Mapping the supply and demand of the erosion control ecosystem service in the Carpathian Ecoregion

Gabriel TANASE[1]*, Marcel MÎNDRESCU[1]

[1] Ștefan cel Mare" University of Suceava, Department of Geography, Suceava, Romania

* Correspondence to: Gabriel TANASE. E-mail: gabriel.tanase91@yahoo.com.

 Vol. 27/2017, 26-34

ABSTRACT: The purpose of this paper was to apply the Revised Universal Soil Loss Equation (RUSLE) and geographical information system (GIS) to the maping of erosion control ecosystem service in the Carpathian Ecoregion. The study area covers more than 200,000 km^2, and is subject to environmental change such as land use change and deforestation, which are increasing the vulnerability to various natural and anthropogenic phenomena. The results of the study show that about 90% of the area has low risk of erosion (less than 10.95 tons/ha/year), while 10% has a much higher erosion rate, those values being usually found in medium and high-altitude mountains. This reveals that the Carpathian region has a high supply of erosion control ecosystem service, and the area where the demand of erosion control is unsatisfied is less than 3%.

KEY WORDS: ecosystem services, erosion control, RUSLE, Carpathians.

1. Introduction

Soil is the support for vegetation growth and numerous ecosystems, as well as a major component in keeping healthy forests and water circulation. Surface soil is an important resource, and areas with a high potential for soil erosion face issues of low crop productivity and reduced water storage capacity. Information on soil loss and erosion prevention can provide essential data for diminishing environmental impacts and developing plans and policies based on predicted soil loss.

The Carpathian Mountains are the largest, longest and most twisted and fragmented mountain chain in Europe. Covering an area of 207,308 km^2, the Carpathians extend over seven European countries, from Romania in the south, through Ukraine, Poland, Slovakia and Hungary to the Czech Republic and Austria in the north (Figure 1). This unique region is home to a wide array of biodiversity (Europe's largest continuous temperate forest, one-third of all European vascular plant species and many endemic species can be found here), wildlife (greatest population of mammals from Europe), diverse nationalities and a rich cultural heritage and traditional knowledge.

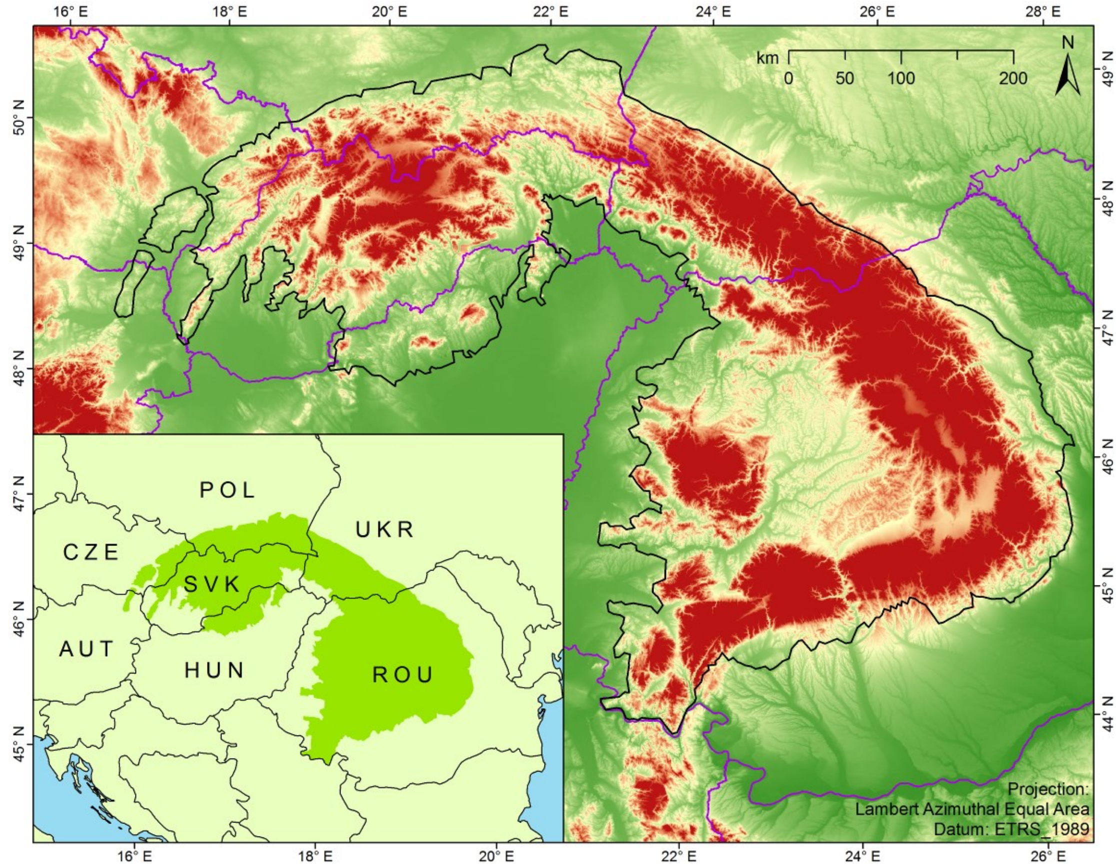

Figure 1 Study area – The Carpathian Ecoregion.

The main motivation for this research lies in the fact that currently the Carpathian region faces fast environmental, social and political changes, and the present development pattern is causing losses of biodiversity, and of traditional knowledge, livelihoods, practices and values. It is therefore critically fundamental that sustainable and comprehensible policies to be developed and put into action for the Carpathians, in order to preserve and fulfill the region's specificity, biodiversity and ecosystems.

2. Methods & datasets used

2.1. Supply

For mapping the supply of the erosion control ecosystem service, the Revised Universal Soil Loss Equation (RUSLE) was used. Revised Universal Soil Loss Equation (Renard et al., 1991, 1997) is an updated version of the Universal Soil Loss Equation (USLE) model (Wischmeier and Smith, 1965, 1978) and it is used to estimate soil erosion loss, to assess soil erosion risk, and to guide development and conservation plans in order to control erosion under different land cover conditions (Millward and Mersey, 1999). It is denoted by the following formula:

$$A = R * K * LS * C * P$$

where A is the mean soil loss, expressed in tons/ha/year, R is the rainfall erosivity factor (MJ/mm/ha/h/year), K is the soil erodibility factor (tons/ha/h/ha/MJ/mm), LS is the slope length and steepness factor, C is the cover management factor and P is the conservation practice factor.

The *rainfall erosivity factor (R)* is determined originally from rainfall amount and intensity. This factor represents the driving force of sheet and rill erosion by rainfall and runoff. Due to insufficient long-term records of rainfall intensity, many researches have tried to establish relationships between the R-factor and available precipitation data, such as monthly and annual total precipitation. The R-factor was obtained by computing an arithmetic average of 3 relations (Figure 2) that has been chosen from literature (Renard and Freimund, 1994; Renard et al., 1997), which use the annual precipitation data and has shown similar results.

The *soil erodibility factor (K)* represents the average long-term soil and soil-profile response to the erosive power associated with rainfall and runoff. The RUSLE estimates the K-factor using soil properties that are most closely correlated with soil erodibility: percent of silt (0.002-0.1 mm), percent of sand (0.1-2 mm), percent of organic matter, soil structure and permeability (Wischmeier et al., 1971; Renard et al., 1997). The K-factor values (5 classes, from 0.01 to 0.05) were assigned by using the Soil erodibility raster from the European Soil Database and based on literature (Van der Knijff et al., 2000; Panagos et al., 2014).

The *slope length and steepness factor (LS)* refers to the topographic influence on soil erosion. The slope length (L) is defined as the distance from the origin of overland flow to the point where deposition begins to occur, while steepness (S) refers to the inclination of the slope section. The soil erosion increases as the slope length increases due to the runoff accumulation, and the steeper the slope is, the higher the amount of soil loss is (Desmet and Govers, 1996). The LS-factor was computed using the equation shown in Figure 2. The flow accumulation raster and slope raster were generated from a Digital Elevation Model (DEM) with a resolution of 90 m.

The *cover management factor (C)* reflects the effect of cropping and management practices on the soil erosion rate, and thus, it is mainly related to the vegetation's cover percentage. High values (nearing 1) occur on bare land with little vegetation, while low values (less than 0.1) are found in areas of dense forest or grain cover (Park et al., 2011). Usually, the C-factor is derived using empirical equations based on the measurements of many variables related to ground covers collected in the sample plots (Lu et al., 2004).

The *conservation practice factor (P)* is the ratio of soil erosion with a specific support practice to the corresponding soil loss with straight-row upslope and downslope tillage. The P-factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity and hydraulic forces exerted by runoff on soil (Renard et al., 1997). The values of P-factor ranges from 0 to 1, in which the highest value is assigned to areas with no conservation, and lower value means that the conservation practices are more effective (Prasannakumar et al., 2011).

For our study region, both factors, C and P, were assigned, by utilizing the values given in the literature (Table 1), to the classes of the Land cover map, map which was based on Corine Land Cover data for E.U. countries (EEA, 2010) and Landsat images for Ukraine (Kuemmerle et al., 2010).

Table 1 C-factor values (Rozos et al., 2013) and P-factor values (Yang et al., 2003) of the Corine Land Cover classes.

Land cover	km^2	%	C-factor	P-factor
Forest	101,098	48.79	0.001	1
Pastures	38,554	18.61	0.100	0.8
Non-irrigated arable land	32,585	15.72	0.050	0.5

Complex cultivation patterns	25,119	12.12	0.080	0.5
Urban areas	8,850	4.27	0.050	1
Water bodies	1,015	0.49	0.001	1

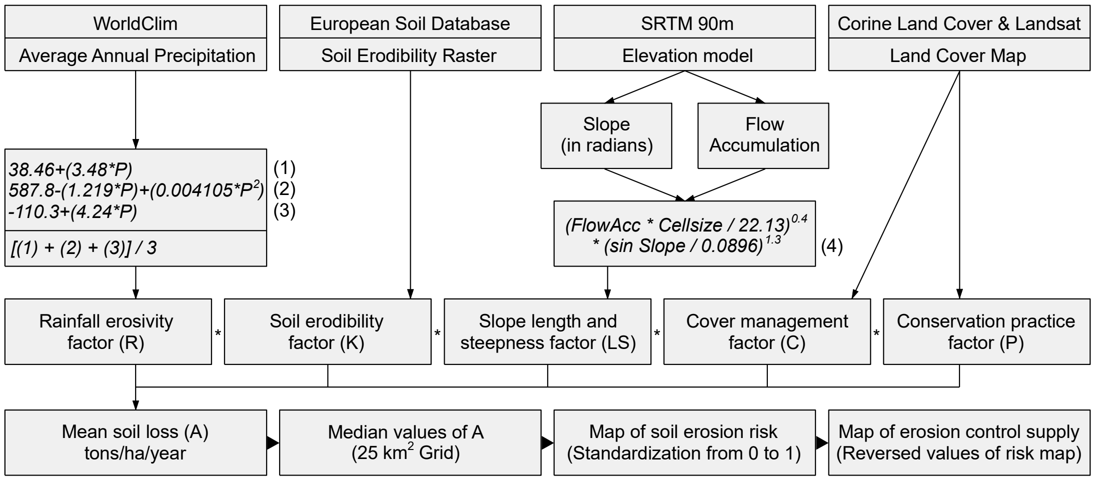

Figure 2 Methodology of the Revised Universal Soil Loss Equation (RUSLE) and of the Erosion control supply map. Equations sources: R-factor: Renard and Fremund, 1994 (1 and 2), Renard et al., 1997 (3); LS-factor: Prasannakumar et al., 2011, after Moore and Burch, 1986 (4).

2.2. Demand

In order to calculate the demand for the erosion control ecosystem service, the Land cover map and the Population density map were used. Both rasters were reclassified in 5 categories from 0 to 4, 0 meaning no importance, and 4 meaning the highest importance for the demand.

The *Land cover map* was reclassified in a subjective manner, as follows: 0 for Water bodies, 1 for forest, 2 for pastures, 3 for non-irrigated arable land, and 4 for complex cultivation patterns and urban areas.

The *Population density map* was classified using quantile method, resulting the following categories: 0 for non-populated areas, 1 for a density population between 0-2 people/km^2, 2 for 2-7 people/km^2, 3 for 7-61 people/km^2 and 4 for >61 people/km^2. The average population density was 48 people/km^2.

The rasters were weighted by correlating them with the Erosion control supply map (Figure 3), and the resulting coefficients were added to the following equation:

Demand=([Land_cover_map]*0.046)+([Population_density_map]*0.063)

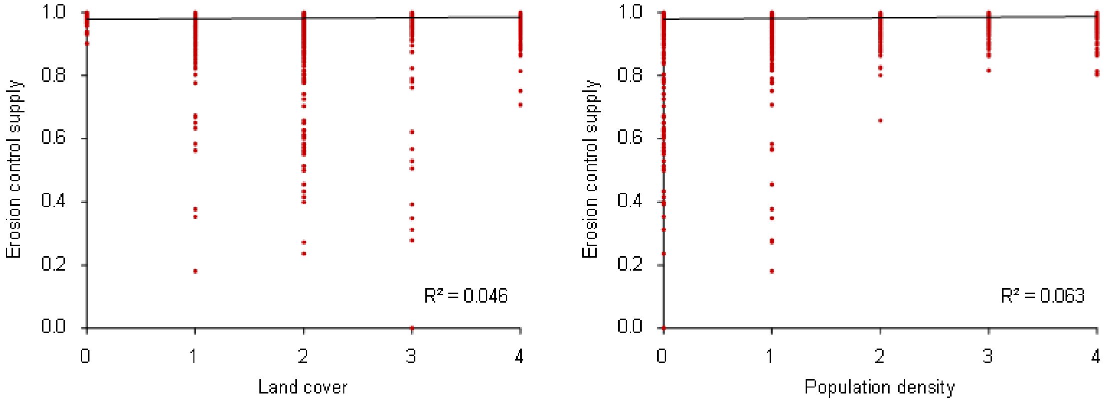

Figure 3 The correlation between erosion control supply and land cover (left) and between erosion control supply and population density (right). R2 was calculated using the R statistical software.

3. Results

3.1. Supply

The RUSLE factors and the mean soil loss (A) have been calculated using the raster calculator function of ArcMap 9.3, using the equations and methodology shown before (Figure 2). The results of each RUSLE factor are detailed in Table 2. The result for A ranges from 0 to 533.22 tons/ha/year, with a mean value of 4.35 and a standard deviation of 13.96. The results were transformed by chosing the median value of A within a grid with a cell size of 25 km2 (5 km x 5 km), resulting values from 0 to 59.21 tons/ha/year (mean value: 1.01 tons/ha/year, standard deviation: 2.56). Further, the values were standardized from 0 to 1. Map of erosion control supply (Figure 4) was realized by inverting the standardized values of the RUSLE model.

Table 2 Minimum, maximum, mean and standard deviation values of the RUSLE factors.

RUSLE factor	Min	Max	Mean	St. dev.
Rainfall erosivity factor (R)	1629.5	8224.46	2506	549
Soil erodibility factor (K)	0.01	0.05	0.036	0.009
Slope length and steepness factor (LS)	0	42.76	2.16	2.91
Cover management factor (C)	0.001	0.1	0.038	0.04
Conservation practice factor (P)	0.5	1	0.823	0.21

As seen in Figure 4, the lowest values of the erosion control supply are found mainly in areas where the precipitations and slopes are high, usually on high-altitude mountains: in Western Carpathians: Tatra Mountains, in Southern Carpathians: Făgăraș Mountains, Parâng Mountains, Retezat-Godeanu Mountains, in Eastern Carpathians: Rodna Mountains, Ceahlău & Hășmaș Mountains, and some parts of the Ukrainian Carpathians.

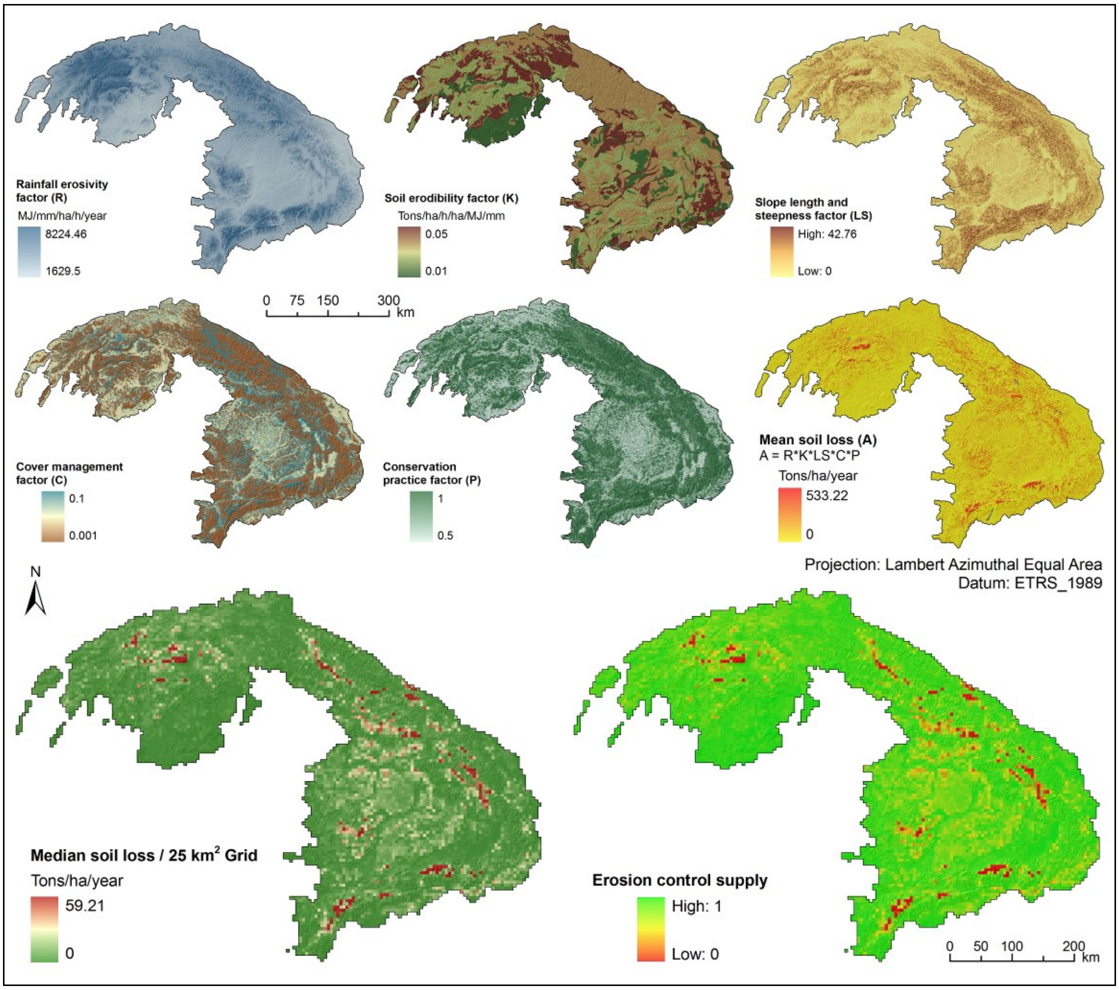

Figure 4 Maps of the Revised Universal Soil Loss Equation (RUSLE) model, and map of Erosion control supply. From left-to-right and top-to-bottom: R-factor, K-factor, LS-factor, C-factor, P-factor, Mean soil loss (A=R*K*LS*C*P), Median soil loss (25 km^2 grid) of the mean soil loss, Erosion control supply.

3.2. Demand

The demand for the erosion control was obtained through raster calculator, computed as shown in the methodology (Formula 2), and the values ranges from 0 to 0.436, with a mean value of 0.175, and a standard deviation of 0.119. The values were standardized from 0 to 1, after previously was computed the median values for the 25 km^2 grid, in order to calculate the budget between supply and demand of the erosion control ecosystem service.

Areas of high demand were found where the population density is high (Figure 5, left-bottom map): in the Beskids Mountains, in Poland and Czech Republic, but also in Romania, in Eastern Subcarpathians and Curvature Subcarpathians, in some intra-mountainous depressions such as Brașov depression; and medium but large area of demand was found in the Transylvanian Plateau.

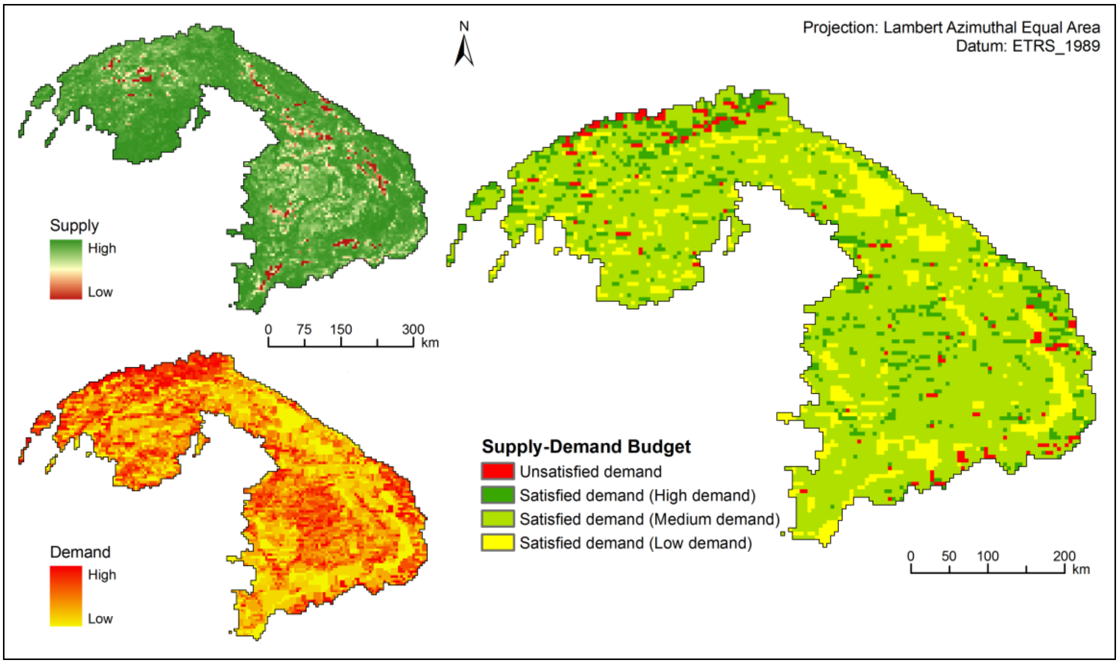

Figure 5 Maps of Supply and Demand of the Erosion control ecosystem service, and map of the Supply-Demand budget.

4. Conclusion and discussion

Estimation of soil erosion loss in a large area is often difficult, as well as its validation (Lu et al., 2004). The main study that can be compared with our results is the map of Soil erosion risk in Europe, made by the European Soil Bureau (Van der Knijff et al., 2000). The data has 7 classes, from very low to very high, and in the Carpathian region, the first 2 classes are predominant, while the third class is negligible, which shows that the erosion risk in the Carpathians is quite low if we compare with other mountain areas from Europe.

Our results show that about 90% of the area has low risk of erosion, less than 10.95 tons/ha/year, while 10% has an erosion rate of >10.95 tons/ha/year. Morgan (1995) argues that 10 tons/ha/year is an appropriate threshold of soil loss over which agriculturists should be concerned (Millward and Mersey, 1999). The maximum value was 533.22 tons/ha/year, but values from >40 tons/ha/year were present only islander.

The annual soil loss values are influenced the most by the value of R-factor. How the R-factor is calculate makes the difference between the final results of various studies. There is a good relation between average annual precipitation and R-values. Van der Poel (1980) suggest a 400 MJ/mm/ha/h/year change in the R-factor value for every 100 mm precipitation increment (Renard and Fremund, 1994). The average annual precipitation in the Carpathians varies from 492 mm to 1760 mm, and the R-factor is between 1629.5 and 8224.46 MJ/mm/ha/h/year, which makes the R-values credible.

In conclusion, the Carpathian region has a high supply of erosion control ecosystem service, and the area where the demand of erosion control is unsatisfied is less than 3% (Figure 5). This is caused also due to low population density, which makes the demand values to be low. Unlike many other ecosystem services, erosion control services cannot be imported from other regions, the service supply areas being physically linked to the demand area.

Acknowledgements

This paper has been realized based on the individiual final report of the Ecosystem Services & Biodiversity Module 2014, which has been made during the ERASMUS Mobility stay at the Humboldt University of Berlin. Many thanks to staff of the Geography Department and colleagues from the Ecosystem Services & Biodiversity Module.

References

Carpathian Ecoregion Initiative, 2001. The status of the Carpathians, Danube-Carpathian Programme, WWF International, Vienna, Austria.

Desmet, P.J.J., Govers, G., 1996. A GIS-procedure for automatically calculating the USLE LS-factor on topographically complex landscape units, Journal of Soil and Water Conservation, 51: 427-433.

EEA, 2010. Corine Land Cover 2006 seamless vector data, Version 13, European Environmental Agency, Copenhagen. Available at: https://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version [Last accessed: 04.09.2014]

Kuemmerle, T., Perzanowski, K., Chaskovskyy, O., Ostapowicz, K., Halada, L., Bashta, A-T., Hostert, P., Waller, D.M., & Radeloff, V.C., 2010. European bison habitat in the Carpathian Mountains, Biological Conservation, 143: 908-916.

Lu, D., Li, G., Valladares, G.S., Batistella, M., 2004. Mapping soil erosion risk in Rondonia, Brazilian Amazonia: using RUSLE, Remote sensing and GIS, Land degradation and development, 15: 499-512.

Millward, A.A., Mersey, J.E., 1999. Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed, Catena, 38: 109-129.

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Alewell, C., 2014. Soil erodibility in Europe: A high-resolution dataset based on LUCAS, Science of the Total Environment, 479-480: 189-200.

Park, S., Oha, C., Jeon, S., Jung, H., Choi, C., 2011. Soil erosion risk in Korean watersheds, assessed using the revised universal soil loss equation, Journal of Hydrology, 399: 263-273.

Prasannakumar, V., Vijith, H., Abinod, S., Geetha, N., 2012. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology, Geoscience Frontiers, 3(2): 209-215.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Soil Loss Equation (RUSLE), U.S. Department of Agriculture, Agriculture Handbook, No. 703.

Renard, K.G., Foster, G.R., Weesies, G.A., Porter, J.P., 1991. RUSLE – Revised Universal Soil Loss Equation, Journal of Soil and Water Conservation, 46(1): 30-33.

Renard, K.G., Fremund, J.R., 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE, Journal of Hydrology, 157: 287-306.

Rozos, D., Skilodimou, H.D., Loupasakis, C., Bathrellos, G.D., 2013. Application of the revised universal soil loss equation model on landslide prevention. An example from N. Euboea (Evia) Island, Greece, Environmental Earth Sciences, 70: 3255-3266.

United Nations Environment Programme, 2007. Carpathians Environment Outlook, UNEP/DEWA – Europe, Geneva, Switzerland.

Van der Knijff, J.M., Jones, R.J.A., Montanarella, L., 2000. Soil erosion risk assessment in Europe, European Soil Bureau, Joint Research Center – European Commission.

Wischmeier, W.H., Smith, D.D., 1965. Predicting Rainfall Erosion Losses from Cropland East of the Rocky Mountains: Guide for Selection of Practices for Soil and Water Conservation, Agricultural Research Service, U.S. Department of Agriculture, Washington D.C., Agriculture Handbook, No. 282.

Wischmeier, W.H., Smith, D.D., 1978. Predicting Rainfall Erosion Losses: A guide to conservation planning, U.S. Department of Agriculture, Agriculture Handbook, No. 537.

Yang, D., Kanae, S., Oki, T., Koike, T., Musiake, K., 2003. Global potential soil erosion with reference to land use and climate changes, Hydrological Processes, 17: 2913-2928.