ASSESSING SOIL EROSION RISK FOR RHODES ISLAND, GREECE WITH A GIS-BASED MULTI-CRITERIA DECISION ANALYSIS

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ABSTRACT
Reducing erosion in the Mediterranean region is a major priority because of its susceptibility and millennia long human inhabitation. The objective of this paper was to assess soil erosion risk on the semi-arid island of Rhodes, Greece. Rhodes has many protected areas that are part of the Natura 2000 network. To implement this assessment a Geographic Information System based Multi-criteria Decision Analysis was conducted. The Multi-criteria Decision Analysis was a combination of the Analytic Hierarchy Process and the Weighted Linear Combination. The criteria used, in the order of importance, were: I) Land-use, II) Slope, III) Normalized Difference Vegetation Index (NDVI), IV) Geology, V) Distance from Streams, VI) Fire Density, VII) Precipitation, VIII) Soil Quality, IX) Flow Length, X) Distance to Roads XI) Aspect and XII) Wetness. The final erosion risk map for the entire island had ranking values only of 3-6 although the scale ranged from 1-9. This indicates that there are no areas with extreme erosion risk. While less than 1% of the area had an erosion risk of 6, a significant percentage (15.4\%) ranked as 5. Land managers should firstly implement best management practices in these areas (ranked as a 5 and 6). When comparing the Natura 2000 areas to the non-Natura 2000 areas, the Natura 2000 had a larger percentage (~ 6\%) of areas that ranked as 5, while the non-Natura 2000 areas had a larger percentage (~ 6\%) of areas that ranked as 4. Since the Natura 2000 areas are protected by the European Union, it was expected that they would be less vulnerable to erosion. The percentages of this study indicate that additional measures need to be implemented in these Natura 2000 areas to reduce soil erosion.

KEY WORDS
Soil erosion, geographic information systems, risk assessment, best management practices, non-point source pollution, watershed planning

1. Introduction
Soil erosion is a natural geomorphologic phenomenon but today it is one of the most serious environmental problems in the world [1]. Unsustainable anthropogenic activities have accelerated soil erosion worldwide, especially since the beginning of the 19\textsuperscript{th} century [2, 3]. These activities have resulted in substantial changes of the natural vegetation cover that lead to soil erosion levels that exceed soil formation levels (soil forms slowly). Reducing soil erosion is essential because it threatens the sustainability of agriculture, natural resources and the environment. Common problems linked to soil erosion include loss of the fertile topsoil of agricultural areas, siltation of streams and lakes, eutrophication of surface water bodies, loss of aquatic and land biodiversity and land degradation and desertification [4]. The Mediterranean region has been impacted by humans more than any other region in the world [5]. These impacts are evident in the few remaining patches of natural ecosystems as well as the unsustainable agricultural lands of the region. The semi-arid and arid environment also limits vegetation growth and cover, leaving large tracts of land vulnerable to intense precipitation events that lead to accelerated soil erosion. In the European Union in order to conserve and protect its biodiversity, while also ensuring the sustainability of its agriculture, energy and transport policies, the Natura 2000 network has been established [6]. The successful protection of the biodiversity of an area can be achieved by minimizing the major risks, such as soil loss [4, 7]. To accurately estimate soil erosion loss or vulnerability, a large number of different parameters such as soil conditions, climate characteristics, topography, vegetation and ground cover, need to be taken into consideration [8]. Soil erosion loss and soil vulnerability have also very high spatial variability. Field measurements are time-consuming and expensive, so other tools need be used to estimate soil erosion, especially for large areas.
Specifically models have been developed to study soil loss [9] such as the USLE [10] and its successor the RUSLE. However, these models in many cases are inaccurate when applied over wide regions because they aim at evaluating soil loss quantitatively. Spatial technologies, such as GIS, in combination with an ‘expert system’ can be powerful tools for an ecological and environmental assessment [11, 12]. An expert system is a computer-based system that employs reasoning methodologies to transfer expertise and produce recommendations, much like a human expert [13]. Incorporating a Multi-criteria Decision Analysis (MCDA) is among the most flexible and intuitive methods of expert knowledge systems incorporated into the GIS [14, 15]. Implementing an integrated analytical approach can be a great tool in assessing soil erosion risk for land managers because of the many problems they face when trying to quantify relationships between soil erosion and the factors that influence it. The objective of this study was to assess the areas that have the greatest risk of soil erosion on the semi-arid Mediterranean island of Rhodes, Greece. Comparisons in erosion vulnerability were also done among the Natura 2000 areas of the island and the non Natura 2000 areas.

Natura 2000 areas are expected to have substantially lower erosion vulnerability since they are protected. Assessing the erosion risk of the various areas of the island could help land managers to concentrate the best management practices for preventing soil erosion particularly to the areas of “greatest risk”. This could help implement best management practises that are cost-effectively and minimize soil erosion the most.

2. Methods and Materials

2.1 Study Area

The study site was the island of Rhodes (36°10′N 28°0′E) of Greece (Figure 1). It is located in the southeastern Aegean Sea, northeast of Crete, southeast of Athens and southwest of the coast of Turkey. It is the largest of the Dodecanese islands (prefecture of Greece) in terms of both land area and population, with a population of 163,000. It has a spearhead shape (80 km long and 38 km wide), with a total area of approximately 1,400 km². The climate is Mediterranean with warm and dry summer and mild and moist winter. Maximum temperatures in the summer can reach 34°C, while minimum temperatures in the winter can reach 10°C. Most rainfall occurs from November till February.

The municipality and principal town of the island is also named Rhodes and has approximately 54,000 residents. It is located at the northern tip of the island. The city of Rhodes is famous for the Colossus of Rhodes, one of the Seven Wonders of the Ancient World, the medieval Old Town of the City of Rhodes, while it is one of the most popular touristic destinations in Europe. Along the seacoast, as expected, there are many sandy beaches, while the interior of the island is quite mountainous. It is sparsely covered with pine (Pinus brutia) and cypress (Cupressus sempervirens) forests and shrublands (primarily phrygana) (Figure 2). There are also arable strips of land where citrus fruit, wine grapes, vegetables, olives and other crops are grown (Figure 2). The island also has unique fauna, such as the Rhodian fallow deer that has proved to be genetically distinct (in 2005) and is of urgent conservation importance. In Petaludes Valley, large numbers of tiger moths are gathered during the summer months. The island has five Natura 2000 areas with some of their protected areas overlapping. These are the following: 1) Akramytis, Armenistis, Attavyros, Remata kai Thalassia Zoni (Karavola-Ormos Glyfada) (GR 4210005), 2) Profitis Ilias, Epta Piges, Petaloudes, Remata (GR 4210006), 3) Profitis Ilias, Epta Piges, Ekvoli Loutani, Katergo, Rema Gadoura, Chersonisos Lindou, Nisides Pantanisa kai Petropolis, Lofos Psalidi (GR 4210029), 4) Oroi Attavyros & Akramytis, Techniti Limni Apolakkias kai Nisides Georgiou, Strongyli, Chteniew & Karavolas and 5) Notio Akro Rodou, Prasonisi, Ygrotopos Livadi Kattavias (GR 4210031), 5) Oroi Attavyros & Akramytis, Techniti Limni Apolakkias kai Nisides Georgiou, Figure 1. The study area, Rhodes island of Greece. The area in gray is not protected. The other colours indicate the Natura 2000 network protected areas of the European Union.
Strongyli, Chteniew & Karavolas. The Natura 2000 areas cover approximately one third of the entire island. Despite the declaration of these areas as protected, minimal management measures have been taken to enhance their protection.

2.2 Geographical Information System based Multi-Criteria Decision Analysis (GIS-based MCDA)

The MCDA is a formalized method that facilitates knowledge mining and its translation into a computer language, most often by means of assigning weights for the most influential factors [13, 15]. For each factor a weight is given that represents the importance that an expert attributes to the factor regarding how it affects the studied phenomenon (e.g. soil erosion). This is a method that is widely used although problem structuring (a very critical part) can lead to different weights and rankings [16]. In this study the MCDA method was within a GIS-based environment and a combination of the Analytic Hierarchy Process (AHP) and the Weighted Linear Combination (WLC).

Specifically to implement this methodology four steps were required: I) Criteria selection, II) Application of the pair-wise comparison method (AHP) for placing weights on the criteria, III) Gathering of GIS and remotely sensed data for the spatial database design of the criteria and IV) Application of the GIS-based WLC method to create a risk map regarding soil erosion potential.

2.2.1 Selection of the Criteria

The selection of the criteria for the implementation of MCDA was done based on the literature, the data available for the study area and the authors’ personal expertise on soil erosion. A total of 12 criteria were chosen for the analysis taking into account topographic, environmental, climatic and anthropogenic parameters (Table 1).

Table 1. The ranking of the twelve criteria and their assigned weights.

<table>
<thead>
<tr>
<th>RANK</th>
<th>CRITERIA</th>
<th>WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Land Use</td>
<td>17</td>
</tr>
<tr>
<td>II</td>
<td>Slope</td>
<td>15</td>
</tr>
<tr>
<td>III</td>
<td>NDVI</td>
<td>13</td>
</tr>
<tr>
<td>IV</td>
<td>Geology</td>
<td>11</td>
</tr>
<tr>
<td>V</td>
<td>Distance from Stream</td>
<td>9</td>
</tr>
<tr>
<td>VI</td>
<td>Fire Density</td>
<td>8</td>
</tr>
<tr>
<td>VII</td>
<td>Precipitation</td>
<td>7</td>
</tr>
<tr>
<td>VIII</td>
<td>Soil Quality Index (SQI)</td>
<td>6</td>
</tr>
<tr>
<td>IX</td>
<td>Flow Length</td>
<td>5</td>
</tr>
<tr>
<td>X</td>
<td>Distance from Roads</td>
<td>4</td>
</tr>
<tr>
<td>XI</td>
<td>Aspect</td>
<td>3</td>
</tr>
<tr>
<td>XII</td>
<td>Wetness TC3</td>
<td>2</td>
</tr>
</tbody>
</table>

A brief description of each criterion follows: I) Land Use. The current land use can have major positive and negative impacts of soil erosion. In this study the land uses were: urban, agricultural, forested, shrublands, water, mining, agroforestry, sparsely vegetated areas and sandy areas. II) Slope. Topography is very influential in many soil erosion processes. Erosion is dependent on the slopes length, steepness and shape. The slope classes are in Table 2. III) Normalized Difference Vegetation Index (NDVI), is the most common vegetation spectral index. The NDVI combines the reflectance in the R (Red) and near infrared (NIR) spectral region and is a measure of vegetation density, health and heterogeneity [17]. It has a theoretical range of values between -1 (no vegetation) to +1 (very dense vegetation). In this study the ranges were from -0.45 to +0.53. IV) Geology. On the island of Rhodes the following types were found: i) Calcite reginae and grey Mediterranean soils, ii) Marle-type reginae, dry reginae, grey silva soils and Regosols, iii) Alluvial deposits in mixture with Regosols, iv) Medium depth Grey and grey-red soils in mixture with sceletic features and v) Alluvial acidic (Table 2). V) Distance to Stream. The closer an area is to the stream the greater the potential for the sediment to reach the streams.Buffers around both sides of the stream were developed at 50, 100, 150 and 200 m

Figure 2.Rhodes Island has different land-uses. The top picture shows orchards within natural vegetation, the middle natural forested and sparsely forested areas and the bottom shrublands and bare areas.
(Table 2). VI) Fire Density. This was measured as the fire occurrences per square kilometer. In fire-prone regions such as the Mediterranean, fire events need to be considered in the soil erosion estimations. Soil structure can be destroyed and water infiltration rates can be reduced, producing rapid runoff and hillside erosion, in areas greatly heated by fire [18]. VII) Precipitation. High intensity and long duration precipitation events lead to higher runoff events and amounts. On Rhodes Island, annual precipitation had two ranges, 601-800 and 801-1200 mm. VIII) Soil Quality Index (SQI). Soil quality influences infiltration, runoff and erosivity. SQI is given by the geometric average of the indexes of four parameters and is calculated as: (Parent Material x Soil Depth x Soil Texture x Soil Slope)\(^{1/4}\) [19]. IX) Flow Length. It describes the time water will take to reach the outlet. It is estimated as the distance from any point in the watershed to the watershed outlet and measured along the direction of flow. The flow length assigned to the outlet pixel is zero. Assuming constant flow velocity the pixel with the greatest flow length to the outlet represents the hydrologically most remote pixel [20]. X) Distance from Roads. Roads increase runoff and consequently erosion. A 30 m buffer was placed along all type of roads. XI) Aspect. Aspect impacts the amount of sunlight that an area receives. This influences soil (e.g. weathering, soil moisture) and water processes (e.g. evaporation) and consequently soil erodibility. The four basic aspects were used. XII) Wetness TC3. In this study the Tasseled Cap-wetness (TC3) Linear transformation was used that contrasts TM bands 1–5 and 7 [21]. TC3 emphasizes the mid-infrared bands and may be related to vegetation and moisture conditions.

2.2.2 Pair-wise Comparison

A pair-wise comparison is considered an advanced approach to corroborate a reliable definition of the relative importance according to the decision maker’s preferences. The comparison between every possible pair of criteria is carried out by means of an importance scale (with values ranging typically from 1 to 9) in the form of a relative matrix developed by Saaty [14, 22]. In this study this was conducted with the AHP. The value 1 indicates that two criteria are “equally” important and the value 9 implies that one criterion is “extremely” more important. The results of these comparisons among each criterion determine the weight of each criterion. The weights derived for each criterion are illustrated in Table 1.

2.2.3 Data Used

To estimate the values of the above criteria, a number of different datasets were used. Specifically: i) Landsat TM-5 satellite imagery (10/8/2011) were used to assess the Land use (classification according to CORINE program) and to derive NDVI and Wetness TC3, (ii) Digital Elevation Model (DEM) 30 m resolution were used to derive Slope, Flow Length and Aspect, (iii) spatial data developed by European Topic Centre on Terrestrial Environment and were used for the SQI, iv) Digital maps for the Geology, Stream Network, Precipitation and Road Network, and v) historical records for Fire Density. The values of some of the criteria were numerical (e.g. slope, precipitation), while for others categorical (e.g. land-use, geology). Each value of each criterion received an expert value that could range from 1-9. This was done so all values of all the criteria had the same numerical scale. A value of 1 indicated minimum erosion risk, while a value of 9 indicated maximum erosion risk. The values assigned to each variable of each criterion were based on the soil erosion literature and the expertise of the authors and other soil erosion experts. Examples of the values of the variables of only three criteria are presented in Table 2.

### 2.2.4 GIS-based Weighted Linear Combination

Once the erosion values for each criterion were in a digital and in the GIS environment the degree of erosion risk for each pixel was estimated with the WLC method [23]. The values of the criteria were based on the expert values (Table 2), while the criteria corresponding relative weights were derived from the pair-wise comparison (AHP) (Table 1). In the WLC, the values of all criteria are overlaid and multiplied with its corresponding weight in each pixel and the integrated value is used to determine the final risk score. The integrated assessment value of

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>Numerical or Categorical VALUES</th>
<th>EXPERT VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLOPE</td>
<td>&lt; 10°</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>11-20°</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>21-30°</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>31-40°</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>41-50°</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>&gt; 51°</td>
<td>9</td>
</tr>
<tr>
<td>GEOLOGY</td>
<td>Medium depth grey and grey-red soils in mixture with sceletic features</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Calcite reginae and grey Mediterranean soils</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Marle-type reginae, dry reginae, grey silva soils and Regosols</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Alluvial deposits in mixture with Regosols</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Alluvial soil acidic</td>
<td>8</td>
</tr>
<tr>
<td>DIST. TO STREAM</td>
<td>151-200 m</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>101-150 m</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>51-100 m</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>0-50 m</td>
<td>9</td>
</tr>
</tbody>
</table>
each pixel is the sum of the corresponding weight values of all the factors and is expressed by the following equation:

$$ R_i = \sum_{i=1}^{n} W_i X_i $$

where $R_i$ is defined as the value of risk of pixel $i$, $n$ the number of criteria used, $W_i$ is the weight of a criterion $i$ and $X_i$ is the rank of criterion $i$ according to the range of the criterion values. The value of risk of each pixel based on all the criteria will provide the input for the production of the final map of the study area.

3. Results and Discussion

Assessing soil erosion is difficult since multiple factors influence it. Each factor (criterion) influences soil erosion in a different way. This was evident in the map of each criterion that had different high, medium and low soil erosion risk areas (Figure 2).

In the study area the integrated risk values based on all 12 criteria ranged only from 3-6 (Figure 3 and 4) although the original scale ranged from 1-9. These results show that there are no areas that have a high risk of erosion (with values of 7, 8 and 9). Even the areas with a value of 6 were minimal (< 0.5%). Still, a significant percentage of the island had a moderate risk for soil erosion (values of 4 and 5). These are the areas that should be of main concern. The conservation practices implemented should initially focus in the areas with values of 5 and greater. The map with the integrated risk values also indicates the high spatial variability of soil erosion. The areas ranked with 5 were all over the island. This indicates that in order to implement cost-effective soil conservation measures, specific areas need to be targeted. Other studies have also found that if conservation practices are implemented randomly, the conservation measures are not always a success [24, 25]. Spatially distributed soil erosion risk maps can provide a starting point for policy makers and land managers when implementing regional intervention policy for soil erosion control and conservation [8, 26].

A careful examination of the areas that have the highest erosion risk (primarily values of 5 and 6) in our study areas revealed two distinct patterns. Specifically, there is a large area with these values in the central western part of the island. This is where Attavyros Mountain is located with many bare areas and sparsely vegetated areas, primarily phrygana shrublands (Figure 2). Phrygana are widespread in Greece since they are adapted in areas with long, dry and hot summers and mild and rainy winters. Their soils profiles are typically thin with residual clays and oxides that favour shrubs such as Quercus coccifera and Sarcopoterium spinosum rather than vigorous grass growth. The results of the MCDA of this study correspond well with a field study, also conducted by the authors in Rhodes island, that found that the phrygana shrubland areas had 5-13 times higher soil erosion rates than the forested areas and the vineyards of the island [27].

Other areas that seem to have high values of erosion risk are those adjacent to streams, the riparian areas, especially in the lower elevation areas. Riparian areas are of great conservation interest because of the many ecosystem services they offer [28]. Some of these services include wildlife and fish habitat, recreation opportunities, water protection from non-point source pollutants and protection from flooding. Riparian areas are considered the most degraded ecosystems by humans [28]. Interestingly, few studies have been conducted in Greece regarding riparian areas [29]. More research needs to be done on how to protect Greek riparian areas in order to fill this scientific gap.

When comparing the Natura 2000 areas to the non Natura 2000 areas the results were not as hypothesized (Figure 3 and 4). It was expected that since the Natura 2000 areas are protected they would have areas with smaller soil erosion risk values. This was the case when comparing areas that had a risk value of 4 but the opposite was observed in the areas with a risk value of 5 (Figure 4). Specifically, the Natura 2000 had approximately 47.7% of their areas with a risk value of 4 while the non Natura 2000 had a higher percentage with approximately 55.0%. In contrast, the Natura 2000 areas had approximately 19.6% of their areas with a risk value of 5 that was higher than the non Natura 2000 areas that had a percentage of only 13.1%. For a risk value of 3 the percentages among the Natuta 2000 and non Natura 2000 areas were similar while for the risk value of 6 the percentages were quite small (< 0.5%). Overall, the results indicated that more conservation practices need to be implemented in the Natura 2000 areas, since soil erosion risk could be considered similar or even worse in these areas than the rest of the island. The conservation practices implemented particularly in the Natura 2000 should be environmentally-friendly because these areas could provide great opportunities for ecotourism. These practices should include primarily replanting efforts of native vegetation. In cases were erosion cannot be stopped with just replanting, bioengineering techniques that are minimally intrusive to the environment should be implemented. These should be implemented in burned areas, steep slopes of bare areas and bare stream banks. Examples of such techniques include live-staking, brush-mattress, wattle fences, prevegetated mats and fascines.

A study for the Mediterranean region recognized that one of the major threats that will increase in Rhodes Island because of climate changes is soil erosion [30]. Climate change will lead to longer drought periods and more intense rainfall events. These conditions will lead to higher and more surface runoff increasing sediment transport capacity, while longer droughts will enhance the potential of severe fires. Careful and effective management plans that consider climate change impacts need to be developed for the island of Rhodes.
Figure 3. The final soil erosion risk (vulnerability) map by combining all 12 criteria with the Weighted Linear Combination (WLC) method. The map on the left is for the entire island of Rhodes, the middle map is only for the 5 protected (Natura 2000) areas and the map on the right is for the non protected 2000 areas.

Figure 4. The percentages of areas in each ranking category for the entire island of Rhodes, for the protected (Natura 2000) areas and for the non Natura 2000 areas. These percentages are based on twelve criteria after using the Weighted Linear Combination (WLC) method.
4. Conclusion

Soil erosion risk for the island of Rhodes was moderate. This is especially encouraging since Rhodes is a semi-arid island in the Mediterranean that typically faces many erosion problems. Still, erosion does occur and conservation measures need to be implemented. The need for conservation practices is also required because of climate change impacts that will increase soil erosion in the Mediterranean region, particularly its islands.

The high spatial variability, in regard to the risk values, indicated that in order to place cost-effectively conservation practices a targeted approach is required. The development of such an erosion risk map, based on important factors that cause soil erosion, can indicate to the decision makers and land managers what areas should be targeted first. Nonetheless, for the final conservation site selection field validation is required.

The areas that have the highest erosion risk appear to be on Attavyros Mountain and the riparian areas of the streams that flow on the island. Phrygana that are sparsely vegetated shrublands dominate the Attavyros Mountain and have been found to be susceptible to erosion. As for the riparian areas, because of the many ecosystem services they offer, establishment of conservation practices should be a high priority.

Since the island has many Natura 2000 areas and many visitors because of its natural beauty, the conservation measures implemented to reduce soil erosion, need also to be environmentally friendly. These conservation measures should be primarily replanting of native vegetation. In cases where is difficult to reduce erosion only with replanting, bioengineering techniques should also be implemented.

Finally, the Natura 2000 areas do not seem to have significantly lower erosion risk than the non Natura 2000 areas. This indicates that the measures implemented up to this point (that are minimal) have not been very successful. Because these areas are of great biodiversity importance, decision makers and land managers should firstly focus on implementing conservation practices in these protected areas.

References


