

Assessing soil erosion risk using USLE with GIS and SWAT for Thassos Island, Greece.

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Keywords: SWAT, USLE, Thassos, Erosion

ABSTRACT

Soil erosion is a natural geological process but today is one of the most important environmental threats in the world because it is accelerated due to the human activities and the climate change. The Mediterranean Basin is a very prone region to erosion as the climate change effects are already visible. In addition, it is high populated it receives millions of tourists every year. The aim of this study is the spatial and quantitative assessment of the soil losses on Thassos Island, a typical Mediterranean island that receives thousands of tourists every summer. The assessment was conducted with two methodologies: the Universal Soil Loss Equation and the Soil and Water Assessment Tool. The final results of the two methodologies were the creation of the soil erosion maps of the island based on both methodologies. The erosion maps were classified in eight categories of different erosion rates. Both maps indicated the areas of high erosion risk that are dangerous. These areas must be further evaluated in order to mitigate the erosion.

1. INTRODUCTION

Soil erosion is a natural geomorphologic process that describes the removal and transportation of the soil particles by forces such as water and wind (Gitas et al. 2009; Zaimes et al. 2012b). The factors that trigger erosion are: topography (steep slopes), climate (extreme precipitation events or strong windstorms), land-use/vegetation coverage, natural disasters (earthquakes, tsunamis, forest fires, etc) and finally, human activities and intervention to the physical environment (agricultural fields, roads, dams, etc) (Gitas et al. 2009; Montgomery 2007).

The Mediterranean Basin is a very significant region that has been settled since the Pre-Historic era (Knapp and van Dommelen 2005). Millions of tourists visit the region throughout the year, especially the Mediterranean islands, making it one of the world's most visited regions (UNWTO 2013). It is important to protect the natural environment of the Mediterranean Basin because it has suffered from many human interventions for thousands of years (Bathrellos et al. 2010; Montgomery 2007). The region's environment is naturally prone to soil erosion because of the dominant semi-arid and arid conditions (Zaimes et al. 2012a). The impending climate change impacts should also be a concern. The climate change scenarios predict a warmer climate that will cause longer drought periods and more intense precipitation events (IPCC 2007a, b). These conditions are expected to exacerbate the risk of soil erosion.

The current and future conditions of the Mediterranean make the study and mitigation of soil erosion risk a necessity (UNWTO 2013). This needs to be done using new and innovative techniques that will assist in the effective and efficient management of the land of the region. Otherwise without firstly understanding the potential risk of erosion and afterwards taking the appropriate mitigating measures, land degradation and potentially desertification is highly probable (Symeonakis et al. 2004).

In this study, two different methods were applied the Universal Soil Loss Equation (USLE) through ArcGIS and the Soil and Water Assessment Tool (SWAT) through ArcSWAT which is its interface to ArcGIS. USLE is a very common, simple and effective approach to estimate soil erosion (Gitas et al. 2009) while the SWAT model requires almost the same data and it is also frequently used for erosion studies (Panagopoulos et al. 2008).

2. STUDY AREA

The study area is the island of Thassos, located in northern Greece, opposite of the coast of Eastern Macedonia (Fig. 1). It is the northernmost Greek island and the 12th largest by area. The surface of the island occupies about 378 km² while the shape of the island is almost rounded and the perimeter is approximately 102 km (Mallios et al. 2009; Vlachopoulou and Emmanouloudis 2014). The terrain is mountainous; while the highest peak is Ypsarion with an elevation of 1203 m. The climate of the island is characterized as Mediterranean. The average annual temperature is approximately 15.8 °C and the average annual precipitation is approximately 770mm (Vlachopoulou and Emmanouloudis 2014). The total population of the island is 13,770 inhabitants according to the Census of 2011 (Greek Statistical Authority 2012). The island receives thousands of tourists, especially during the summer season, resulting in the increasing residents' involvement in the tourism and other relevant occupations. Agricultural also plays an important role in the local economy, as well as fishing and apiculture (Mallios et al. 2009). Finally, other main economic activities are the marble quarries and the petroleum drilling.



Figure 1. Satellite image of Thassos Island (source: ESRI, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGP, IGN and the GIS User Community).

3. MATERIALS AND METHODS

3.1. THE DATA

The data used in this study was the topographic map of Thassos developed by the Military Geographic Service that had a scale of 1:50,000. This map was used to create the Digital Elevation Model (DEM) in ArcGIS 10.1 by digitizing the contour lines and the stream network. The CORINE 2000 vector files by European Environment Agency were acquired in order to display the land-uses of the island and had a scale of 1:100,000. The soil map was downloaded from the European Soil Portal and the Harmonised World Soil Database Viewer 2012 that had a scale of 1:1,000,000. Finally, the weather data were obtained by a meteorological station located in the city of Limena, Thassos and covered the period 1975-1999.

3.2. THE USLE METHOD

In this study two different methods were used in order to estimate the potential erosion risk areas. The first one was the Universal Soil Loss Equation developed by Wischmeier and Smith

in 1960. USLE estimates the average annual soil loss in tons/yr. The factors used to estimate soils erosion include (Eq. 1): rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cropping management (C) and conservation supporting practice (P).

Equation 1. The Universal Soil Loss Equation.

$$USLE = R \times K \times LS \times C \times P$$

a) The R factor for a given location is derived from the precipitation records. The data used were acquired from the Forest Service of Kavala and concern only one meteorological station that is located in Limena. The annual R factor was calculated from the empirical equation (Eq. 2) (Schwertmann et al. 1990) where P is the mean annual rainfall amount in mm.

Equation 2. The R factor empirical equation.

$$R = 0.083 \times P - 1.77$$

b) The K factor represents the sensitivity of the soil to erosion. Soil texture, organic matter, structure and permeability are the parameters that determine the value of a particular soil (Jones et al. 1996). The K factor value was assigned based on the characteristics of each soil type (Fig. 2). The K value was calculated from the Wischmeier and Smith 1978 equation (Eq. 3):

Equation 3. The K factor equation.

$$K = 0.00021 \times M^{1.14} \times (12 - OM) + 3.25 \times (C_{soilstr} - 2) + 2.5 \times (C_{perm} - 3)$$

where M is the particle-size parameter $M = (silt_{\%} + sand_{\%}) \times (100 - clay_{\%})$ (Equation 4)

OM is the organic matter content $OM = 1.72 \times orgC$ (Equation 5)

$C_{soilstr}$ is the structure of the soil and takes the values: 1=very fine granular, 2=fine granular, 3=medium or coarse granular and 4=blocky, platy or massive.

c) The LS factor map (Fig. 4) was created from the DEM by using the “Terrain Analysis” in ArcGIS. The procedure is done by filling the sinks of the DEM and calculating the flow accumulation in order to create the slope map. The LS factor was derived from the Stone and Hilborn equation (Eq. 6) (Sinha and Labi 2007).

Equation 6. The LS factor equation.

$$LS = (0.065 + 0.0456 \times s + 0.006541 \times s^2 \times (slope\ length \div 22.1)^{NN}$$

Where s is the slope steepness in %, slope length is the length of slope based on the DEM and NN is a value depended on the average slope (Tab. 1) (Sinha and Labi 2007).

Table 1. The values of NN based on the average slope.

Slope	NN
<1	0.2
$1 \leq s < 3$	0.3
$3 \leq s < 5$	0.4
>5	0.5

d) The C factor reflects the effects of the different land-uses on the rate of the erosion and it is mainly related with the vegetation’s cover percentage (Jones et al. 1996). The C value ranges from 0.001 to 1 (Sinha and Labi 2007). The C factor of each land-use (Fig. 3) was assigned as other similar studies in Greece (Table 2) (Bathrellos et al. 2010; Manolis 2010). Table 2 also shows the conversion of the CORINE land-uses C factor for USLE model.

Table 2. The C factor based on land-use from the Corine 2000 database. In addition the respective land-uses based on the SWAT classification is presented.

CORINE 2000		SWAT DATABASE		USLE
Code	Land-use	Code	Land-use	C FACTOR
112	Discontinuous urban fabric	URML	Urban medium low density	0.001
121	Industrial-commercial unit	UCOM	Urban commercial units	0.05
131	Mineral extraction	UIDU	Urban industrial units	0.05
211	Non-irrigated arable lands	AGRL	Agricultural land Generic	0.05
223	Olives	OLIV	Olives	0.08
243	Agricultural-natural lands	AGRRL	Agricultural land row crops	0.05
311	Broad-leaved forests	FRSD	Forest deciduous	0.004
312	Coniferous forests	FRSE	Forest evergreen	0.004
313	Mixed forests	FRST	Forest mixed	0.004
321	Natural grasslands	PAST	Pastures	0.05
323	Sclerophyllous vegetation	SHRB	Shrubland	0.03
324	Woodlands-shrubs	SHRB	Shrubland	0.01
331	Beaches, dunes, sands	BSVG	Barren-sparsely vegetated areas	0.5
332	Bare rocks	TUBG	Bare ground Tundra	0.5
333	Sparsely vegetated areas	BSVG	Barren-sparsely vegetated areas	0.3
334	Burnt areas	BSVG	Barren-sparsely vegetated areas	0.3
421	Salt marshes	WEHB	Herbaceous wetlands	0

e) The P factor represents the mitigation effects of the different conservation practices like contouring, strip cropping and terraces (Gitas et al. 2009) on soil erosion. In most cases, this value is set to one (1) as there no data to retrieve regarding this factor. In this paper however, an empirical table (Tab. 3) was used in order to create the P factor map (Fig 4).

Table 3. The P factor based on the support practice.

SUPPORT PRACTICE	P Factor
Up and Down slope	1
Cross slope	0.75
Contour farming	0.5
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

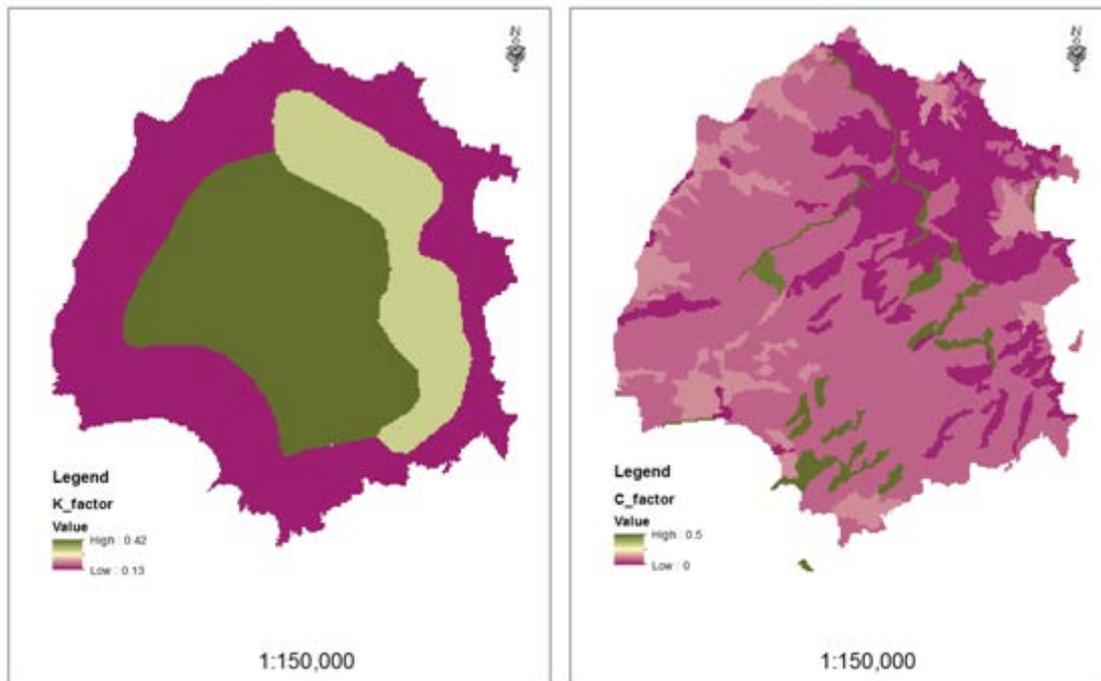


Figure 2. a) The K factor as a raster map for Thassos Island (left), b) the C factor as a raster map for Thassos Island (right).

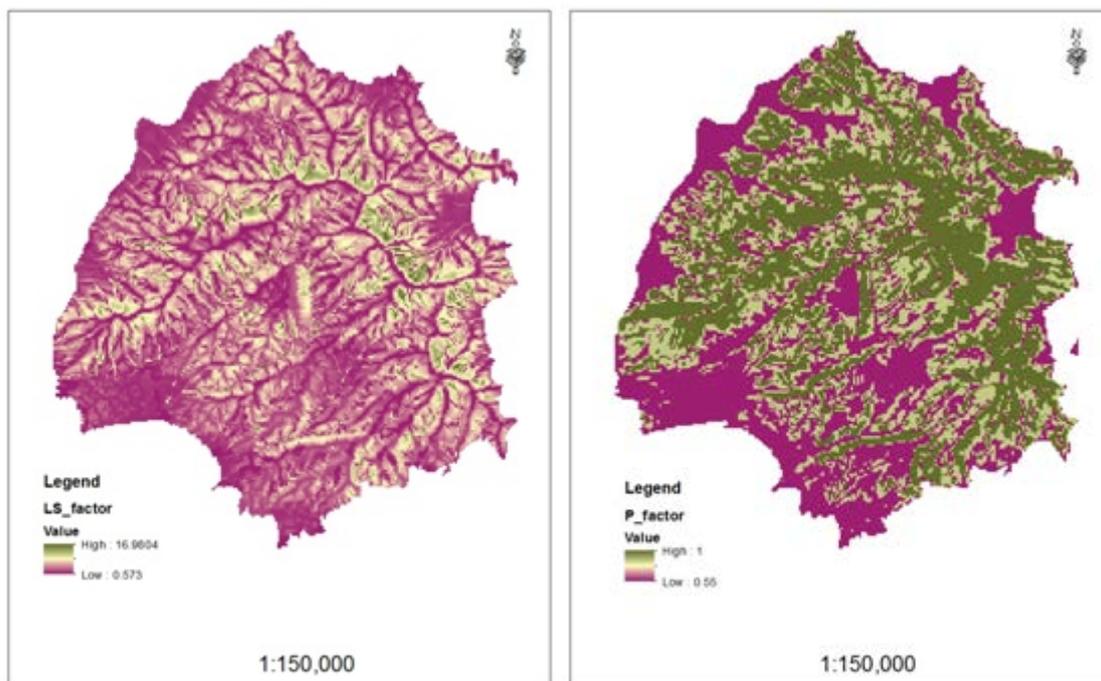


Figure 3. a) The LS factor as a raster map for Thassos Island (left), b) the P factor as a raster map for Thassos Island(right).

3.3. THE SWAT METHOD

The second method used is the Soil and Water Assessment Tool (SWAT). The SWAT has been developed in order to predict the impact of land management practices on water, sediments and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions (Neitsch et al. 2011; Arnold et al. 2012). It is a physically based model which computes readily available data (e.g. weather, soil, vegetation, land management

practices), and allows the study of short to long-term impacts, processing data on a continuous time mode as it receives continuous meteorological time series (Neitsch et al. 2011). The study area is divided into watersheds based on the DEM and these watersheds are further divided into hydrologic response units (HRU) that consist of unique combinations of soils, land-uses and slope categories (Arnold et al. 2012). SWAT simulates the hydrologic cycle, using the water balance equation (Eq. 7).

Equation 7. The water balance equation considered by SWAT.

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - ET_{day} - w_{day} - Q_{gw})$$

where t is the simulation period, SW_t is the soil water content after the simulation period, SW_0 is the soil water content at the beginning of the simulation period, and R_{day} , Q_{surf} , ET_{day} , w_{day} and Q_{gw} are daily values (in mm) for precipitation, runoff, evapotranspiration, infiltration and return flow, respectively. In the second phase it simulates the channel hydrology, where the loadings calculated earlier are routed through the stream network of the basin (Neitsch et al. 2011).

The erosion processes of SWAT include the detachment, transport and deposition of soil particles by the forces of rainfall and surface flow of the water. Raindrop impact can detach soil particles and transport them through the stream network (Neitsch et al. 2011). The SWAT uses the Modified Universal Soil Loss Equation (Eq. 8) (MUSLE) (Williams 1975). The difference from USLE is that the rainfall energy factor is replaced with a runoff factor.

Equation 8. The MUSLE equation considered by SWAT.

$$Sed = 11.8 \times (Q_{surf} \times q_{peak} \times area_{hru}) \times 0.56 \times K_{usle} \times C_{usle} \times P_{usle} \times LS_{usle} \times CFRG$$

where S_{ed} is the sediment yield on a given day (tons), Q_{surf} is the surface runoff volume (mm H₂O/ha), q_{peak} is the peak runoff rate (m³/s), $area_{hru}$ is the area of the HRU (ha), K_{usle} the USLE soil erodibility factor, C_{usle} the USLE cover and management factor, P_{usle} the USLE support practice factor, LS_{usle} the USLE topographic factor and $CFRG$ is the coarse fragment factor given by the equation 9.

Equation 9. The CFRG equation.

$$CFRG = \exp(-0.053 \times rock_{\%})$$

The DEM (Fig. 4a) was inputted in the SWAT model in order to create the streams, the outlets and the watersheds (Fig. 5a). Also the digitized stream network was inserted into the DEM to have more reliable results (Fig. 4b). This process created 145 watersheds for Thassos Island (Fig. 5a). The HRU were defined based on the different soils (Fig. 5b), land-uses (Fig. 6a) and slope categories (Fig. 6b). The weather data of the meteorological station of Limena were added in order to finalize the set up of the model. The erosion map that is finally produced contains the average annual soil losses (in tons/yr) that were transported through the main stream of each watershed.

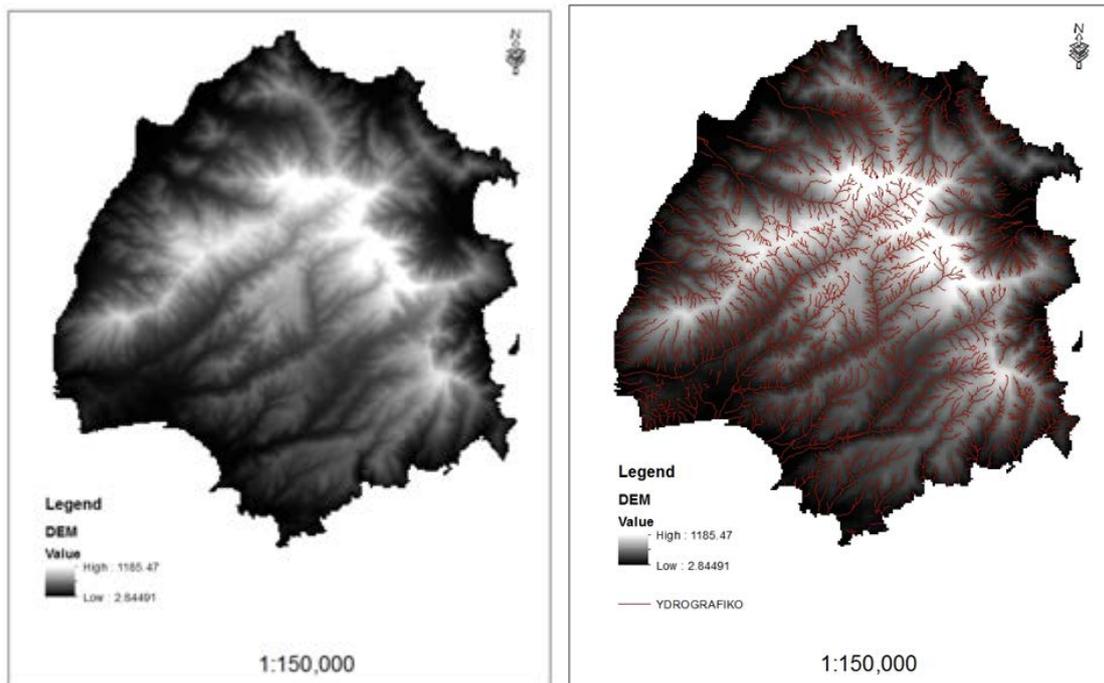


Figure 4. a) The Digital Elevation Model (DEM) of Thassos Island (left), b) The Digital Elevation Model (DEM) with the stream network of Thassos Island (right).

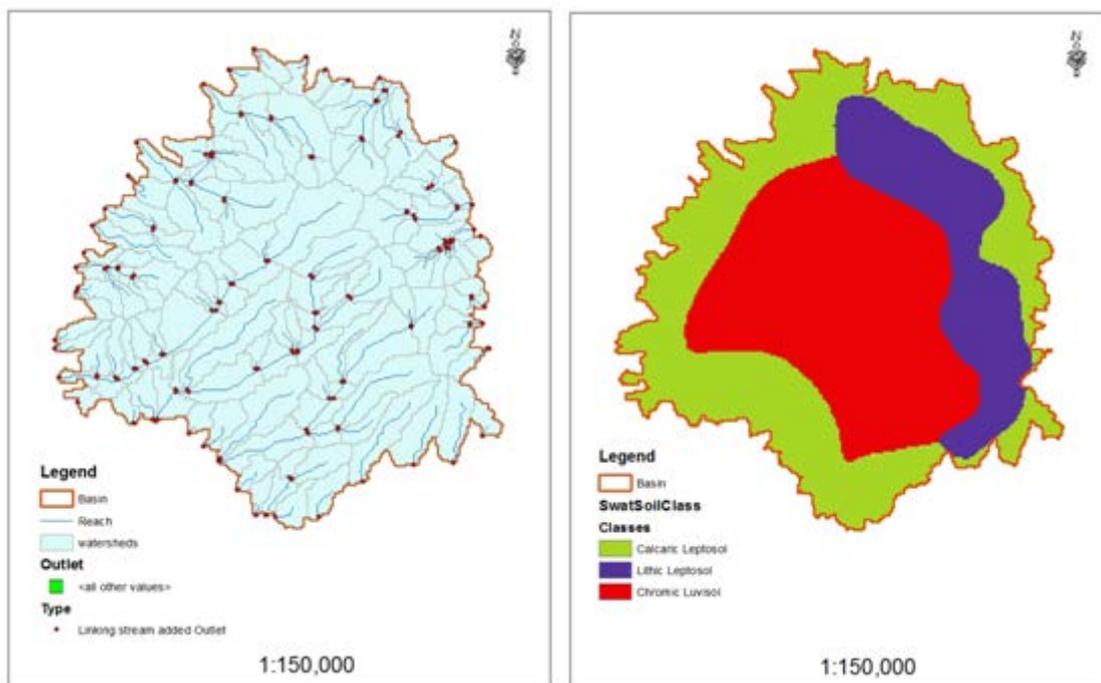


Figure 5. a) The watersheds, streams and outlets of Thassos Islands (left), b) The soil map of Thassos Island (right).

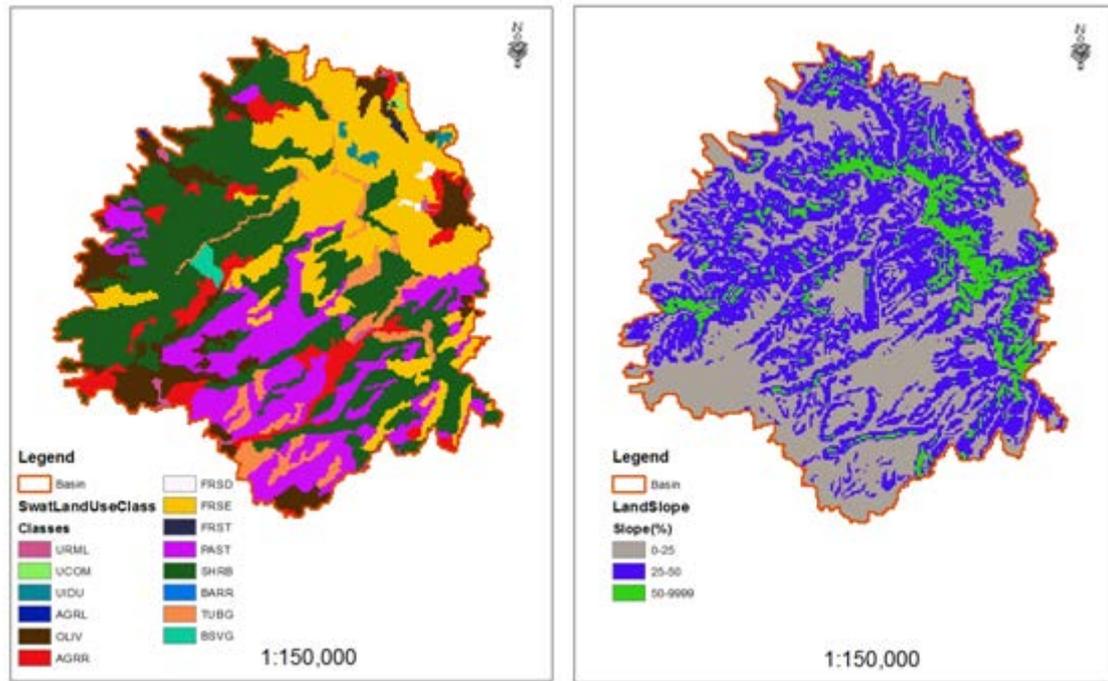


Figure 6. a) The land-use map of Thassos Island (left), b) the slope categories map of Thassos Island (right).

4. RESULTS-DISCUSSION

The results the USLE and the SWAT method are shown in the following Figures 7 and 8, respectively. The factors of equation 1 were defined and were combined into one raster using the “Map Algebra Tool” in ArcGIS. The equation gave an initial value in each cell. In order to obtain a better view and understanding, the values of erosion (in tons/yr) were classified into 8 categories as other similar studies, in order to represent the rate of the erosion: I) 0-0.05 is harmless, II) 0.051-0.1 is very low, III) 0.11-1 is low, IV) 1,1-5 is moderate low, V) 5,1-10 is moderate high, VI) 10,1-20 is high, VII) 20,1-30 is very high and VIII) >30,1 is severe.

On the other hand, the SWAT model produced the results of the streamflow and the sediment yield in each watershed. The values of the watershed sediment yield (Fig. 8) were also classified into the same eight categories.

Based on the USLE method, the highest erosion rates occur mainly in the eastern part of the island, particularly in the higher elevations of Ypsarion Mountain and near the village of Theologos. Also, there are high risk areas near other villages such as southwest of Maries and northeast of Potos. The topographic factor takes very high values due to the steep slopes and in conjunction with the land use and soils that occur in the area indicate the potential of high risk erosion phenomena.

The soil erosion map created by SWAT also indicates that the same areas have a high-risk erosion potential. However, the values are lower than the previous method. The model adds new potential high risk erosion areas that are not shown on the USLE map, mainly in the eastern areas of the island such as the villages of Panagia and Potamia but also in the South-East region near Aliko. In contrast, the areas near the two villages of Maries and Potos are characterized by a moderate erosion risk.

The erosion is frequently a huge contributor to the flood phenomena. Furthermore, areas that were previously burnt are prone to the erosion and also to the flood events. According to Kontos and Chlykas (1997), many recorded forest fires between the period of 1980-2006 burned 75% of the coniferous forests in the areas of Theologos, Limenaria, Maries and Ypsarion. The absence of vegetation enhances the runoff and as the soil cannot be retained the amount of detached soil particles is increased. The excessive loss of soil can cause flood events mainly in low-lying coastal areas such as Potamia, Prinós, Kallirahi, Limenaria and Potos. Such phenomena have been recorded previously in the above mentioned areas by the local authorities.

The two methods calculated the erosion rates with an almost similar equation. The MUSLE equation (used in SWAT) differs from USLE as it replaces the factor of the precipitation with the runoff. The runoff, which is considered as an input for MUSLE, is a better indicator than rainfall for sediment prediction. MUSLE is used to predict the sediment yield on a single rainfall event but it can also be used for an annual prediction. Also, the SWAT model (MUSLE) simulates the erosion in the HRU level and watershed level while the USLE method is more site specific. Further research is needed in order to confirm the accuracy of the results. The estimated values must be compared with field measurements taken from the mentioned locations.

It is also essential to mention that there are some limitations regarding the availability of the required data for both methods. Specifically the limited number of meteorological stations (only one located in Limena) and the coarse soil maps and management practices that were used. These limitations could be minimized by retrieving more detailed data and also by taking field measurements in order to validate the produced results.

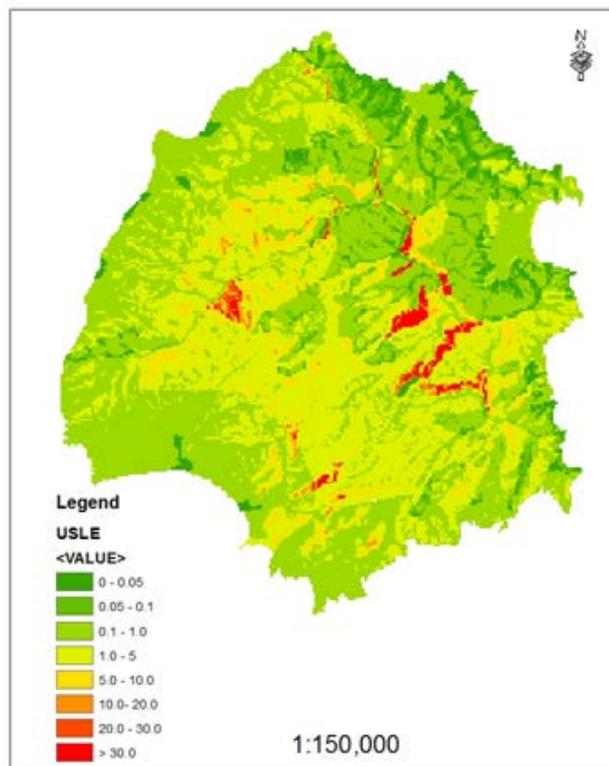


Figure 7. The soil erosion risk map of Thassos based on the implementation of the Universal Soil Loss Equation.

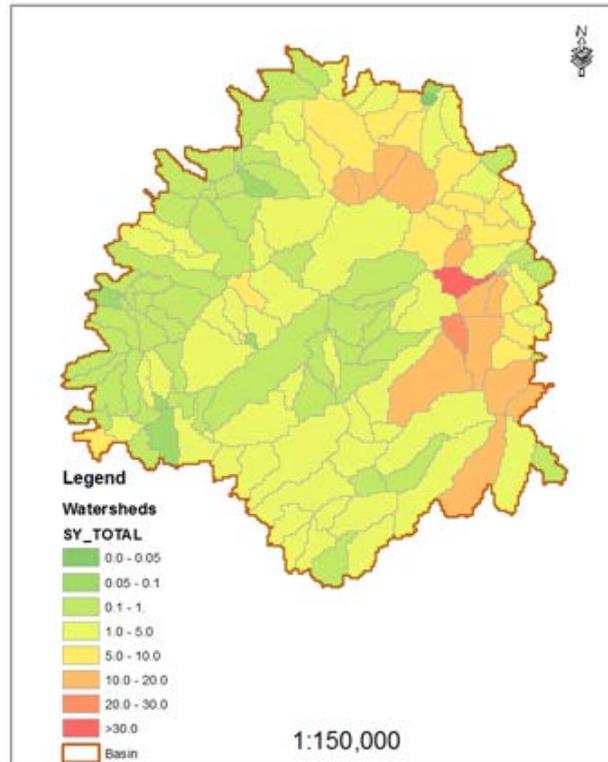


Figure 8. The soil erosion risk map of Thassos Island based on the implementation of the Soil and Water Assessment Tool.

5. CONCLUSIONS

This study is an effort to assess the soil erosion risk map of the Thassos Island. Most studies of Mediterranean island focus on the sea-level impacts or the coastal erosion. However, the specific study is focused on the rainfall-runoff impacts on the land that create the sheet, rill and gully erosion. The assessment was conducted with two methodologies: the USLE method and the SWAT model. The final results of the two methodologies were the creation of the soil erosion maps for the island. Although different methods were applied, the comparison of the two maps indicates the common areas sensitive to high erosion rates. These maps provide essential information to land managers on where the mitigation efforts on soil erosion should be prioritized. Further study is needed in order to obtain a better view of the erosion threat. This can be achieved by taking field measurements. Finally, this will help to make plans and projects in order to secure the effective conservation of the sensitive to erosion areas as well as the people that live there.

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