Spatial and temporal assessment of potential soil erosion over Greece

A.P. Kazamias* and M. Sapountzis
Department of Forest and Water Engineering, School of Forestry and Natural Environment, Aristotle University of Thessaloniki, University Campus 54124, Thessaloniki, Greece
*e-mail: kazamias.petros@gmail.com

Abstract: Soil erosion is considered as one of the most important environmental problems in the Mediterranean region threatening soil and water resources. The main purpose of this study is to investigate the spatial and seasonal distribution of potential soil loss across Greece. The Revised Universal Soil Loss Equation (RUSLE) model is applied at monthly time-step in a geographic information system (GIS) framework using freely available gridded datasets and remote sensing derived products. The rainfall erosivity (R-factor) is estimated using long-term monthly average precipitation from the CHELSA high-resolution gridded climate data set. The soil erodibility factor (K-factor) is estimated using ISRIC-World Soil Information SoilGrids250m global gridded maps of soil properties and classes. The cover management factor (C-factor) and the topographic factor (LS-factor) are assessed using remote sensing data. Time-series normalized difference vegetation index (NDVI) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) are used for the C-factor and the digital elevation model (DEM) from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is used for the LS-factor. The average annual soil erosion over Greece is estimated at 4.75 t ha⁻¹ yr⁻¹. About 12.33% of the Greek territory is observed with soil erosion rates higher than 10 t ha⁻¹ yr⁻¹, mainly located in high relief areas. Autumn and winter months are the most erosive, demonstrating high rainfall erosivity (R-factor) and vegetation cover (C-factor) values. Finally, 4 out of the 46 Greek River Basins (RBs) are particularly prone to soil erosion with rates greater than 15 t ha⁻¹ yr⁻¹. The results of this study further confirm the seasonality of soil erosion under Mediterranean climate and vegetation conditions.

Key words: Soil erosion, RUSLE, GIS, Remote sensing, Greece

1. INTRODUCTION

Soil erosion is considered as one of the most important environmental problems across the earth as it threatens soil fertility, water resources and agriculture productivity (Rahman et al., 2009). The semiarid Mediterranean regions are particularly vulnerable to erosion because of major land-use changes over the last decades and the long dry periods followed by intensive and erosive rainfalls (Van Der Knijff et al., 1999). Monitoring soil erosion in situ is very costly and usually limited to small experimental sites. The development of many empirical and physical soil erosion models coupled with remote sensing and GIS allowed the assessment of soil erosion risk across a wide range of spatiotemporal scales (Millward and Mersey, 1999; Wu and Wang, 2007). Among these models, the most widely used are the empirical USLE-family models (USLE/RUSLE) because of their simplicity, robustness and efficiency (Xiaosong et al., 2011).

Several studies have been conducted in the Greek territory for soil erosion risk assessment at local/regional scales, but none of them at country-scale. The majority of these studies estimated the potential annual soil loss without taking into account the intra-annual temporal variability of vegetation and rainfall, two important factors affecting soil erosion processes. Some recent studies explored soil erosion at monthly or seasonal time-step (Alexandridis et al., 2015; Panagos et al., 2012) and their findings suggest this approach as much more consistent for estimating the potential annual soil erosion. The objective of this study is to assess and map the spatial distribution of soil erosion over Greece at a monthly time-step and identify River Basins prone to soil erosion.
2. MATERIAL AND METHODS

2.1 Study area

Greece is a Mediterranean country, located in southeastern Europe (34° - 42° N, 19° - 28° E), covering an area of 131,957 km² with a coastline stretching for 15,000 km. It has a typical Mediterranean climate characterized by mild, wet winters and dry, hot summers. The complex topography of Greece and particularly the Pindos mountain range crossing Greece from NW to SE contribute to the spatial heterogeneity of climate. The average annual precipitation ranges from more than 2000 mm in the mountainous areas of northwest Greece to less than 400 mm in Attica basin of central Greece and western Cyclades (Nastos et al., 2016). According to CORINE Land Cover 2012 (CLC2012) of the European Environment Agency (EEA, Copenhagen, 2012; http://www.eea.europa.eu) 69.2% of the Greek territory is covered by forest and semi-natural vegetation (shrublands and grasslands), followed by agricultural areas which cover 23.1%, artificial surfaces cover 3.5%, water bodies and wetland cover 1.9% and finally other land cover types comprise 2.2% of the total area. Following the implementation of the EU Water Framework Directive (WFD) Greece was divided into 46 River Basins (RBs).

2.2 Soil erosion prediction by RUSLE

The Revised Universal Soil Loss Equation (RUSLE) model was developed by Renard et al. (1997) as a revision and update on the Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1978). The RUSLE function (Eq. 1) incorporates five different factors related with climatology, pedology, topography, land cover and land management for the calculation of soil loss.

\[ A = R \times K \times LS \times C \times P \]  

where \( A \) is the average annual soil loss (t ha\(^{-1}\) yr\(^{-1}\)), \( R \) is the rainfall erosivity factor (MJ mm ha\(^{-1}\) h\(^{-1}\) yr\(^{-1}\)), \( K \) is the soil erodibility factor (t ha h ha\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\)), \( L \) is the slope length factor (dimensionless), \( S \) is the slope steepness factor (dimensionless), \( C \) is the vegetation cover factor (dimensionless), \( P \) is the conservation practice factor (dimensionless).

In the present study, RUSLE has been adopted in a Geographical Information System (GIS) framework to predict annual soil erosion on a pixel-by-pixel basis (Eq. 2), where the monthly soil loss (\( A_{\text{monthly}} \)) values were computed for each month of the year 2013 (Eq. 3).

\[ A_{\text{annual}} = \sum_{j=1}^{12} (A_{\text{monthly}})_j \]  
\[ A_{\text{monthly}} = R_{\text{monthly}} \times K \times LS \times C_{\text{monthly}} \times P \]

Two factors, the rainfall erosivity (R-factor) and the vegetation cover (C-factor) were calculated with different data for each month, while soil erodibility (K-factor) and slope length and steepness (LS-factor) were assumed constant for the entire year. The conservation practice (P-factor) was assigned the value of 1 because there were no reliable data to define its value. Each factor of the RUSLE model was calculated in raster format. In order to have consistent results all raster layers were projected to the Universal Transverse Mercator (UTM) Zone 34N projection system and were resampled to the same pixel size of 250 m x 250 m. Also, artificial surfaces, water bodies and wetlands were masked out from the produced soil loss raster maps. The study was supported by SAGA GIS 2.1.2, ESRI ArcGIS 10.0 and R programming language.
2.3 RUSLE input data

2.3.1 Rainfall erosivity factor (R)

The rainfall erosivity factor (R) measures the erosive force of a specific rainfall in a particular location (Morgan, 2004). In the present study, long-term average monthly precipitation data from the CHELSA climate data set (Karger et al., 2016) were used to calculate monthly R-factor values, following Eq. 4, 5 developed by Arnoldus (1980). CHELSA is a high resolution (30 arcsec, ~1 km) gridded climate data set providing mean monthly temperature and precipitation values for the time period 1979-2013 for the earth’s land surface areas.

\[
R_{\text{annual}} = \sum_{i=1}^{12} (R_{\text{monthly}})^i
\]  
\[
R_{\text{monthly}} = 1.735 \times 10^{-1.5 \log_{10}(p^2)} - 0.08188
\]

where \(R_{\text{annual}}\) is the annual rainfall erosivity (MJ mm h\(^{-1}\) yr\(^{-1}\)), \(R_{\text{monthly}}\) is the monthly rainfall erosivity (MJ mm h\(^{-1}\)), \(p\) is the monthly rainfall (mm) and \(P\) is the annual rainfall (mm).

2.3.2 Soil erodibility factor (K)

Soil erodibility depends on many soil properties such as soil texture, aggregate stability, shear strength, infiltration capacity, organic content and chemical composition (Morgan, 2004). In practical terms, the soil erodibility factor is a quantitative annual value defining the resistance of soil to both detachment and transport. In the present study, the soil erodibility factor (K) was calculated using Eq. 6 suggested by Renard et al. (1997), which is based on the geometric mean particle size and requires the percentage of sand, silt and clay contents. The soil texture information were derived from ISRIC-World Soil Information SoilGrids250m (Hengl et al., 2016), a dataset with global gridded soil information based on machine learning techniques. Three raster layers at 250 m resolution with clay content (weight %), silt content (weight %) and sand content (weight %) of topsoil (15 cm depth) were downloaded from http://soilgrids.org. Combining the above three raster layers, the geometric mean particle size was derived for each grid cell (Eq. 7). Afterwards, the K-factor was estimated for each grid cell (Eq. 6):

\[
K = 0.0034 + 0.0405 \times \exp \left[ -0.5 \left( \frac{\log D_g + 1.659}{0.7101} \right)^2 \right]
\]

\[
D_g = \exp(0.01 \sum f_i \ln m_i)
\]

where \(K\) is the soil erodibility factor (t ha h\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\)), \(D_g\) is the geometric mean particle size for each particle size class (clay, silt, sand), \(f_i\) is the corresponding particle mass fraction for each particle class in percent and \(m_i\) is the arithmetic mean of the diameter limits for each particle size class (mm) based on the USDA classification. The \(m_i\) values for each soil particle class are the following: for clay 0.0010 mm, for silt 0.0026 mm and for sand 1.025 mm.

2.3.3 Topographic factor (LS)

The slope length factor (L) and slope steepness factor (S) are generally lumped together as the topographic factor (LS), reflecting the effect of terrain morphology and topography on soil erosion processes (Lou et al., 2004). In this work, the LS-factor was computed in the System for Automated
Geoscientific Analyses (SAGA) GIS software using the Module LS factor and following the algorithm developed by Desmet and Govers (1996). The LS-factor calculation required a digital elevation model (DEM) which was derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with a cell size of 30 m.

2.3 Vegetation cover factor (C)

The vegetation cover factor (C) reflects the effect of cropping and management practices on soil erosion rates in agricultural areas and the effect of natural vegetation on reducing soil erosion in forested areas (Renard et al., 1997; Wischmeier and Smith, 1978). The C-factor gets values between 0 and 1; values closer to 0 indicate dense vegetation, while values closer to 1 are for bare soil. Several methodologies are proposed in the bibliography for calculating C-factor at regional scale by incorporating vegetation indices derived from satellite images. In the present study, monthly C-factor maps were produced from monthly Normalized Difference Vegetation Index (NDVI) products following Eq.8 proposed by Van Der Knijff et al. (1999):

\[ C = \exp \left( -a \frac{NDVI}{b-NDVI} \right) \]  

where a and b are unitless parameters that determine the shape of the curve relating NDVI and C-factor values.

Van Der Knijff et al. (1999) suggested that this scaling approach gives better results than assuming linear relationship. Also, the values of 2 and 1 were selected for the parameters a and b, respectively (Gitas et al., 2009; Kouli et al., 2009; Van Der Knijff et al., 1999). The monthly NDVI products were calculated from the 16-day MODIS NDVI (MOD13Q1) composites for the year 2013. The resulting monthly C-factor maps have the same spatial resolution as the MODIS NDVI composites, namely 250 m pixel size.

3. RESULTS AND DISCUSSION

3.1 RUSLE factors

For the period 1979-2013, the average rainfall erosivity over Greece was found to be 372.2 MJ mm ha\(^{-1}\) h\(^{-1}\) yr\(^{-1}\), with values ranging from 80.86 to 1316.37 MJ mm ha\(^{-1}\) h\(^{-1}\) yr\(^{-1}\). From the spatial distribution of the R-factor (Figure 1D), it can be clearly denoted that the Pindos mountain range affects the values of R-factor, acting as a boundary between western and eastern Greece. High values were observed in the western part of Greece, the Ionian Islands, western Crete and some islands located in the south-eastern Aegean Sea, while low values were found in the eastern and northern Greek mainland. Concerning the temporal variability of rainfall erosivity, the highest values were observed during the winter period and late autumn. The highest monthly rainfall erosivity rates were observed in December, with values ranging from 19.96 to 464.95 MJ mm ha\(^{-1}\) h\(^{-1}\) and a mean value of 112.07 MJ mm ha\(^{-1}\) h\(^{-1}\). The lowest monthly rainfall erosivity rates were observed during the summer period, ranging from 0 to 2.59 MJ mm ha\(^{-1}\) h\(^{-1}\).

The soil erodibility values for Greece ranged from 0.0025 to 0.045 t ha h ha\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\), with a mean value of 0.038 t ha h ha\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\) and standard deviation (SD) of 0.0024 t ha h ha\(^{-1}\) MJ\(^{-1}\) mm\(^{-1}\) (Figure 1C).

The topographic factor (LS) values ranged from 0 to 16, with a mean value of 2.86 and standard deviation (SD) of 2.47 (Figure 1B). The highest values for LS-factor occurred in the steep hillslopes of Pindos mountain range and on Mount Olympus.
The highest C-factor values were observed during the winter months (December, January, February) ranging from 0.187 to 0.439, with a mean value of 0.246. Similar high values were found in autumn (September, October, November) and March with mean C-factor values in the range of 0.163 for each month. The lowest values were noticed in spring and summer period (April-August) with mean C-factor values close to 0.1.

### 3.2 Monthly and annual potential soil loss

The boxplots in Figure 2 depict the distribution of potential monthly soil loss for Greece. The highest values were observed in December with a mean soil loss of 1.78 t ha\(^{-1}\) m\(^{-1}\) (SD=5.92), whereas the lowest monthly soil loss rates were observed during summer months (June, July and August) with mean values of 0.1 t ha\(^{-1}\) m\(^{-1}\) (SD=0.020). The contribution of each season to annual soil loss is the following: winter (December, January, February) with 63.1%, autumn (September, October, November) with 26.19%, spring (March, April, May) with 10.39% and summer (June, July, August) with 0.32%.

The estimated annual soil loss for Greece ranged from 0.1 to 148.16 t ha\(^{-1}\) yr\(^{-1}\), with an average value of 4.75 ha\(^{-1}\) yr\(^{-1}\). The potential annual soil erosion was subdivided into 6 classes and the resulting map is illustrated in Figure 3A. Approximately 77.56% of the Greek territory is classified as either very low (0-1 t ha\(^{-1}\) yr\(^{-1}\)) or low (1-5 t ha\(^{-1}\) yr\(^{-1}\)) potential soil erosion risk, 10.11% as moderate (5-10 t ha\(^{-1}\) yr\(^{-1}\)) and 9.95% as high (10-20 t ha\(^{-1}\) yr\(^{-1}\)) and very high (20-50 t ha\(^{-1}\) yr\(^{-1}\)). Finally, only 2.38% of the investigated area is prone to severe erosion (> 50 t ha\(^{-1}\) yr\(^{-1}\)). The areas with severe erosion rates were located across the Pindos mountain range and in Crete Island, due to high rainfall erosivity and large LS-factor values.
The final objective of this study was to quantify potential soil erosion rates across all Greek River Basins. In Figure 3B the average potential annual soil erosion values of each River Basin are classified into 6 classes. Half of the river basins, located in Eastern Macedonia, Central Macedonia, Western Macedonia, Thessaly, Central Greece and Attica, have average soil erosion rates lower than 5 t ha\(^{-1}\) yr\(^{-1}\). River basins located in the western part of the Pindus mountain range, in North/South Aegean and in the Peleponnese region show higher average soil erosion rates with values ranging from 5 to 15 t ha\(^{-1}\) yr\(^{-1}\). Finally, four river basins are prone to high erosion rates (>15 t ha\(^{-1}\) yr\(^{-1}\)), Aoos (GR11) and all three RBs in Crete Island (GR39, GR40 and GR41).

4. CONCLUSIONS

The present study was a first attempt to estimate the spatial and temporal distribution of potential soil erosion in Greece and identify River Basins with high soil erosion risk. The average annual soil erosion was found to be 4.75 ha\(^{-1}\) yr\(^{-1}\), of which almost 90% was produced during autumn and winter seasons of the year. These results follow the seasonal pattern of rainfall erosivity (R-factor) and vegetation cover (C-factor), which both showed high values in autumn and winter, and low values.
in summer and spring. These findings have also been confirmed in other studies conducted in the Mediterranean region (Karydas and Panagos, 2016; Panagos et al., 2014, 2012). The spatial distribution of soil erosion in Greece confirmed the findings of many other studies suggesting that soil movement is mainly controlled by topography, and furthermore, that soil loss results from the RUSLE model are strongly correlated with steep slopes and the topographic factor (Ali and De Boer, 2010; Kouli et al., 2009; Prasannakumar et al., 2012).

It must be noted that the quantitative assessment of soil loss using an empirical model like RUSLE with coarse resolution datasets as inputs has great uncertainty. Nevertheless, the spatial and seasonal distribution of soil erosion across Greece seems to be accurately simulated, leading in the identification of River Basins with high erosion rates. These results can be used for effective environmental policy management and the implementation of mitigation measures to protect agricultural and urban areas.

REFERENCES


