Quantitative estimation of soil surface erosion in a mountain catchment (Gemenea, Eastern Carpathians)

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ABSTRACT: This study aims to estimate soil removal via sheet erosion in a mountain catchment and highlight the stabilizing role of vegetation on sloping land. Spatial representation of the results was performed through the implementation of GIS techniques. The estimation method used is ROMSEM, which is based on six factors that can be separated into two groups, i.e. i) factors that trigger erosion (rainfall erosivity, topography, soils) and ii) factors controlling erosion (vegetation, anti- erosion measures). These factors constitute the database which generated the maps of potential and effective soil erosion. Based on our results, mean potential erosion is very high, 99.64 t ha^{-1} yr^{-1} respectively, and thereby falls into the severe erosion class. Mean effective erosion indicates current soil loss and falls within the insignificant erosion class, with 0.98 t ha^{-1} yr^{-1}, which suggests that at the catchment scale, soil is eroded at a rate of 7620 t yr^{-1}

KEY WORDS: ROMSEM, GIS, soil erosion, mountain catchment, Eastern Carpathians

1. Introduction

Sheet erosion of land, to which gully and rill erosion are added, provides the highest sediment supply to drainage networks, of which arable land produces 80% of the total soil loss in Romania (Dumitriu et. al. 2016). In mountain and high plateau areas, soil loss through sheet erosion is rather low, as recent estimates show a contribution of 20-30% of the total soil loss (Dumitriu, 2007).

In Suceava County, soil erosion occurs on approximately 11.45% of the county area, and mainly results from massive deforestation, improper use of meadows and agricultural land (National Agency of Land Reclamation (A.N.I.F., Suceava). In 2010, 2299.6 thousand cubic meters of wood were harvested from the Suceava County forests. Historically, this was the highest amount of harvested wood, equivalent to the summed production of 20 counties. A comparative analysis of wood harvesting from 2000 and 2010 shows that in Suceava County it increased by 46%, thus making Suceava the only county in Romania that has exceeded the 2,000 thousand cubic meters threshold (Econtext, 2011). Located in the south part of Suceava County, in the mountainous area

at the foothills of the Rarău Massif, the Gemenea catchment has an overall afforestation coefficient of 75%. Nevertheless, this has not prevented the catchment from being affected by Law no. 1/2000 for restoring ownership rights on farmland and forest. Clear cutting affects small areas, but the consistency of forests has been much diminished over the last 10 years; floods occurred in 2006, 2008 (a historical maximum discharge of 68,9 m^3/s) and 2016 (37.9 m^3/s) are an indicator of reduced precipitation storage in the forest canopy.

In this context, and given the recent changes in vegetation cover, we focused on assessing land degradation and soil loss in this small catchment, located in the mountainous area of Suceava County. The assessment method was indirect, by applying a deterministic model for calculating soil loss, which was later on verified with measurement data on the transfer of sediment eroded in the control sections of the studied catchment.

2. Study area

Gemenea catchment is positioned in the north-eastern part of Romania, in the Eastern Carpathians, Stânişoara Mountains subunit (Figure 1). Together with its main tributary Slatioara, the Gemenea River drains an area of 77.7 km², which places it into the category of small catchments (Rădoane, 2002). Gemenea catchment covers 21% of the Suha Bucovineană catchment area and 3.9% of the Stânişoara Mountains total area respectively. Based on its hydrological characteristics and position relative to the Carpathian Mountain range, the Gemenea catchment is included in the eastern Romanian river network group and is part of the Siret River hydrological system (Diaconu, 1971).

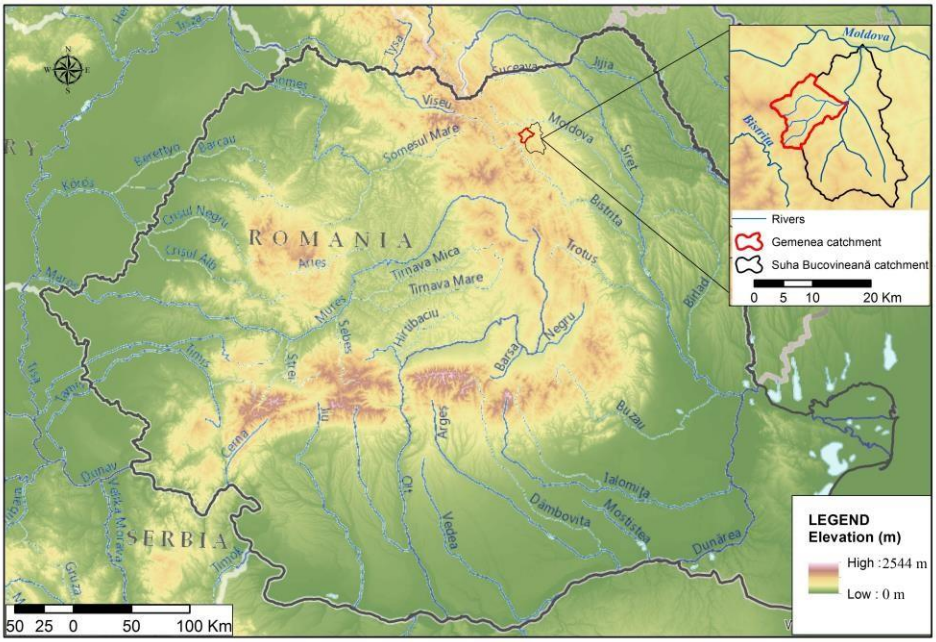

Figure 1 Position of the studied catchment.

From the morphogenetic perspective, Gemenea and Slătioara valleys are longitudinal, tectonic contact valleys, with a net dominance of confluences from the direction of the nappes. Moreover, the upper part of these valleys, together with Brăteasa, Cotârgaşi and Bistrita valleys, constitute the western boundary of Stânişoara Mountains (Ichim, 1979).

Lithologically, the western part of the catchment corresponds to the eastern extremity of the Rarău marginal syncline and the crystalline-Mesozoic area, whereas the eastern part belongs to the Carpathian flysch belt, Ceahlău, Teleajen and Audia nappes respectively. These two lithologies are distinctive through higher altitudes and slope gradients in the western half of the catchment and gentler landforms in the eastern half.

From the morphometric point of view, the catchment extends between 1628 m a.s.l. (Colţii Rarăului) and 580 m a.s.l. (confluence with Suha Bucovineană), with an average elevation of 1104 m (Table 1). The geomorphology of the Gemenea catchment is characterized by the presence of the Slătioara - Gemenea valley system, by selective erosion forms and river terraces.

Table 1 Data on the Gemenea river catchment.

Perimeter, P, km	44,80
Area, A, km^2	77,76
Maximum elevation, Hmax, m	1628
Minimum elevation, Hmin, m	580
Average elevation, Hmed, m	1104
Maximum energy, Emax, m	1048
Average slope gradient, Ib, %	33
Circularity($C = P/(2\pi\sqrt{A})$)	1,43
Afforestation, Af, %	75

The soils present in the study area are categorized as follows: Cambisol 78%, Cernisol 11%, Protisol 4%, Spodisol 3%, Luvisol 3%, Hidrisol 1% (according to the soil maps provided by the Office of Pedological and Agrochemical Studies (O.S.P.A. thereafter) Suceava and Forest Division (O.S.) Stulpicani. From the soil description sheets, it can be noted that most soils are developed on silty textures (silt loam, silty clay loam, loam) as a result of parent material derived from the geological structure, namely sandstone-shale flysch, which induces a silty texture in most soil profiles (O.S.P.A. Suceava).

Our study catchment has a moderate temperate continental climate, with mountain particularities. Mean annual temperatures are around 6.9°C and mean annual precipitation ranges from 778.0 l/m^2 at the Gemenea 2 hydrometric station to 813.7 l/m^2 at Gemenea 5 (Livarciuc. et. al. 2015).

3. Methodology

For estimating soil removal by sheet erosion, ROMSEM (Romanian Soil Erosion Model) is the most used method in Romania. This method is derived from the USLE equation (Universal Soil Loss Equation, Wischmeier and Smith, 1978). It was adapted by Moţoc et al. (1975, 1979) to the particularities of Romanian territory and resulted from processing experimental data provided by several national research stations: Perieni - Vaslui County, Aldeni - Buzau County, Bâlceşti - Arges County, Valea Călugărească - Prahova County and Câmpia Turzii – Cluj County (Patriche, 2016).

Later on, the method was adopted by National Research and Development Institute for Soil Science, Agrochemistry and Environmental Protection (ICPA) Bucharest (1987) and applied by other researchers for different regions of the country: the Tutovei hills (Biali and Popovici, 2003), the Codrului Ridge and Piedmont (Arghius and Arghius, 2011); the Someşean Plateau (Bilaşco et al, 2009); the Larga catchment - Tigheci Hills (Popuşoi and Patriche, 2015); the Măhăceni Tableland (Onac, 2009) e.t.c.

Estimating soil erosion is based on the following formula (Moţoc and Sevastel, 2002):

$$E= K \times L^{m} \times I^{n} \times S \times C \times Cs$$

Where:

E - mean soil erosion rate (t ha-1 yr-1); K : rainfall erosivity factor;
Lm - slope length factor, m=0,3;
In - slope angle factor, n=1,5 (%); S : soil erodibility factor;
C - correction coefficient by categories of land use;
Cs - correction coefficient for the effect of soil conservation practices.

With few exceptions (Arghius and Arghius, 2011), the ROMSEM calculation algorithm has been successfully applied particularly for arable land on relatively small areas, also using mainly large-scale cartographic materials (1: 10,000). In this study we attempt to adapt this method to mountainous terrain with steep slopes, sparse soils and vegetation predominantly consisting of forest cover. The adaptation implies a correction of the factor C from the formula above. For this purpose, we used measurements on sheet erosion obtained for parcels located in climatic, drainage conditions and soil types similar to those in the studied catchment (Arghiriade et al., 1977; Gaşpar et al., 1982; Rădoane, 2002). To this we added detailed geomorphological mapping of sheet erosion on categories of slope gradients, land use and slope surfaces.

In Figure 2 we schematically present the working steps followed to obtain the map of soil sheet erosion in the studied catchment. Firstly, a database was needed, composed of the digital elevation model (DEM), in this case with the spatial resolution of 10 m. Secondly, soil map, land use map were filled with the appropriate values for each factor. The vector database was then converted into raster / grid in order to be combined using the Raster Calculator function implemented in the ArcGIS 9.2 software by ESRI (2014).

Thus, the first step was to create a database in grid / raster format for each factor in the ROMSEM formula:

- Rainfall erosivity (K) - is the average annual soil loss per unit rainfall aggressiveness index, under standard conditions of soil, topography and land-use and it enters as a single coefficient in the formula used for calculating average annual soil loss caused by sheet erosion.

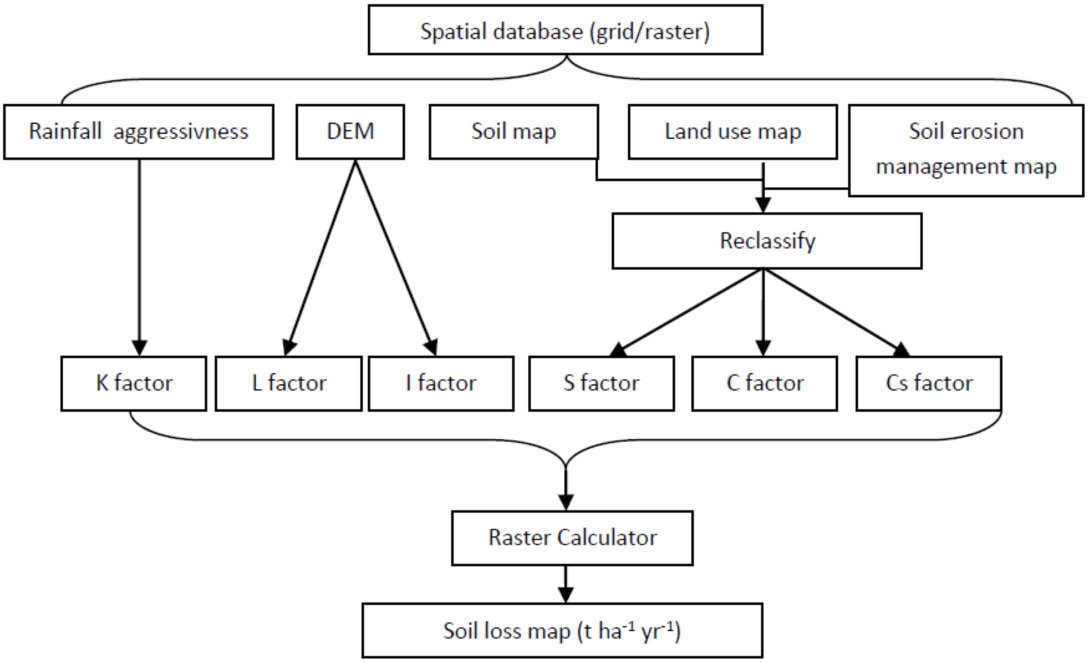

Figure 2 The flow chart showing the methodology for quantification of surface erosion using GIS techniques (adapted from Arghiuș and Arghiuș, 2011).

- **Slope length (L^m, m = 0.3)** - By slope length we refer to "the distance from the flow origin to the point where slope gradients decrease enough to allow accumulation or flow is concentrated in a confined channel" (Wischmeier and Smith, 1978). For the present study, the slope length factor was calculated based on the 10 meters resolution DEM, using the SAGA GIS software (Conrad et al., 2015). Then, using the Raster Calculator function in ArcGIS 10.2.2., the slope length factor was raised to the power of 0.3 (Moţoc 1975, 1979).
- **Slope angle (I^n, n = 1.5)** - was calculated as percentages based on the 10 m resolution DEM. The resulting raster was raised to the power 1.5 (Moţoc 1975, 1979).
- **Soil erodibility (S)** - a measure of the susceptibility of soil to erosion and depends mainly on the textural characteristics of soil, but also on other factors such as its structure, water permeability, organic matter content. Soil erodibility in the Gemenea catchment was determined in accordance with the Methodology for the preparation of soil studies (National Research and Development Institute for Soil Science, Agrochemistry and Environmental Protection (ICPA), 1987b). To spatially represent soil erodibility, we used maps produced by OSPA Suceava, at a scale of 1: 10,000 and the forestry map of soil types, scale 1: 20000 (OS Stulpicani). In Romania, soil erodibility is generally assessed in six classes, i.e. from Class 0 (not applicable) to Class 1.1 (extremely high erodibility).
- **C factor** (correction coefficient by categories of land use) - quantifies the influence of cultivated or spontaneous vegetation on soil erosion. The C factor at the country level comprises values between 0.001, characteristic of land covered with forest and litter and 1.60 for non-vegetated land (Moţoc et. al. 2010). Land use for our study area was extracted from CORINE Land Cover inventory (CLC, 2000) and updated based on the 2012 orthophotoimage.

- **Cs factor** – refers to the correction coefficient for the effect of soil conservation practices. The value of this coefficient varies depending on the type of practices.

4. Results and discussion

4.1. Analysis of the control factors in the ROMSEM model

K factor (Rainfall erosivity). In Romania, this coefficient varies between a minimum of 0.067 for the Western Plain and 0.207 for the Southern Carpathians and partly for Getic and Curvature Subcarpathians. These values include nine classes grouped into three erosivity categories: low, medium and high. In the Gemenea catchment, rainfall erosivity has an average value of 0.167, thereby falling into the high erosivity class.

Slope length (L^m, m = 0.3). Spatial distribution of slope length factor is inversely related to altitude (Figure 3a). Thus, 63% of the catchment area is characterized by values of the slope length included in the classes <50 m and 50 m - 100 m, particularly at high altitudes. From the viewpoint of area covered, the second most important class, with a 27% share, includes values of the L factor ranging between 100 and 200 m, specific of medium altitudes. The slope length values with the most reduced spatial coverage (only 10%) fall in the classes 200m - 300m and > 300m and extend along the principal and secondary valleys, river terraces and built and arable areas.

Slope angle (I^n, n = 1.5). Averaged for the entire catchment, slope angle equals 18.45^o (33%). However, land inclination varies depending on lithology, therefore values of this morphometric parameter decrease from the west - crystalline schists - towards the east, where flysch rocks are more susceptible to erosion. The largest extension, 68% of the catchment, characterizes slopes with gradients from 7^o to 25^o. These interpose between moderately sloping areas pertaining to the interval 1^0 -7^0, which cover 8% of the catchment. The moderately sloping areas are found especially along main and secondary valleys where river terraces occur, and between areas with very high slope gradients > 25^o, largely overlapping the hard rocks of the crystalline-Mesozoic area and the steep frontal slope of the overthrust nappes (24% of the catchment) (Figure 3b).

Soil erodibility (S). Generally, erodibility values grow from large (sandy) to fine (clayey) textures, being maximum in loamy textures (Figure 3d). In the studied catchment, the S factor values are unevenly distributed and correspond to erodibility classes ranging from 0 (not applicable) to 0.9 (strong erodibility). 34% of the catchment is characterized by S factor values of 0.8, i.e. for this area soil erodibility is moderate. This coefficient is higher at medium and high altitudes, and thus dominates the catchment upstream of the Gemenea valley, where soils belong to the Prepodzol type and are covered with forest vegetation.

The second most widespread value of the S factor is 0.6 and characterizes 27% of the catchment. It indicates areas with very low erodibility, located in the eastern part of the catchment, which are forested and have soils of the Cambisol -type.

Areas included in the low erodibility class have a coefficient equal to 0.7 and extend over 19% of the territory, mostly over meadows and pastures.

The 0 coefficient of the S factor indicates lands affected by accumulation processes, amounting to 5% of the total catchment area, spatially distributed particularly in the floodplains of Gemenea and Slătioara valleys where Aluvisol-type soils are prevalent. The 0.9 coefficient of the S factor characterizes over 15% of the catchment, sporadically along river terraces on the Gemenea valley and more frequent in the upstream part of the Slătioara valley, where the Renzine-type soils are widely spread because of the limestone lithology.

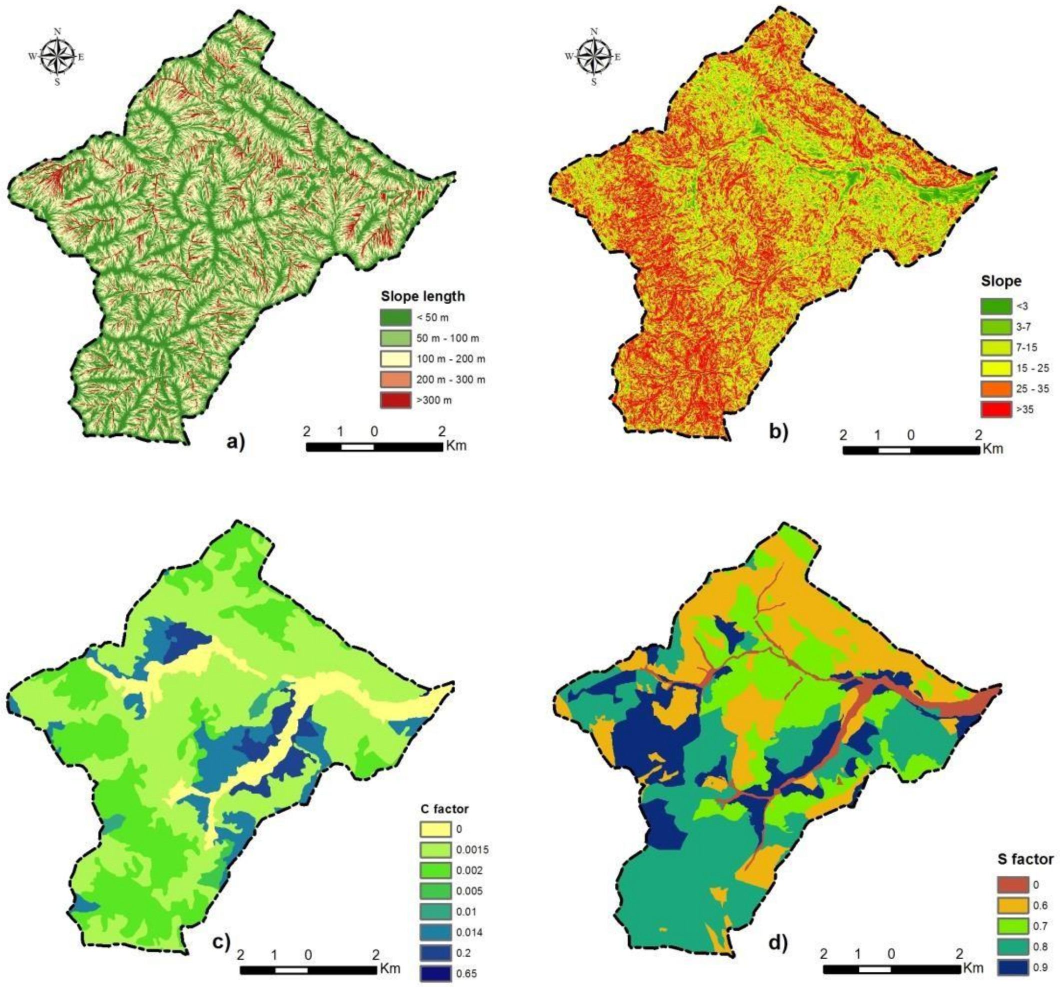

Figure 3 Factors controlling soil erosion: a) slope length, b) slope angle, c) crop and crop management factor, d) soil erodibility factor. This figure is available in colour online at www.georeview.ro.

C factor (correction coefficient by categories of land-use) - Specific to mountainous land, where large areas are covered by forests and grasses, the C factor has low values ranging from 0.001 to 0.65 in the Gemenea catchment. This is because here forests cover 75% of the total area, of which 49% coniferous and 26% mixed forests, and largely dominate steep slopes.

The C factor for these two categories of land use, i.e. mixed and conifer forest, adapted to the Gemenea catchment, is 0.0015 for mixed forests characterized by a thick layer of litter offering better protection for soils, and 0,002 for coniferous forests which, given the absence of litter, are more exposed to sheet erosion. Meadows and pastures are the second most widespread land use category and are generally interposed between the built and cultivated land and forests, also sporadically present at higher altitudes. They extend over 10% of the territory and are characterised by a C factor value equal to 0.014. The 0 value of the C factor overlaps the areas represented by rivers and the built space together with arable land (11%), whereas the highest C factor, 0.65, corresponds to agricultural areas mixed with natural vegetation (4% of the territory) (Figure 3c).

The Cs factor - In the Gemenea catchment there are no land improvement works or measures aimed to control soil erosion, thus this factor equals 1.

4.2. Potential soil erosion

Firstly, potential soil erosion was estimated (Figure. 4), which is defined as the amount of soil loss, in case our catchment was not covered by vegetation. To estimate potential erosion, only the C factor (the correction coefficient for land cover) was excluded from the ROMSEM formula, while retaining the other factors. We thus obtained very high values for potential erosion, i.e. > 31 t ha^{-1} yr^{-1} for 82% of the catchment area, which overlap the areas with the highest slope gradients.

The remaining 18% are split between the other classes of erosion (8% high erosion, 5% absent /non appreciable erosion, 3% moderate erosion, 2% low erosion) that correspond to gentler slopes, where anthropogenic pressure is also higher. Under such circumstances, mean potential erosion is very high, 99.64 t ha^{-1} yr-1 respectively, which suggests that 774800 t yr^{-1} could potentially be eroded from the catchment area.

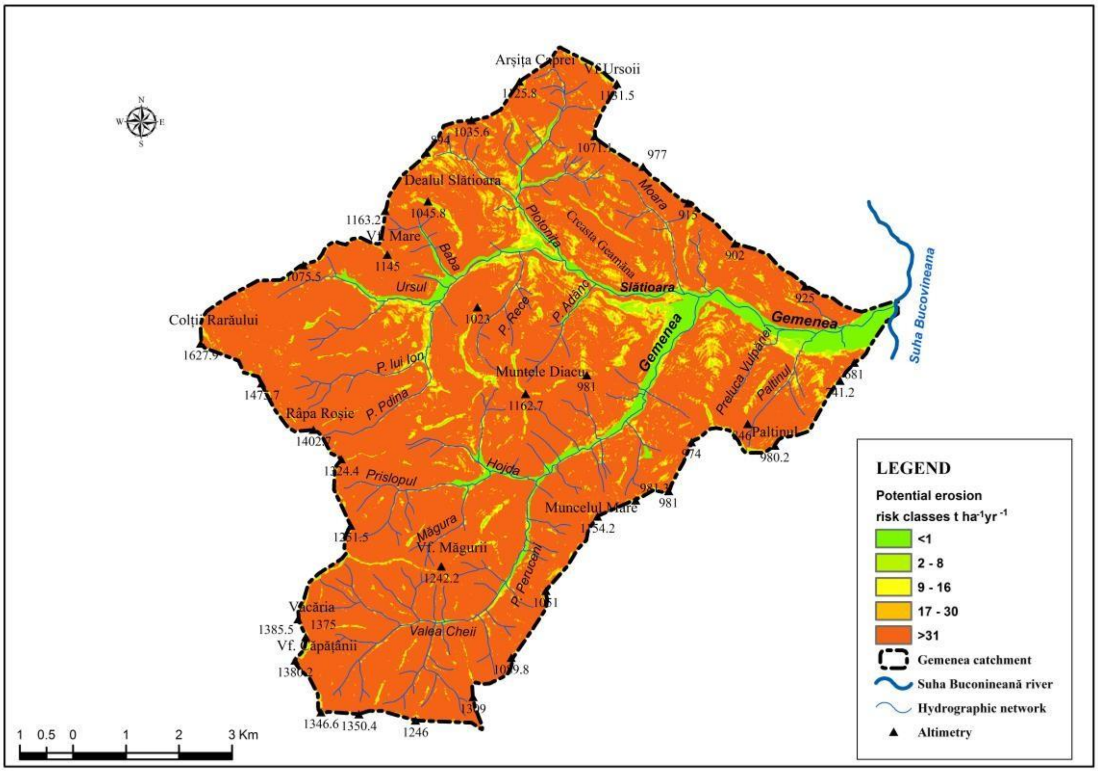

Figure 4 The potential erosion map. This figure is available in colour online at www.georeview.ro.

4.3. Effective soil erosion

The effective soil erosion map (Figure 5) is the second map obtained by applying the ROMSEM equation, and estimates soil loss under current land use. Thus, by introducing the C factor into the equation, soil loss is much diminished, the severe erosion class reduces its extent, whereas the absent /non appreciable erosion class dominates a large part of the catchment.

If in the case of potential erosion, the severe erosion class was the most extensive, affecting 82% of the catchment area, in the case of effective erosion we have a contrasting situation, i.e. 90% of the catchment characterized by the absent / non appreciable erosion (Figure 6, Table 2).

The low erosion class (2-8 t ha^{-1} yr^{-1}) is the second most important in what concerns spatial extent, and generally corresponds to slopes covered by meadows.

The very low erosion values (<1 t ha^{-1} yr^{-1}) largely overlap the areas with steep slopes, covered with forest vegetation that provides good protection for the soil, substantially reducing runoff and sheet erosion.

Classes including moderate, high and very high erosion (9-16 t ha^{-1} yr^{-1}; 17-30 t ha^{-1} yr^{-1}; > 30 t ha-1 yr^{-1} respectively) have a very low extension, each with one percent of the catchment area.

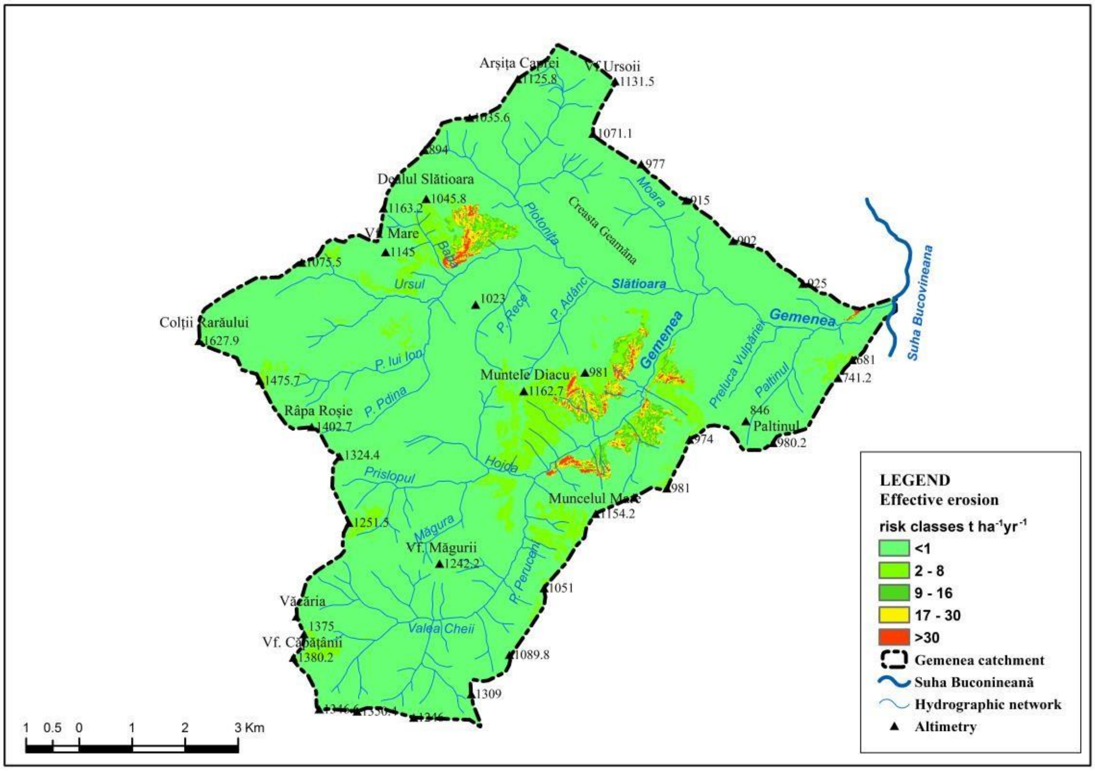

Figure 5 The effective erosion map. This figure is available in colour online at www.georeview.ro.

These sheet erosion classes correspond to communal pastures affected by overgrazing. As such, cattle and sheep overloading of grazing areas, together with grazing during excessively wet weather or extra-season, likely lead to degradation of the grasslands and trigger erosional processes.

Mean effective erosion is 0.98 t ha-1 yr-1, this suggests that in our study area, 7620.48 tonnes of soil are annually transported from the slopes into the river network.

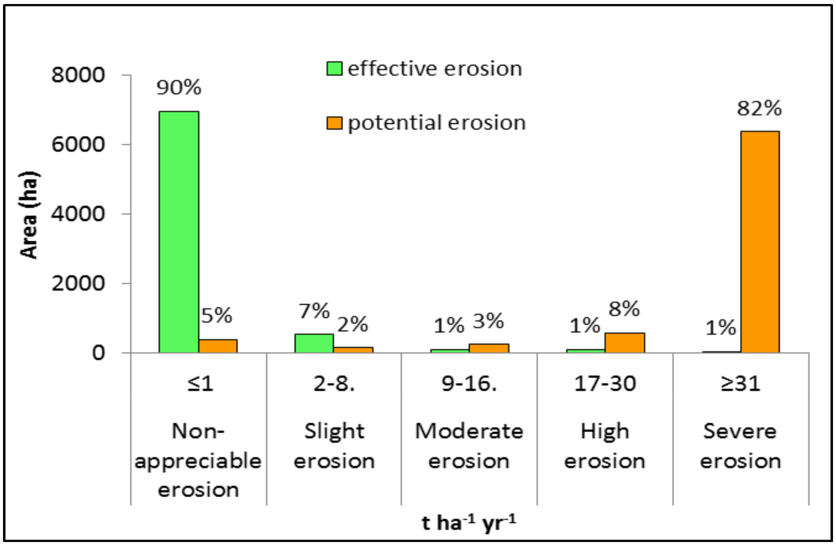

Figure 6 The histogram of the erosion classes.

Table 2 Areas and corresponding percentages for each erosion class

Class of the erosion intensity		The potential erosion		The effective erosion	
		Area (ha)	Percent (%)	Area (ha)	Percent (%)
Non-appreciable erosion	≤ 1 t ha^{-1} yr^{-1}	395.68	5	6976.16	90
Slight erosion	2-8 t ha^{-1} yr^{-1}	157.69	2	531.99	7
Moderate erosion	9-16 t ha^{-1} yr^{-1}	244.1	3	107.42	1
High erosion	17-30 t ha^{-1} yr^{-1}	579.88	8	103.19	1
Severe erosion	≥31 t ha^{-1} yr^{-1}	6398.65	82	57.24	1

The results obtained based on the ROMSEM model were further compared with data obtained from measurements on erosion parcels in the mountainous area. In Romania, assessment of sheet erosion rates for different categories of land use started in 1950 with the use of test plots (Arghiriade et al., 1977; Gaşpar et al., 1982; Rădoane, 2002). The data provided by these studies were later on employed by Dumitriu et al (2016) for a synthesis on sheet erosion of the Romanian land. From the chart constructed by the authors, we extracted the part which describes erosion in the mountain area and compared the obtained information with our results for Gemenea catchment (Figure 7).

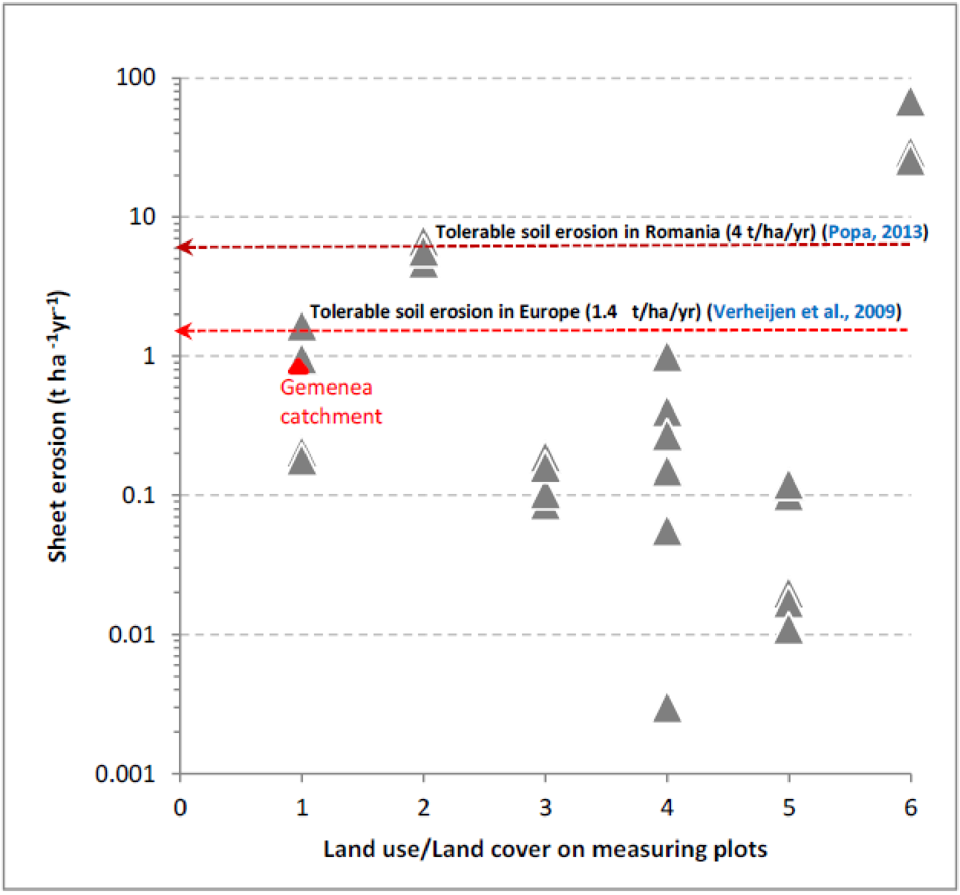

Figure 7 Centralized data on erosion rates by test plots in Romania (summarized from data provided by Arghiriade et al. 1977; Gaşpar et al. 1982; Rădoane 2002; Popa et al. 2013; Dumitriu et al 2016) 1–Spruce forest; 2–Spruce forest without litter; 3–Beech forest; 4–Meadow–land; 5–Pastureland; 6– Non-vegetated land.

Analysis of these comparative data enables us to draw a few conclusions, which are expanded by reference to the findings of the cited authors:

(i) Both runoff and effective soil erosion largely depend on land use / land cover (LULC) (Vanacker et al., 2007). Based on both test plot measurements and the applied ROMSEM model for our study area, we found that the land use / land cover factor controls soil erosion with a proportion of approximately 90% compared to the other factors.

(ii) On land protected by vegetation (pastures, meadows) sheet erosion is very low, ranging between 0.003 and 1.4 t ha^{-1} yr^{-1}. However, for degraded pastures sheet erosion increases with use intensity.

(iii) In deciduous forests with good consistency (consistency index values of 0.8 to 1), characterized by a thick layer of litter, both runoff and sheet erosion are very low, up to 0.2 t ha^{-1} yr^{-1}. Higher values are recorded for spruce forests, or where forests lack the litter layer (in this case values up to approximately 7 t ha^{-1} yr^{-1} were found).

(iv) The highest sheet erosion rates were found for non-vegetated land (between 25.6 and 68.6 t ha^{-1} yr^{-1}). Given that such areas are fairly rare in mountains, sheet erosion is thus generally lower here than in plateau areas.

(v) For the Gemenea catchment we obtained an effective erosion equal to 0.98 t ha^{-1} yr^{-1}. By comparing this value with data from experimental plots (Figure 7), we note that effective erosion in the Gemenea catchments corresponds with the erosion specific to spruce forests.

5. Conclusion

Considering our results, we believe that the ROMSEM method can be successfully employed in estimating soil erosion in small mountain catchments. Particular attention was given to the C factor, in which case forest vegetation was adapted to the study area.

Thus, based on measurements on test plots and taking into account the C factor values, mixed and conifer forests received coefficients of 0.0015 and 0,002 respectively.

Mean effective erosion in the Gemenea catchment is 0.98 t ha-1 yr-1, and falls in the absent / non-appreciable erosion class, specific to spruce forests. As a result, we can estimate that annually, 7620.48 tonnes of soil can be removed by erosion from our study catchment.

According to the effective erosion map for the Gemenea catchment, degraded pastures are heavily exposed to the erosive action of rainwater running down the slopes. Such situations require certain management strategies for free grazing to prevent degradation of grasslands.

By comparing potential and effective erosion, we suggest that in the Gemenea catchment forest vegetation controls sheet erosion at a rate of 90%. The role of the other factors triggering erosion (rainfall erosivity, topography, soils) is greatly diminished by the protective function of forests. As a result, vegetation preservation is required, particularly on sloping areas, to keep runoff at low levels and to prevent the formation of concentrated slope runoff.

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