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Average seasonal soil erosion and sediment deposition in the Aliakmon and Axios river catchments using the RUSLE model

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Abstract Anthropogenic pressures in coastal areas are responsible for various problems that might cause degradation of their environmental status and limitations in the provision of their ecosystem services. In this framework, the assessment of soil erosion and sediment deposition is of major importance since they have significant environmental and economic impact. In this paper, the Revised Universal Soil Loss Equation (RUSLE model) was used to assess the average seasonal soil erosion and sediment deposition in the Aliakmon and Axios river catchments in Thermaikos Gulf, Northern Greece; areas of important environmental and economic value. The RUSLE is an empirical model which in combination with GIS and remote sensing is able to estimate soil erosion through the prediction of long-term seasonal soil loss and sediment deposition.

Keywords: Aegean Sea, RUSLE model, GIS, watershed

1. Introduction

Soil erosion is considered to be a natural process that forms the earth's surface representing nowadays one of the most severe land degradation problems (Rozos et al., 2013). Soil erosion can induce long-term impacts both in the surface water and the cultivable soil quality, as well as changes in the river channel and sediment transfer (Morgan, 2005). Although anthropogenic activities such as uncontrolled land cultivation, urban expansion, infrastructure development, are considered responsible for soil erosion, the natural driving forces, such as wind and water, are of major importance (Gianinetto et al., 2020; Polykretis et al., 2020).

Many areas in southern Europe and especially in the Mediterranean, face long drought periods followed by heavy rainfall, leading in significant amounts of erosion (Onori et al., 2006). Moreover, in many Mediterranean areas, the phenomenon has either reached an irreversible stage or there is no other soil left (Kouli et al., 2009). In Greece, 3.5 million hectares are affected by soil erosion representing the 26.5% of the total area of the country (Mitsios et al., 1995).

Various methods are available in literature for the evaluation of soil erosion and risk assessment. Wischmeier and Smith (1978) introduced the Universal Soil Loss Equation (USLE), an empirical model able to estimate soil erosion through the prediction of long-term average soil loss. This model, with the inclusion of additional data and the incorporation of relevant research results was further improved and the Revised USLE (RUSLE) was proposed (Renard et al., 1997; Kouli et al., 2009). In this paper, RUSLE is used to assess the average seasonal soil erosion and sediment deposition in the Aliakmon and Axios river catchments in Thermaikos Gulf, Northern Greece.

2. Materials and methods

2.1. Study area

The study area (Figure 1) is Thermaikos Gulf, a semi-enclosed, relatively shallow marine system which is strongly influenced by the Aliakmon and Axios river catchments; both catchments are included in the study area. Aliakmon is the longest Greek river (297 km length) flowing entirely in Greek territory. Axios is the second longest transboundary river in the Balkans, with a total length of 380 km, 76 km of which are in Greek territory. Both rivers are the main contributors of freshwater and sediments into Thermaikos Gulf (Karageorgis et al., 2005). The extent of the study area catchments is 12,409.74 km^2 for Aliakmon and 25,867.43 km^2 for Axios, respectively.

2.2 Data and methodology

2.2.1 The Revised Universal Soil Loss Equation (RUSLE)

The RUSLE is an empirical model developed by the US Department of Agriculture and is recognized as a typical method to estimate soil erosion through the prediction of the long-term average soil loss (Renard et al., 1997; Zhou et al., 2014). The model can be applied internationally, since many regions worldwide can adopt and apply it (Chuenchum et al., 2020).

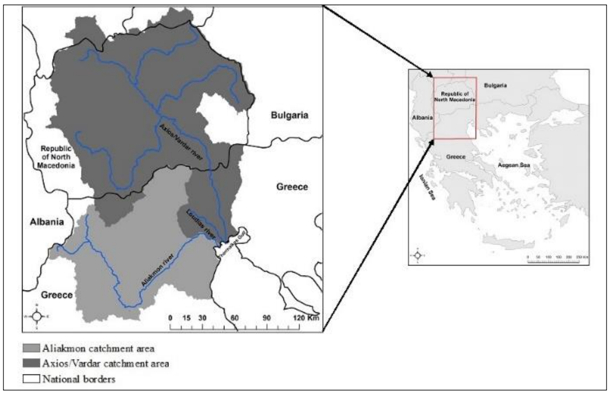


Figure 1. Study area

In this paper, the RUSLE model was applied twice for each catchment area; for winter (November – April) and summer (May – October) using the following equation (Renard et al., 1997):

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

where A is the average seasonal soil loss selected for R, R is the rainfall-runoff erosivity factor, K is the soil erodibility factor, LS is the slope length and steepness factor, C is the cover management factor and P is the conservation practice factor. The necessary data to calculate each factor of the model are presented in the flow chart shown in Figure 2.

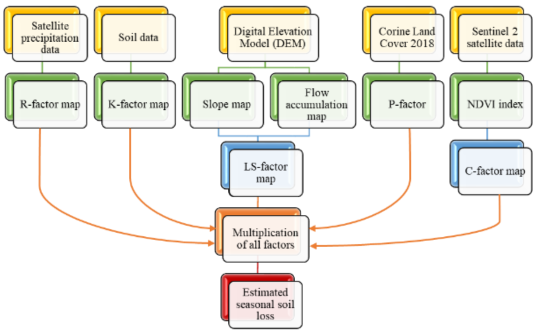


Figure 2. Flow chart of the RUSLE model

All necessary data for the application of the RUSLE model were stored in a geodatabase in raster format with 250 m pixel size in a common coordinate system. All calculations were implemented in a GIS environment using the ESRI, ArcGIS 10.8 software. The precipitation data were retrieved from The Global Precipitation Measurement (GPM mission/NASA) for two periods: winter and summer. The mean seasonal rainfall was obtained by averaging the 20-year monthly rainfall dataset (from 2000 to 2020). The soil data were retrieved from the European Soil Database v2.0 and the Harmonized World Soil Database v1.2. The DEM, retrieved from the Copernicus Land Monitoring Service, was used for the calculation of the LS-factor, which is accountable for the topographical effects on soil erosion, depending on the slope steepness factor (S) and slope length factor (L). The NDVI index, retrieved from Sentinel 2 satellite data, was used to calculate the C-factor, since according to De Jong (1994), vegetation indices are particularly important for the extraction of vegetation parameters; based on his research NDVI and C-factor are correlated. Finally, Corine 2018, retrieved from the Copernicus Land Monitoring Service, was used to calculate the P-factor. A P coefficient value ranging from 0 to 1 was attributed to each land use class, considering an extended literature review (Panagos et al., 2015; Tian et al., 2021) and cross-correlations with the assigned land use class in the study area.

2.2.2 Sediment yield

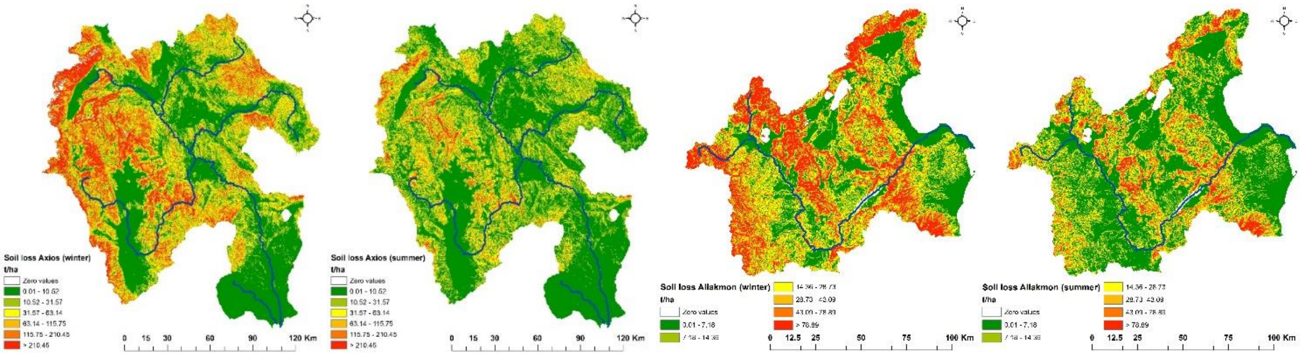
The RUSLE model can estimate the soil erosion but not the subsequent sediment yield of the catchment outlet (Ebrahimzadeh et al., 2018). However, the latter can be quantified through the Sediment Delivery Ratio (SDR) that is the ratio of the sediment yield to the gross erosion estimated by RUSLE (Efthimiou et al., 2014). In this paper, the USDA (2002) empirical equation was applied for the calculation of SDR, due to its extensive scientific acceptance and implementation (Zarris et al., 2011; Ebrahimzadeh et al., 2018). The sediment yield in both catchments was estimated initially by considering no human intervention in the study area, i.e. dams, and nor the relative hydromorphological disturbances. However, the seasonal sediment discharges in the two catchments are significantly reduced due to the existence of dams (Dimitriou et al., 2018). Thereafter, since there is lack of in-situ data regarding the sediment retention capacity of existing dams, a 30% empirical reduction of sediment yield due to human interventions was taken into account (Poulos et al., 2000; Vörösmarty et al., 2003; Kapsimalis et al., 2005).

3. Results

The average seasonal soil loss maps for the two catchment areas and for the two time periods are presented in Figure 3. The values of the estimated mean and total soil loss in the study area are presented in Table 1. The higher values were observed, as expected, for winter.

Regarding the Axios catchment area, higher potential soil loss, both for winter and summer, were observed at the northwest part of the area. The lower values were observed at the southeast part near the estuary. In the Aliakmon catchment, high risk erosion areas for both seasons were observed at the center of the catchment and in areas with high relief.

In this study, the SDR for the Axios catchment area was 0.1668 (16.68%) and for the Aliakmon 0.1808 (18.08%), respectively. Based on these values and the RUSLE results, the potential seasonal sediment yield for the two catchments was calculated and the results are given in Table 1. These outcomes are considered to be consistent with studies carried out in other catchments, either mountainous or semi-mountainous, with similar physiographic characteristics (Zarris et al., 2011; Efthimiou et al., 2014; Dimitriou et al., 2018). However, in-situ measurements are considered necessary, for further confirmation and validation of these results.



(a) (b)

Figure 3. Average seasonal (winter – summer) soil loss maps for the catchment areas of (a) Axios and (b) Aliakmon

Table 1. Estimated seasonal soil loss and sediment yield (with and without consideration of human interventions)

WINTER					SUMMER				
			Human interventions considered					Human interventions considered	
Soil loss			no	yes	Soil loss			no	yes
Axios catchment area									
Total soil loss	26,094,175.68 t/s*	***Total sediment yield***	4,352,508.58 t/s*	1,305,752.58 t/s*	***Total soil loss***	8,512,328.59 t/s*	***Total sediment yield***	1,419,856.51 t/s*	425,956.96 t/s*
Mean soil loss	63.86 t/ha or 6,386 t/km^2	***Mean sediment yield***	10.65 t/ha or 1,065 t/km^2	3.20 t/ha or 320 t/km^2	***Mean soil loss***	20.83 t/ha or 2,083 t/km^2	***Mean sediment yield***	3.48 t/ha or 348 t/km^2	1.04 t/ha or 104 t/km^2
Aliakmon catchment area									
Total soil loss	8,328,427.83 t/s*	***Total sediment yield***	1,505,779.74 t/s*	451,733.95 t/s*	***Total soil loss***	3,330,136.34 t/s*	***Total sediment yield***	602,088.66 t/s*	180,626.61 t/s*
Mean soil loss	42.98 t/ha or 4,298 t/km^2	***Mean sediment yield***	7.77 t/ha or 777 t/km^2	2.33 t/ha or 233 t/km^2	***Mean soil loss***	17.19 t/ha or 1,719 t/km^2	***Mean sediment yield***	3.11 t/ha or 311 t/km^2	0.93 t/ha or 93 t/km^2

** s: season (winter: November – April & summer: May – October)*

4. Conclusions

Soil erosion in Greece is a severe problem, and the application of various methods to assess soil loss in large-scale catchment areas is considered necessary. The RUSLE is one of the most widely applied models, quite simple to parameterize making it a useful tool for estimating soil erosion. In this paper, evaluation of long-term seasonal soil loss and sediment deposition in two major catchments in the Northern Greece was performed. The application of the RUSLE model identified the spatial distribution of the prone to erosion areas and quantified the seasonal soil loss per pixel. However, future works are essential for measuring in-situ sediment deposition in the two catchment areas and therefore, confirm and validate the model results. The latter would be useful in case erosion control measures and management plans should be undertaken in the framework of a decision support system.

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