT

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Abstract. Romanian agricultural lands are currently affected by a network of about 22,500 km of gullies that are located in about 5,600 torrential watersheds, each year being lost from agricultural lands a surface of more than 2,300 hectares due to gulling. In the studied area soil losses locally reach by about 30-45 tons/ha/year, as against to the natural regenerative capacity of the soil, which is about 5-6 tons/ha/year, only. The paper aims to present the state and risk indicators concerning gully erosion impact on environment in some agricultural torrential watersheds, case-study being carried out on 11 small torrential agricultural watersheds, all of them having developed gullies on the valley's talwegs. These indicators were established for one of the most affected area by water erosion in Romania, namely the hilly region of Sub-Carpathians Curvature, Buzău County, and they can be used for the soil erosion modeling. In the meantime, it is presented the adapted conceptual model DPSIR (Driving Forces-Pressures-State-Impact-Responses) for causes-effects analyze of soil erosion process. Due to lack or very little use of such a conceptual model on soil erosion issues, the DPSIR model is intended to be promoted and used in our country on a larger scale within environmental impact assessment studies concerning soil erosion in torrential watersheds. These systematic analyses allow us to learn from the past and could help us to develop strategies and undertake rapid and most appropriate anti-erosion measures in order to prevent land and soil degradation by water erosion. Based on the values of above mentioned indicators, a general evaluation of the gully erosion impact has been done for the studied area, resulting a moderate to high intensity of gully erosion process as well as a major impact on environment.

Key words: soil erosion, gullies, torrential watersheds, impact, sediments, Sub-Carpathians, DPSIR model.

1. INTRODUCTION

Among different types of soil degradation, soil erosion is being recognized as one of the major natural hazard causing land degradation all over the world. The classical forms of water erosion occur within farm fields and forests are sheet, rill and gully erosion. Soil erosion process, in general, is influenced by a series of factors such as the geomorphological ones - slope length and slope steepness, by the climate factor and soil characteristics, land cover management and also by the erosion control measurements - conservation practice.

As regard to gullies, these are very often developed from intense erosion caused by flow over a steep gully headcut, which moves upstream in a natural drainage way. Once established, gullies remove portions of fields completely from production, decreasing in this way land quality and its value. Also, by a continuing development, gully erosion has a great impact not only in-site, but also off-site, in particular downstream, outside of its watershed. In the meantime, another threat of gully erosion process on environment is related to watercourses pollution with sediments and different pollutants, mainly chemicals coming from agricultural lands located on slopes.

As natural hazards, both soil erosion and landslides affect an important part of the Romanian territory, especially agricultural lands, but also the forestry sector (Moţoc et al., 1975, Ioniţă, 2000, Mircea, 2011, Arghiuş & Arghiuş, 2011). Regarding gully erosion, the most significant gullies in the country are the torrents, mainly developed in torrential watersheds covered by forestry, as well as the ephemeral and permanent gullies, which are presented in several locations, especially in the agricultural torrential watersheds (Moțoc et al., 1975, Ioniță, 2000, Rădoane et al., 1999).

Like it is well known, the gully erosion development on the three main directions - in length, width and depth, has a major impact on environment, either on short or long term, and not only on-site but also off-site (Dârja et al., 2002, Ioniță, 2000, Mircea, 2011, Poesen et al., 1996, 2003, Rădoane et al., 1999, Valentin et al., 2005).

A typical example of the gully headcut and the most wide-spread gullies in the studied region of the Curvature Sub-Carpathians is presented in figure 1, showing a very high rate of evolution in length.

Figure 1. Typical shape of the active gully headcut in the Slănic River Basin (Tătarului sub-catchment)

The continuously development of the gullies causes important damages to the environment, in general, to the agricultural lands in special, as well as to the human settlements, watercourses and various socio-economic units, such as reservoirs or hydropower plants, transportation ways etc. (Dârja et al., 2002, Ioniță, 2000, Mircea, 2011, Moțoc & Mircea, 2005, Poesen et al., 1996, 1998, Rădoane et al., 1999). According to some researchers, gully erosion only contributes by 31% to the total soil erosion in Romania, generating about 36 million tons/year of alluvia. Annual losses of agricultural lands have been estimated to about 2,300 hectares, (Moțoc et al, 1979, Moțoc, 1984, Ioniță et al., 2006). Thus, gully erosion evolution and its control have become in time more and more important, trying in this way to recover the discrepancies that have appeared compared with sheet erosion researches. There can be found in literature some recently works concerning this subject, like setting up of some state or risk indicators of gully erosion as well as development of some prediction models (Grimm et al., 2003, Ichim et al., 1990, Ioniță, 2000, Ioniță et al., 2006, Mircea, 2011, Poesen et al., 1998, 2003, Rădoane et al., 1999, Valentin et al., 2005). Most of the prediction models are deterministic ones and have generally been developed as some regressions (simple and/or multiple correlations), using different independent variables, most of them being mainly pedoclimatic and geomorphological characteristics (Ioniță, 2000, Ioniță et al., 2006, Mircea, 2011, Poesen et al., 1998, 2003, Rădoane et al., 1999, Valentin et al., 2005, Yifan et al., 2011).

It should be mentioned that by the end of year 1989 – actually being the same situation even today in Romania, more or less, within an important national programme for soil erosion control, on about 2,280 million hectares have been performed soil erosion woks, but, unfortunately many of these works are now damaged, mainly as a result of land ploughing from up-hill to the down-hill and the lack or poor maintenance of the anti-erosion works (Moțoc et al., 1992, Mircea, 2011). Also, up today there were controlled about 1,500-1,600 km of gullies, which does practically represent less than 10% from the total potential length and area affected by gully erosion (Moțoc et al., 1992, Ioniță et al., 2006, Mircea, 2011).

The relevance of conservation measures to a farming system partly depends on degree of how farmers and other stakeholders perceive the soil erosion problem and its consequences (Dârja et al., 2002, Mircea, 2011). Unfortunately, most farmers are not enough aware of the erosion problem and its huge effects both on- and especially off-site (Grimm et al., 2003, Gobin & Govers, 2003). A deep analysis concerning causes-impact-responses of the erosion process in many parts of the country that are severe affected by water erosion should be carried out immediately at the national level, based on the experience of the known European conceptual model DPSIR (Driving Forces-Pressures-State-Impacts-Responses), (Grimm et al., 2003, Gobin & Govers, 2003, Porta & Poch, 2011). Concerning to the indicators for soil erosion, the main driving force on soil that causes erosion in several regions with potential and actual soil erosion risks, either all over the world as well as in Romania, is the intensification of agriculture, especially in our country the land restitution process according to the Law no 18/1991.

The DPSIR framework is proposed for converting the vulnerability of land use systems to degradation by water erosion into information that is readily usable by policy makers since it identifies possible responses, and the *on-site* and *off-site* impacts (Grimm et al., 2003, Gobin & Grovers, 2003). In the case of soil erosion, DPSIR model is enforced in order to set up some relevant indicators to justify and take the decisions regarding the necessity of implementation of soil erosion measures as well as their selection. Such indicators for soil erosion have to have the main characteristics: soil loss and its impact both on- and off-site must to be measurable (Wathern, 1990, Grimm et al., 2003).

The consequences of soil erosion and sediment deposition occur both on- and off-site. On-site effects are particularly important on agricultural land where redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the decline in organic matter and nutrients result in a reduction of cultivable soil depth and a decline in a soil fertility. Off-site problems result from sedimentation downstream, which reduces the capacity of rivers and retention ponds, enhances the risk of flooding and muddy floods and shortens the design life of reservoirs (Grimm et al., 2003). Sediment is also a pollutant in its own right and, together with some chemicals carried downstream, can increase the level of nutrients in water bodies, contributing in this way to the eutrophycation process (Grimm et al., 2003, Mircea 2011). Compared with on-site impacts, off-site impacts are more easily measured and can be expressed in economic terms too.

The corresponding pressures are cost-effective but unsustainable land use practices, the use of machinery for the cultivation of enlarged fields, the overgrazing and other instruments of intensive land use practices. Also, land cover change and precipitation can be used for pressure indicators of soil erosion, as they are seen to be directly influencing the degree of soil erosion. As regard to the state indicator, the most appropriate, from a scientific and technical point of view, it seems to be the area affected by erosion under different forms of manifestation and intensities. Concerning the indicators of responses, an important indicator is the expenditure for national/regional/local agri-environmental programmes to enforce sustainable farming management systems, that include all types of erosion control measures, but especially the sustainable agri-environmentally practices, being in close connection to the EU GAECs (Good Agricultural and Environmental Conditions).

2. THE STUDY AREA

The long time research has been carried out in one of the most affected area by water erosion in Romania, as well as by landslides, namely the hilly region of Sub-Carpathians Curvature. It is about the Slănic River watershed, Slănic Valey - belonging to Buzău River Basin has a length of about 65 km and a total surface of about 54,500 hectares, and, is indeed one of the most affected area both by surface and gully erosion as well as landslides in this region, being located in Sub-Carpathians Curvature region, Buzău County, (Fig. 2).

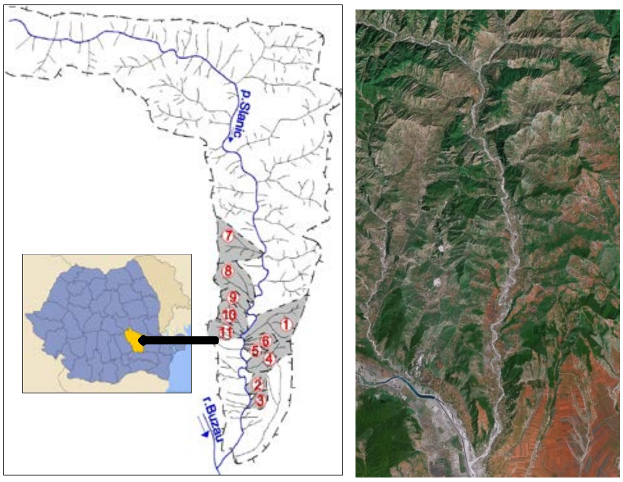

Figure 2. Sketch and aerial photo of the studied area, Slănic-Buzău River Basin, Romania

The region is well known in the literature from erosion point of view because of the high sediments transport in the watercourses, too. In the studied area soil losses locally reach by about 30-45 tons/ha/year, as against to the natural regenerative capacity of the soil, which is about 5-6 tons/ha/year, only (Moțoc et al., 1979, 1992, Moțoc, 1984, Mircea, 2011).

The agricultural lands on the slopes cover about 35% from the total surface of the Buzău County (Moțoc, 1984, Ioniță et al., 2006, Mircea, 2011). Practically, gully erosion represents here about 1,000 km, which actually covers an area of about 1,000 hectares (Mircea, 2011). Actually, it can be said that in this studied hilly region all the torrential valleys are affected in different degrees by gully erosion, gullies being mainly located on the main valley's talwegs (Ioniță et al., 2006, Mircea, 2011).

3. MATERIALS AND METHODS

The research has covered a period of more than 45 years of data recordings, taken both from the available land use and soil erosion maps, i.e. the years 1962 and 1989, at the 1:25,000 scale and 1:5,000 scale, as well as from classical erosion model applying, or, from direct field measurements of the erosion rates, carried out in two different stages, i.e. years 1990 and 2010.

In order to have a general picture of the case-study area of the Curvature Sub-Carpathians, in terms of natural factors contributing to gully erosion, it can be said in brief as follows: from the climatic point of view the area taken into study is characterized by a multi-annual average amount of rainfalls during the vegetation period of about 350-400 mm and the maximum 15-minutes rainfall intensity (I_{15}) of about 1.2-1.5 mm/min (Mircea, 2011). A relationship between the rainfalls intensity and their durations was established for a long period of time for the rainfalls fallen at the Soil Erosion Research Station, Aldeni-Buzău, in the period 1967-2010. As far as pedology is concerned, there are different types of soil in the studied area, but mainly Chernozioms and Pseudorendzines (Faeozioms).

With regard to the land use and vegetation from the studied sub-catchments, there are mainly agricultural lands, covered by arable crops, grasslands, vineyards and orchards - cultivated in general on terraces. The forests are presented especially along the gully riverbanks or, on the steepness and degraded slopes, contributing in this way to their better stabilization.

To determine soil erosion in the field, as a result of singular rainfall, it have been used the runoff plots having the following characteristics: an area of 40 sqm (10x4 m) and the slope of 15% - at the bottom side, respectively, an area of 100 sqm (25x4 m) and the slope of 20% - in the upper side, being every year covered by different crops (Fig. 3).

Figure 3. General view of the Research Station for Soil Erosion - Aldeni, Slănic-Buzău River Basin

In the meantime, soil loss has been estimated by using a Romanian soil erosion model, a model developed as being based on the research results obtained over a period of 15 years in different locations in Romania, amomg them being the Soil Erosion Research Station - Aldeni/Buzău, too. The deterministic model is actually based on the well known Wischmeier's model USLE (Universal Soil Loss Equation), (Wischmeier & Smith, 1978, Renard et al., 1997, Bilașco et al., 2009, Arghiuș & Arghiuș, 2011, Ștefănescu et al., 2011) being adapted by Moțoc et al., in 1979 for the characteristic conditions from Romania, and it is known as ROMSEM (ROManian Soil Erosion Model), (Moțoc & Mircea, 2002, 2005).

The ROMSEM model structure is as follows:

$$E_s = K_a \cdot L^m \cdot i^n \cdot S \cdot C \cdot C_s$$

where $\mathbf{E_s}$ is the mean annual soil loss, in t/ha/year;

$\boldsymbol{K_a}$ is rainfall agressivity correction factor, having the values of 0.08÷0.16 (regionalized in the country), which represents the ratio between soil loss on the standard runoff plots, having an area of 100 m^2 (25×4 m), slope of 15% and maintained as bare soil - and I_p index (this I_p index represents the product by the total amount of precipitation (H - in mm) times the maximum I_{15} intensity (I_{15} - in mm/min) for a given rainfall;

$\boldsymbol{L^m}$ - the slope length factor with L in meters; exponent m = 0.3;

$\boldsymbol{i^n}$ - the slope steepness factor, with i in %; exponent n = 1.42;

S - the soil erodability factor, [0.6÷1.2];

C - the crop management factor, [0.001÷1.0]

$\boldsymbol{C_s}$ - the practice factor, (0÷1].

Based on the field measurements that were conducted on the runoff plots, regarding both - the liquid and solid runoff, carried out in the period 1992-2010, the role of the vegetation and crop factor from the USLE model were then checked. Also, some correlations were established between soil loss on different slopes and vegetation cover, under similar pedoclimatic conditions. It can be said that there is a good correlation between soil loss obtained by using the two above mentioned methods (soil loss measured from the runoff plots, versus using ROMSEM model, applied at a larger scale), but, sometimes, there is an underestimation of soil loss obtained by using prediction model as compared to soil loss obtained by direct field measurements (Moțoc & Mircea, 2002, Mircea, 2011). The justified underestimation of soil loss comes mainly from the great variability of the factors contributing to soil erosion, both natural and antropogenetic ones, as well as from the accuracy of their estimation.

3.1. State indicators for gully erosion evolution

The issue of seting up of such an indicators presents a relevance related to the risk assessment of producing floods in the torrential watersheds, as well as producing damages in the localities, reservoirs and transport infrastructure network. Continuously development of the gullies on the three directions – in lenght, wide and depth, has effects, both on-site and off-site, on short and long term. These effects can be roughly estimated using a series of state and risk indicators concerning the vulnerability of the watersheds to the gully erosion, as they are presented below.

a) Status of affectability of hydrographical network, (%):

- it determines as the ratio $\frac{l}{L} \cdot 100$, (%)

where:

l is the length of the hydrographical network having a permanent or ephemeral flow and presents an active erosion of the riverbed and gully banks, in km;

L - is the total length of the hydrographical network from the same categorie, in km.

b) Status of fragmentation of watershed, (km/km^2)

- it determines as the ratio *L'/S* , (km/km^2);

where:

L' is the length of the main gully as well as of its entire network, in km;

S - total surface of the watershed taken into account, in km^2.

3.2. Risk indicators for gully erosion evolution

Generally speaking, a natural risk (climate, geological etc.) is about the probability to occur a certain natural event that produces damages to the people or affects their activities. Apart the state indicators, the risk indicators category are a very important and complex one for gully erosion development (Grimm et al., 2003). In the literature on soil erosion and landslides there is frequently used the notion of risk rather than hazard (Gobin & Govers, 2003). There are used for gully erosion the following indicators, (Moțoc et al., 1992).

- *gullies advance in length, (m/year);*
- *gullies development in width, (ha/year);*
- *gullies development in volume, (m^3/year).*

In Romania it has been proposed a series of risk indicators concerning gully erosion (Moțoc et al., 1992, Ioniță, 2000, Mircea, 2011), which were checked out in the field, as follows:

a) *Rate of fragmentation of gullies' watersheds and destruction of some social-economic objectives located upstream of gully headcut, such as: civil constructions, transportation ways, water or gas/petrol pipelines, etc., in m/year/ha:*

- it is represented by the ratio between the annual rate of gully headcut advance, in m/year, and the gully headcut's watershed, in ha;

b) *Risk of gully development in width,* in ha/year:

- it does refer to the yearly rate of land lost due to the development of the gullies;

c) *Risk by inundation and/or siltation of the lands or social-economic objectives downstream,* in Euro:

- it does refer to the annual damages, financially evaluated, that are produced downstream of gullies on lands or some social-economic objectives.

A case study has been analyzed in this regard for a number of 11 small torrential watersheds from Slănic/Buzău River Basin (Mircea, 2011), Within the study area all sub-catchments are affected by gully erosion, having the main morphological characteristics as presented in the table 1.

4. RESULTS AND DISCUSSIONS

By analyzing a number of 11 small torrential agricultural sub-watersheds from Slănic/Buzău River Basin (Mircea, 2011) in terms of gully erosion impact on environment, a set of state and risk indicators concerning the vulnerability of the watersheds to the gulling has been established at the level of the year 1989, as they are presented in table 2.

Table 1. Some morphological characteristics of the studied sub-watersheds in Slănic River Basin

No crt.	Sub-catchment/ Gully	Total gully watershed *(ha)*	Gully headcut watershed *(ha)*	Gully length *(m)*	Gully headcut depth *(m)*	Average slope of thalwegs *(%)*
0	1	2	3	4	5	7
1	Băiasca	377.50	4.50	2748	2,35	9.1
2	Oarzei	90.00	20.25	1372	1,50	8.3
3	Irimești	86.25	2.56	1702	1,00	4.6
4	Căldărești	198.73	9.37	2950	2,45	8.0
5	Vladului	98.73	23.45	1375	2,90	9.8
6	Pluteșului	120.50	23.25	1552	3,10	8.6
7	Gălbeaza	101.70	7.54	1674	0,90	11.7
8	Balaurul	288.12	14.06	3786	1,30	5.4
9	Mereului	86.25	35.00	1423	1,70	8.7
10	Tătarului	51.25	15.75	900	3,30	11.4
11	Funduri	92.85	28.85	892	1,20	10.5

Table 2. State and risk indicators set up for some sub-watersheds from Slănic River Basin

No crt.	Watershed/ Gully	Indicators		
		Status of hydrographical network affectability I_1 (%)	Status of watershed fragmentation I_2 (km/km^2)	Rate of fragmentation and damage of watershed I_3 (m/year/ha)
1	Băiasca	60.2	1.32	1.70
2	Oarzei	64.3	1.52	0.21
3	Irimești	68.4	1.97	2.61
4	Căldărești	73.5	2.03	0,26
5	Vladului	62.6	2.91	0.09
6	Pluteșului	64.3	2.28	0.10
7	Gălbeaza	55.8	1.96	0.81
8	Balaurului	48.7	1.35	0.41
9	Mereului	43.6	1.65	0.06
10	Tătarului	52.8	1.76	0.13
11	Funduri	56.4	0.97	0.06

Based on the values of these indicators a general evaluation of the impact of gully erosion can be done for the studied area according to EEA methodology (Grimm et al., 2003). Data from the table 2 show a moderate to high rate of hydrological network affectability by gully erosion.

Function of the values of these state and risk indicators, established for some sub-watersheds from a given area, it can be achieved a general appreciation of the gully erosion impact on environment, by using the indexation method. To do that, there is prior necesarely a qualitative clasification of the studied watersheds into 4 groups, function of the maximum and minimum values of the state and risk indicators, as it is presented in table 3.

Table 3. Watersheds' classification function of state and risk indicators

No crt.	Indicators, on groups			Impact Assessment on environment	Mark
	Status of hydrographical network affectability I_1 (%)	Status of watershed fragmentation I_2 (km/km^2)	Rate of fragmentation and damage of watershed I_3 (m/year/ha)		
1	0 – 25	0 – 1	0 – 1	Slight	0 – 25
2	25 – 50	1 – 2	1 – 2	Moderate	25 – 50
3	50 – 75	2 – 3	2 – 3	Strong	50 – 75
4	75 – 100	> 3	> 3	Very strong	75 – 100

Table 4. Gully erosion impact assessment for the studied sub-watersheds from Slănic/Buzău River Basin

No	Sub - watershed /Gully	Indicators			General mark	Impact on environment
		Status of hydrographical network affectability I_1 (%)	Status of watershed fragmentation I_2 (km/km^2)	Rate of fragmentation and damage of watershed. I_3 (m/an.ha)	(as a weighted average) $40\%I_1+40\%I_2+20\%I_3$	
1	Băiasca	60.2	33.0	42.5	458	Moderate
2	Oarzei	64.3	38.0	5.2	42.0	Moderate
3	Irimești	68.4	49.2	65.2	60.0	Strong
4	Căldărești	73.5	50.7	6.5	50.9	Strong
5	Vladului	62.6	72.7	2.2	54.5	Strong
6	Pluteșului	64.3	57.0	2.5	49.0	Moderate
7	Gălbeaza	55.8	49.0	20.2	45.9	Moderate
8	Balaurul	48.7	33.7	10.2	35.0	Moderate
9	Mereului	43.6	41.2	1.5	34.2	Moderate
10	Tătarului	52.8	44.0	3.2	39.4	Moderate
11	Funduri	56.4	24.2	1.5	32.5	Moderate

Afterwards, the evaluation matrice is build up, using the established indicators and the marks given to the each watershed, as proportion. In the end, a general mark of gully erosion impact assesment is given, in accordance with the current worldwide methodologies of environment impact assessment, based on the indexation method of the established indicators, as a weighted average, as follows: General mark = $40\%I_1+40\%I_2+20\%I_3$ (Table 4).

Based on the values of above mentioned indicators, a general evaluation of the gully erosion impact has been done for the studied area, for the 11 small torrential agricultural watersheds, resulting a moderate to high intensity of gully erosion process as well as a major impact on environment.

As a result of gully erosion impact assessment carried out, obviously, there is a real need for antierosional works in the region, especially – as a first urgency, on the gullies that have a strong impact on environment. Unfortunately, generally speaking, the current situation in the field is not so good in terms of new investments or maintenance of the already existing antierosion works, so that many such of antierosion works are either partially destroyed or totally abandoned.

5. CONCLUSIONS

The consequences of soil erosion – both sheet and gully erosion, as well as sediment deposition occurs both on- and off-site. The continuously development of the gullies causes important damages to the environment, in general, to the agricultural lands in special, as well as to the human settlements, watercourses and various socio-economic units, such as reservoirs or hydropower plants, transportation ways etc. The paper highlights the significance of considering the necessity for a very deep analysis concerning state and risk factor of gully erosion, as well as the causes-effects-responses analyze by using modern conceptual models, like DPSIR model, addressing then to the scientists and mainly to the decision-makers to be able to develop strategies and undertake rapid and most appropriate anti-erosion measures in order to prevent land and soil degradation by water erosion, both for the new works or for the rehabilitation of the already existing works. A such impact assesment for the Slănic/Buzău watersheds that are strongly affected by gully erosion, having a predominant agricultural land cover, shows a moderate to strong impact of the gullying on environment. As an immediate consequence of a such negative impact, there is a real need for rehabilating or new investments on antierosion works in the region.

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