Soil erosion risk and sediment transport within Paros Island, Greece

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Abstract

Paros Island is part of the complex of Cyclades Islands, situated in the central Aegean Sea, Greece. It is characterized by the Mediterranean type of climate, with abrupt rainfalls and lower temperatures during winters and long term sunshine accompanied by dry periods during the summer, which constitutes a tough environment for the land.

The low vegetation of the island leaves the ground exposed and very vulnerable to erosion. Also the recent change to the activities of the local people from agricultural to touristic ones and especially the abandonment of the agricultural terraces during the last 50 years has influenced the soil cover of the island in an unfavorable way, leading to total soil loss and exposure of the bedrock in many areas. Aggravating this fact, the slopes of the island are high in general terms thus making soil regeneration almost impossible. The soil that is transferred is either moving towards the small alluvial plains or, in most cases, is lost directly to the sea.

In this paper there is an effort to depict the situation that currently exists on the island by pointing out the areas that still appear to be in a high risk for erosion and to estimate the average amount of soil loss. For the later the Universal Soil Loss Equation (USLE) was tested on the data of the island. The application of the USLE took place with the use of MapInfo and ArcGIS Tools.

Keywords: Paros Island, erosion risk, soil loss, modelling, USLE

1. Introduction

Soil erosion is the natural process of soil material and sediment transfer because of the surficial water flow. Erosion depends on a series of different factors such as the climatic status of an area, the vegetation, the soil structure, the topography. A factor that acts as an accelerator to erosion is usually the human intervention, like in the case of land use change or inappropriate land use (Evelpidou, 2006; Hacisalihoglu, 2007).

From the factors mentioned above, the climatic status is the most direct parameter for erosion, since rainfall or snowfall produces the water runoff in streams and rivers, or in areas between streams in the form of sheet flow or rill flow.

For the human activities, one of the most concerning problems caused by erosion, is land degradation. Land degradation occurs mostly because of sheet erosion or rill erosion, processes very usual in areas such as cultivated lands. The eroding capacity of these processes progressively increases downslope and is strongly related to the vegetative cover (Langbein and Schumm, 1958).

A factor that aggravated the erosion rates during the last 50 years in Paros Island, as in many other Cycladic islands was the turn of the local people into touristic professions, thus abandoning the cultivated land of the more disadvantaged areas. The case is more common in the cultivation sites on biggest slopes where the need to create terraces to uphold the soil from eroding, the costs of their preservation, and the inability to use machinery on the crops, often led the farming systems to operate close to the margins of viability. The result from the abandonment of the terraces is the progressive loss of the soil's resources leading to soil thinning and shrub growth. The decreasing landscape diversity makes the area more prone to erosion and fire events (Marin-Yasseli and Martinez, 2003). This is of major importance since erosion of soil and surface rocks are very active processes in the Mediterranean environments (Poesen, & Hooke, 1977).

The effort to overcome the problems caused by erosion, has led to the need for methods to calculate the amounts of soil loss, in order to introduce the necessary soil conservation methods at the time and place it was most needed. The soil loss equation that is used in the most countries, for the most purposes, is the USLE model (Universal Soil Loss Equation). The USLE was firstly introduced in by Wischmeier et al. (1958) and was announced to the form that it is used today by Wischmeier and Smith (1978).

The USLE uses the factors of rainfall erosivity, Soil Erodibility, Slope Length and Slope Steepness, Vegetation and Conservation Techniques as input parameters and calculates the amount of Annual Soil Loss per Hectar. USLE only predicts the amount of soil loss that results from sheet or rill erosion on slopes and does not account for additional soil losses that might occur from gully, wind or tillage erosion.

In this study the USLE was used in the entire area of Paros Island to locate the areas with the major problems, as well as to propose for solutions especially for the arable parts of the island.

2. Area Description

Paros belongs to the complex of Cyclades islands in the Aegean Sea. As seen on figure 2.1 it is situated between Naxos and Sifnos islands and is within a distance of 90 sea miles from Athens.

Paros has an area close to 192sqkm and the landscape is mountainous towards the center of the island, with a highest altitude of 771m. The areas close to the coastline are more flat and the coasts in the NE and the NW are strongly dissected. The biggest plains of the island are those of Naoussa in the North, Marmara in the East, Dryos in the South-East and Pounta in the West (figure 2.1).

The Vegetation on the island is poor and exists mostly on the mountainous part and the South-Eastern Plains where water is more abundant. The South-Eastern plains are the most fertile in the island. The most usual crops are vineyards and wheat, while there are also plantations of olive trees.

The climate is mild Mediterranean, with light winters and very rare frost or snowfall. The summer is cool, with strong winds and extended rainless periods. The prevalent winds are North with a frequency of 55% and are very intense (7 Beaufort). The summer is characterized by North and North-East winds, while spring is characterized by South-East winds. The mean annual Temperature is 18,5^{o}C (HNMS, 1999).

2.1. Geomorphology

As it is already mentioned, the slopes are steeper as we move towards the mountainous part at the center of the island. Though, the main reason for the distribution of the intermediate slope values in Paros seems to be the lithology and the tectonic status.

Likewise, these two parameters influence the drainage network. The directions of the drainage characteristics (streams, watersheds, knick points are often related to the tectonic lines of the area (Evelpidou, 1997).

The coastlines of the island are mostly rocky and characterized by steep slopes usually more than 20%. The flat coasts are met within the bays and generally within the areas with loose material. The sandy coasts are strictly appearing within the small bays of the island and possess the shortest part of the coastline.

2.2. Land Use

In the mountainous area the vegetation is poor and according to the Corine maps the prevalent land covers there are sclerophyllus bushes and natural vegetation. Generally Paros is a non-agricultural island and the only organized cultivations take place in the East and North plains of the island. In the eastern part along with the arable lands, we have olive tree plantations and some vineyards.

The human activities dramatize a very important role on the island throughout history, since from the very old times it was inhabited for the extraction of its marbles of perfect quality. This led to the creation of many extraction sites throughout the entire island. Another characteristic human intervention on the landscape is the construction of innumerous terraces along the mountain slopes. Terraces can be found almost everywhere on the island and were also created during older times, but are still preserved until today as the only way of soil stabilization on the slopes.

3. Methodology

The application of the USLE has taken place within GIS Environment. ArcGIS and MapInfo GIS software were both used for the necessary digitization, the maintenance of the geospatial database and the processing analysis of the input data in order to produce the expected results. GIS technology was combined with GPS technology in order to update during fieldwork, the mapped information.

The primary data were acquired in the form of maps and digitized layers provided by the corresponding Greek Organizations. For this study we acquired the Geological map, scale 1:50.000 (IGME, 1996) and the Land Resources and land Compatibility maps, scale 1:50.000 (NAgReF, 1999) for Paros Island. Also the topographic map, scale 1:50.000 (HMGS, 1970) was acquired as well as the digitized information concerning the Corine Land Cover data of Paros, scale 1:100.000 (HeMCO, 2002). The accurate perimeter of Paros Island was digitized by the LANDSAT satellite image of the island.

The georeferencing and the digitization of the maps and the satellite image occurred in MapInfo GIS environment and the projection system that was used was the UTM WGS 84, zone 32 northern Hemisphere. All the digitized data were imported into ArcInfo/ ArcGIS software, maintaining the same projection system, in order to administrate the database and proceed the analysis to extract the necessary factors for the USLE.

The USLE, is characterized by the following equation (Wischmeier and Smith, 1978):

$$A = R * K * L * S * C * P$$

Where A is the average yearly soil loss (measured in $t \cdot ha^{-1} \cdot y^{-1}$).

Therefore the USLE, in order to operate has an input need for factors concerning:

R = Rainfall erosivity factor [$MJ\ mm\ ha^{-1} \cdot h^{-1} \cdot y^{-1}$],

K = Soil erodibility factor [$t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$],

L = Slope length factor [no dimension],

S = Slope steepness factor [no dimension],

C = Crop management and vegetation cover factor [no dimension],

P = Efficiency of anti-erosion measures [no dimension].

Within ArcGIS, we created a separate information layer for each one of the above factors by retrieving the needed information mostly from the prototype maps.

The next step was the creation of a new information layer containing a grid 5m x 5m that covered the entire area of Paros Island, where for each cell we calculated the corresponding USLE input factors.

The final step was the calculation of the A factor in each cell of the grid, and the results came in map depictions of each input factor as well as the output factor.

3.1. Input Data

R factor:

For the R factor we took into account the monthly rainfall measurements on the island for the 20-year sequence from 1975 to 1995. The mean monthly rainfall values are summarized in table 3.1.A (HNMS, 1999). The R factor, according to the handbook of Wischmeier and Smith (1978) was estimated to be: R = 930 MJ*mm*ha-1*h-1*έv-1, with a 2 year return frequency.

K factor

The K factor was calculated on the basis of the land resource and land capability maps (NAgReF, 1999). The data from these maps referred to soil depth (figure 3.1.1a), erosion rill severity on the soil top structure and aspect. This data was combined with the geological data of the area in order to get information on the bedrock. Finally, according to the study of Christodoulou and Nakos (1999) and the on-site observations we defined the soil textures that appear on the island. The K factor calculation is possible based on soil physical type (clay, sand, sandy clay etc.) (Centeri, 2002). The distribution of the K factor is shown in figure 3.1.1b.

LS factor

For the calculation of the LS factor we created a Digital Elevation Model (DEM) in ArcGIS environment, of 5x5m raster size. The DEM derived from the digitization of the contours per 20m of the local topographic map. The digitization took place in MapInfo GIS and the DEM was created in ArcGIS (Figure 3.1.2a). To calculate the LS factor we set a grid of 5x5m dimensions. The calculation was done for each grid cell separately, using an algorithm firstly introduced by Hickey et al. (1994) which was later alternated to the one used in this study by Pataki (2000). The distribution of the LS factor is in figure 3.1.2b.

C Factor

The C factor was based on the Corine land use and land cover maps. The Corine types that appear on Paros Island appear on table 3.1.B.

For most of the Corine types the C factor is precise and is given by the USLE manual (Wischmeier and Smith, 1978). In the case of arable lands though, it is defined by the type of crop that is used by the farmer. Since the crops are not specific but are decided by each separate farmer, the only way to insert proper C values is to introduce several different scenarios based on different types of crop. In the case of Paros we introduced four different scenarios, which appear on table 3.1.C. The 1st and 4th scenarios also appear on figure 3.1.3

4. Results

The four different scenarios for the C factor, give correspondingly four different scenarios of soil loss on the study area. The table 4.A contains the results of the application of the USLE in each case.

The spatial distribution of the soil loss rates in the 1st and 4th scenario is depicted in the maps of figure 4.1. As we can see from both the maps and the Table 4.A, the lower the C factor, the lower the loss rate. What is important is that it is possible to achieve low C factors even by choosing specific crop types, like in the 1st scenario, so the land use of the specific areas is not necessary to change, in order to prevent the soil loss.

From the maps of figure 4.1 we can see that the areas that are more prone to runoff erosion and soil loss are the highest areas with intense slope values. The four plains of Naoussa, Dryos, Marmara and Pounta appear low soil loss rates at the first scenario, but some parts of the Naoussa and Dryos plain are severely influenced as the scenarios are getting worse.

5. Conclusions

Paros today is a non agricultural island. The cultivations that for many centuries took place on the innumerous terraces within every spot of the island have notably diminished into the late 20th century due to the turn of local people to touristic and other modern professions. This fact aggravated the soil loss rates on the island since the terraces were abandoned decreasing the landscape diversity. The depiction of the soil loss rates with the use of the USLE and GIS software on the island shows clearly that the problem is very intense mostly on the higher slopes and less on the flatter areas of the island. The main active cultivations on the island take part on the East part. The introduction of different crop scenarios on the C factor of the USLE for this case study, shows that selective crops can be really useful in the two main cultivated plains in the North and South-East part of the island even decreasing the soil loss rates in some cases less than 2 t/ha yearly. Along with the selective crops, the preservation and recreation of some terraces even for non agricultural reasons can prove to be effective solutions to the soil restoration on the island.

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Tables

Table 3.1.A Mean Monthly Rainfall Values for Paros isl. in mm. (years 1975-1995)						
Jan	Feb	Mar	Apr	May	Jun	
83,0	63,1	50,5	20,9	8,6	2,2	
Jul	Aug	Sep	Oct	Nov	Dec	Year
0,5	0,4	6,6	40,1	65,0	90,7	431,6

Table 3.1.B. Corine Types on Paros Island			
Code	Area (sq km)	% of tot. Area	Description
111	0,47	0,23	Continuous Urban Fabric
112	3,72	1,87	Discontinuous Urban Fabric
131	0,40	0,20	Mineral Extraction Sites
211	16,71	8,42	Non irrigated arable land
221	0,91	0,46	Vineyards
223	1,93	0,97	Olive Trees
242	51,68	26,04	Complex Cultivation Patterns
243	54,00	27,20	Principally Agriculture, with Natural vegetation
321	32,43	16,34	Natural Grasslands
323	33,27	16,76	Sclerophyllus Vegetation
334	2,97	1,50	Burnt Areas
total	**198,479**	**100**	

Table 3.1.C. C values for different crop scenarios in arable lands		
Scenarios	Type of Crop	C
1st	a. Maximal value for winter wheat or other similar plants (barley, oat etc.). 4-5 years crop stability, with residues worked into the soil, b. Peas, beans, soybean, potato after 1 year with residues left on the surface.	0,1

2nd	a. Maize, sunflower, tobacco, sugarbeet with 1 year crop stability with residues left on the surface, b. Peas, beans, soybean, potato after 3 years with residues worked into the soil	0,25
3rd	Maize, sunflower, tobacco, sugarbeet monoculture after 3 years with residues worked into the soil	0,5
4th	a. Maize, sunflower, tobacco, sugarbeet monoculture after 5 years with residues worked into the soil; b. Orchards	0,6

Table 4.A. Yearly amounts of soil loss in four different scenarios

	A $(t.ha^{-1}.y^{-1})$	Cell Count	Area (km^2)	% of total area
Scenario 1	0 - 2	3201961	80,05	40,33
	2 - 11	2106646	52,67	26,53
	11<	2630555	65,76	33,13
	Total	7939162	198,48	100,00
Scenario 2	0 - 2	2940242	73,51	37,03
	2 - 11	1865043	46,63	23,49
	11<	3133877	78,35	39,47
	Total	7939162	198,48	100,00
Scenario 3	0 - 2	2824400	70,6100	35,58
	2 - 11	1668453	41,7113	21,02
	11<	3446309	86,1577	43,41
	Total	7939162	198,4791	100,00
Scenario 4	0 - 2	2787736	69,6934	35,11
	2 - 11	1635170	40,8793	20,60
	11<	3516256	87,9064	44,29
	Total	7939162	198,4791	100,00

Figure Captions

Figure 2.1. *The Case study of Paros Island.*

Figure 3.1.1a. *Soil Depth Distribution in Paros Island.(NAgReF, 1999)*

Figure 3.1.1b. *Spatial Distribution of the K factor.*

Figure 3.1.2a. *The Digital Elevation Model.*

Figure 3.1.2b. *Spatial Distribution of the LS factor.*

Figure 3.1.3a. *Spatial Distribution of the C factor according to the 1st scenario.*

Figure 3.1.3b. *Spatial Distribution of the C factor according to the 2nd scenario.*

Figure 4.1a. *Spatial Distribution of the Soil Loss Rates according to the 1st scenario.*

Figure 4.1b. *Spatial Distribution of the Soil Loss Rates according to the 2nd scenario.*

Figures

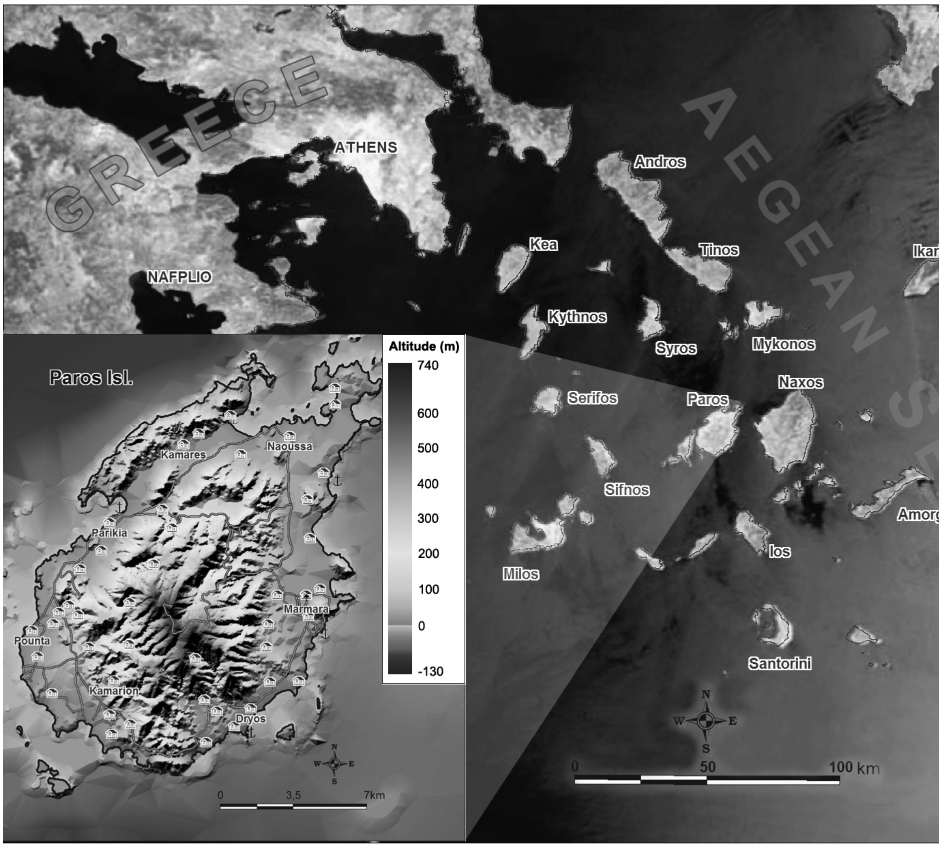

Figure 2.1

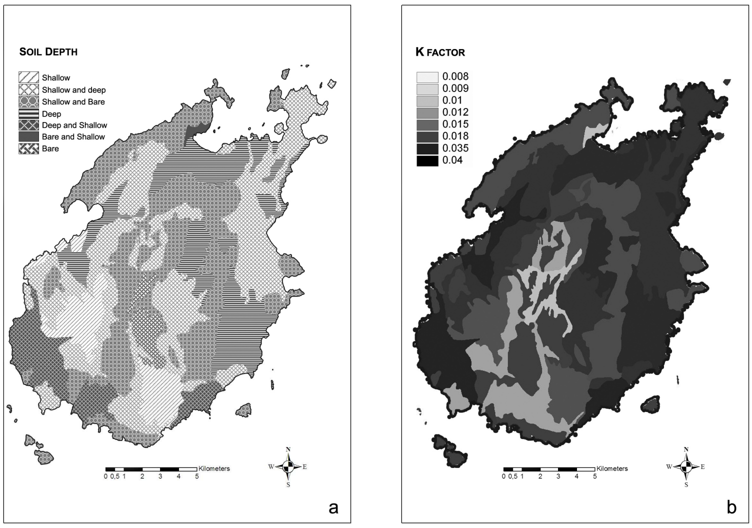

Figure 3.1.1

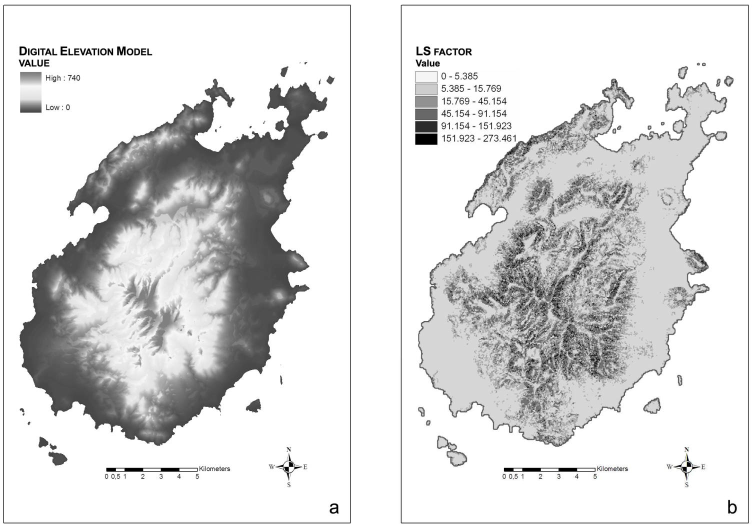

Figure 3.1.2

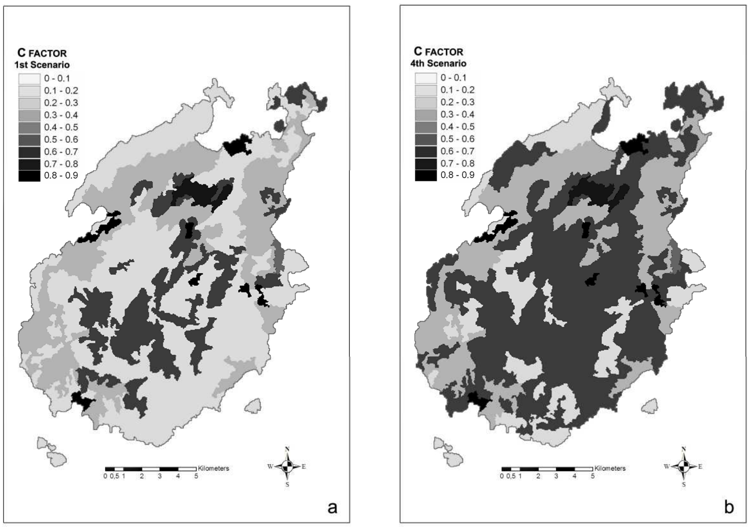

Figure 3.1.3

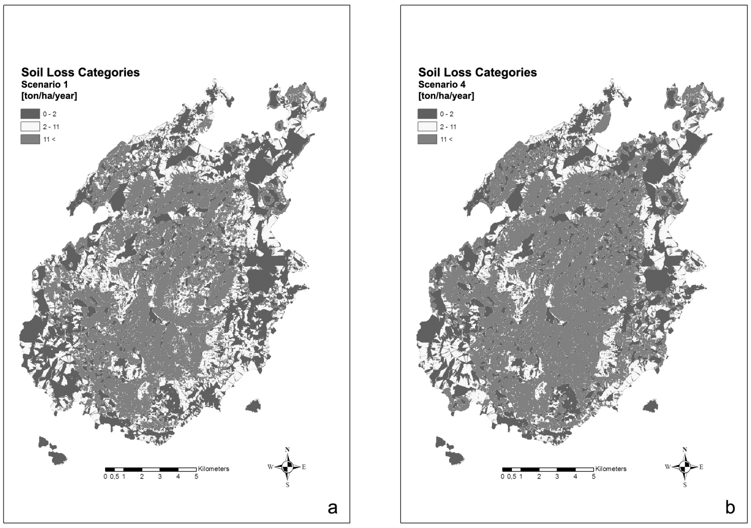

Figure 4.1