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Estimation of soil erosion by water and climate influence in a small alpine catchment

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ABSTRACT

This study aims at evaluating water erosion and the average annual soil loss considering potential effects of climate change in the Guerna watershed, a small alpine catchment in north central Italy. Soil erosion by water was estimated using two empirical models (RUSLE and EPM) in a GIS environment and the results were compared to other case studies reported in literature with similar characteristics. Future climate scenarios were built on the basis of CORDEX data and Representative Concentration Pathways set by the 5th IPCC assessment report. Precipitation and air temperature are the variables used in the models to consider climate influence. Also the potential effects on land use were analysed. Results obtained showed that the effects of climate change on water erosion may not be negligible even by the mid of the current century and that a major role is being played by seasonality in rainfall peak intensity.

1. Introduction and study site

Soil loss due to water may occur at high rates in the alpine and pre-alpine environment, due primarily to its features (climate, geology, topography). It is particularly difficult to measure directly its values and therefore water erosion is often evaluated by employing models. The knowledge of climate change impacts on this phenomenon is an important piece of information to ensure a good management of the territory and to identify potential hydrogeological risk areas. Different factors contributing to soil erosion in mountainous areas can be affected by a changing climate (Berteni, 2019). The study area is the Guerna watershed, which is small alpine basin (31 km^2) located in northcentral Italy. Its average slope is about 50%, the maximum elevation is 1332 m a.s.l. and the minimum is 185 m a.s.l.

2. Methods

To assess the impact of climate change on water erosion applying two empirical models (RUSLE and EPM), three future climate projections were built on the basis of CORDEX data (http://www.cordex.org/) and according to the Representative Concentration Pathways (RCP) set by IPCC (Intergovernmental Panel on Climate Change): RCP 2.6 (from 2041 to 2060), RCP 4.5 (from 2041 to 2060), RCP 8.5 (from 2041 to 2060). By comparing historical (from 1986 to 2005) and future climate simulations, changes in the average and extreme values of precipitation and air temperature were used to build future local scenarios. It was also found that future variations of the land use in the Guerna watershed could be omitted.

2.1. The RUSLE model

The sediment loss by water at the basin scale was estimated in a GIS environment using the RUSLE (Revised Universal Soil Loss Equation) model, which is represented by the following equation (Renard et al., 1991):

$$A = R \cdot K \cdot LS \cdot C \cdot P \tag{1}$$

where A – computed soil loss [t ha^{-1} year^{-1}], R – rainfall-runoff erosivity factor [MJ mm ha^{-1} h^{-1} year^{-1}], computed by using semi-hourly rainfall records at Sarnico (BG) from year 2008 to year 2011, EI (Erosivity Index) parameter (Wischmeier and Smith, 1978) and the updating suggested by Brown and Foster (1987), K – soil erodibility factor [t ha h ha^{-1} MJ^{-1} mm^{-1}] calculated using Romkens et al. (1986) and the grain size distribution curve of the samples (determined by wet-sieving and sedimentation), LS – topographic factor [-] calculated using Moore and Burch's equation (1986) and Nearing's formula (1997) , C – cover-management factor [-] and P – supporting practices factor [-]. C and P factors were calculated using the land use map. Both R and K factors were considered uniform in the Guerna catchment, unlike the other factors. Only the R factor was modified according to climate change for the future climate.

2.2. The EPM method

Water erosion at the basin scale was estimated in a GIS environment using the EPM (Erosion Potential Method) method, which is represented by the following equation (Gavrilovic, 1988):

$$W = a \cdot T \cdot H \cdot \pi \cdot \sqrt{Z^3} \tag{2}$$

where W – average annual production of erosional sediments in the basin area [m^3 $year^{-1}$], a – surface area [km^2], T – temperature coefficient [-], computed by using monthly temperature data from year 2008 to year 2011 recorded at Sarnico (BG) and Ranzanico (BG) station. A linear decrease of air temperature as a function of altitude was assumed. H – mean annual amount of precipitation [mm], calculated by aggregating daily precipitation data from year 2008 to year 2011 recorded at Sarnico (BG) station, Z – coefficient of erosion [-], which depends on the land use, the soil resistance to erosion, the observed erosion processes and the land slope. Both T and Z coefficients have a spatial variability in the study area; $H$was considered uniform. Only the T factor and the amount of precipitation H were modified according to climate change for the future climate.

3. Results and discussion

Through the application of the RUSLE and EPM models maps of computed soil loss by water were built for the Guerna catchment. Table 1 shows the summary of the results.

Table 1. Summary of the results of soil loss (from 2008 to 2011) considering a specific weight of 2.65 t/m^3 (Efthimiou et al., 2016)

Model	Without considering climate change scenario	RCP 2.6	RCP 4.5	RCP 8.5
RUSLE	269140.9 t/year	283427.5 t/year	167406.6 t/year	247365.4 t/year
EPM	34193.2 m^3/year equivalent to 90612.1 t/year	36358.0 m^3/year equivalent to 96348.6 t/year	31516.0 m^3/year equivalent to 83517.4 t/year	37881.5 m^3/year equivalent to 100385.9 t/year

Results showed that soil loss computed without considering climate change scenario by the RUSLE equation was about three times higher than its evaluation according to the EPM method. On one hand, even if some authors decided to use the RUSLE model in an alpine environment because of its wide usage and usability, the overestimate may be due to the fact that the RUSLE methodology was originally developed to estimate water erosion in agricultural areas and not in mountain catchments. On the other hand, the EPM method accounts for a more complete description of the meteorological forcing, since both precipitation and air temperature are included in the equation and might be more suitable for mountainous areas. Validation was performed by comparing the results obtained using both methodologies with other case studies with similar features. Considering the application of RUSLE equation, RCP 2.6 and RCP 8.5 scenarios show respectively a low growth and a low reduction of entity of soil losses while the RCP 4.5 scenario shows a strong reduction in soil loss. Considering the EPM method and RCP 2.6, RCP 4.5 and RCP 8.5, the annual average soil loss could change by 6-10% on a basin scale. Therefore, soil erosion rates may increase or decrease under climate change, depending on a combination of different elements; especially seasonality in peak rainfall intensity plays an important role (Berteni, 2019). Empirical models are a useful analysis tool when detailed information is missing. Nevertheless, field measurements could further increase the accuracy and reliability of the whole methodology.

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