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(Article begins on next page)

26 April 2024

Research Article   **Open Access**

GIS and Remote Sensing Technologies for the Assessment of Soil Erosion Hazard in the Mediterranean Island Landscapes

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Abstract The islands of the Mediterranean Sea are widely subjected to desertification problems due to the concurrent impact of deforestation and climate change leading to soil losses. The Cyclades islands represent a typical example of such a situation and in particular the island of Naxos is a very suitable prototype site for studying the evolution, the characteristics and the possible methods to mitigate soil erosion and soil loss risks. Here we develop an RS and GIS-based method to evaluate a multi-temporal model for soil loss prediction and management in Naxos. The model, a modified distributed version of the USLE equation, is based on a set of variables depending on land cover, soil characteristics, hydrology and morphometry. Remote sensing techniques and field surveys and measurements, applied to different periods of time from 1987 to 2006, have been used to produce GIS based soil, land cover, topographic and geological maps. Such data has been used to assess the soil loss potential through the distributed cell-based application of the modified USLE equation using GIS tools. The results show that there has been a notable increase in soil losses from 1987 to recent times and that future scenario forecast a possible complete loss of soil in the Naxos Island in the next century, unless countermeasures are taken. We demonstrate that soil conservation practices have degraded in the last 30 years mainly due to the widespread change of land use and to the progressive abandon of agriculture from rural communities that have shifted their main activity towards tourism development and exploitation. Possible countermeasures are represented by the restoration of terracing systems throughout the island and by the construction of micro-dams acting as sediment repository and water storage system within steep sloping channels.

Keywords *Soil Erosion; Naxos Island; USLE; Landsat; ASTER; Soil Depth*

1. Introduction

Mediterranean islands are characterized by a widespread scarcity of forest coverage. This trait is a known heritage of centuries of man overexploitation with respect to the environment. It is known, in fact, that most of the islands in the entire Mediterranean Sea were completely vegetated by dense forests at the beginning of historic times. Main clearances started around 8000 yrs BP (Ruddiman,

2003) and were probably concentrated in the period between 8000 and 2000 yrs BP in the Mediterranean area (Zohary and Hopf, 1993).

After the starting of the main civilizations facing the challenge of navigation for exploration and commerce, the forests which were typical of such environments were quickly depleted so that just after the tenth century A.D. most of the main islands were already bare lands. Nowadays, only a few of them have been partly reforested (for example the Elba island in Italy) whilst the great majority still show a landscape typical of semi-arid climates. Some authors have recently verified that this trend will be further increased by climate change, with a general shift from humid to semi-arid conditions in all the Mediterranean (Nunes et al., 2008).

In such conditions the probability for accelerated soil erosion is high, also owing to the rainfall regimes typical in the Mediterranean, characterized by very dry summers, mild winters and high frequency of severe, intense rainstorms which strongly contribute to the annual total rainfall.

The status of soil in most of the islands is thus critical and it has even worsened in the last twenty years by the increase of meteorological extremes probably connected to climate change.

The soil is a non-renewable resource that is crucial for the ecosystems equilibrium and existence. At the same time, it is also of paramount importance for agriculture, a very important component of socio-economic welfare for the Mediterranean populations, and for cultural heritage protection (Canuti et al., 2000). The rate of soil depletion by accelerated erosion is therefore a fundamental indicator of sustainability (Pimentel et al., 1995; Bianchi and Catani, 2002; Montgomery, 2007), especially in insular ecosystems which are by definition closed, fragile and vulnerable to rapid changes. Despite the wide diffusion and perfection level of hydrological-erosive models able to predict losses, one of the main challenges in fighting soil erosion is the lack of up-to-date information on the fundamental parameters and on the rate and spatial extent at which depletion processes operates (Bianchi et al., 2001, Rossi et al., 2013). An important research issue is thus the development, implementation and proposal of methods able to gather and summarize distributed continuous environmental information related to the assessment of soil erosion over large areas with the purpose of building future scenarios and designing possible countermeasures. The European Union, through the establishment of the Joint Research Center (JRC) Soil Portal and the funding of specific projects on soil protection (such as the ENVASSO http://eusoils.jrc.ec.europa.eu/projects/envasso/) has defined the main key points for soil conservation and proposed a process-based spatially distributed soil erosion assessment model (the Pan-European Soil Erosion Risk Assessment PESERA model, Kirkby et al., 2008) which gives an estimate of soil losses for the entire EU territory. This estimate, even though derived from a specific and modern soil erosion model, is carried out at a scale (grid map at spatial resolution 500 m) which is not suitable for assessing the local distribution of hazardous areas within Mediterranean complex landscapes such as islands or coasts. Therefore, a simple soil erosion mapping method able to make use of easily available local data in a GIS environment to produce high resolution estimates of soil losses at the basin scale is still needed.

In this work we explore these issues with the help of a test site represented by the island of Naxos (Cyclades, Greece) and we show how a simple combination of field techniques and remote sensing GIS applications can be used to map the spatial extension and intensity of potential soil losses over time. After a brief explanation of the environmental settings we will then describe the methods and materials used for the study and thence focus on the results which compare the situation in 1987 and 2006.

2. The Island of Naxos

The island of Naxos is located in the middle of the Cyclades archipelago (Greece) in the eastern part of the Mediterranean Sea (Figure 1) and is the largest, with an area of about 430 km^2 and a coastal perimeter of 148 km. The topography of the island is varied with flat coastal margins to the west and steep rocky cliffs to the north-eastern part. The main elevation (1001 m.a.s.l.) is reached at the top of mount Zas but most of the interior is characterized by high relief energy, rugged terrain and mountain ecosystems. By contrast, on the coasts, especially to west and south-west, gentle hills, dunes and alluvial plains are dominant. There, the main agricultural settlements were located since ancient times. One of the peculiar features of Naxos, with respect to the other Cyclades, is, however, the presence of important villages in the interior mountain part of the island. The principal activities carried out in such areas are pasture and mining. It is clear that pasture in particular has exerted a strong impact on soils which were already endangered by clear cutting.

As to the climate, Naxos shows again something very specific. The rainfall regime is typical of Mediterranean islands, with a very dry summer (average monthly rainfall of June, July and August near zero) and precipitation concentrated in autumn and spring. However, the spatial distribution of the cumulated rainfall is quite uneven. If we look at the mean annual precipitation at the three main rain gauge stations on the island, we easily see that the mountains (Kinidaros rain gauge: 400 m.a.s.l. with 730 mm/year and Apirathos rain gauge: 600 m.a.s.l. with 750 mm/year) experience a much higher rainfall amount than the coasts (Naxos rain gauge: 10 m.a.s.l. with 350 mm/year).

Everywhere on the island, the strongest impact is exerted by the short but intense storms that are typical of the end of summer and winter (see e.g. the storms of October 1994, February 2003 and October 2006). According to the Koppen classification Naxos has a climate of Csa type.

From a geological point of view, Naxos is part of the Attic-Cycladic massif, mainly constituted by magmatic and metamorphic rocks of Alpine age an connected to the Hellenic trench, locus of the subduction of the African plate beneath the Apulian-Anatolian. The main feature at the center of the island is an anticline with a migmatite core and a variegated sequence of overlaying marbles, schists and metavolcanites of Mesozoic age (Durr, 1987). These terrains are in turn overlaid, at least partially, by sedimentary units of Mio-Pliocene age among which the Upper Pliocene conglomerates that probably represent the remains of the erosive processes on the flanks of the dome during unroofing. Nowadays, the outcropping formations are mainly represented by the gneiss of the migmatite in the central mountain part of the island, the very large Mesozoic complex of interbedded marble and schist formations and, mainly to the west, by the Pliocene Upper Unit (conglomerates, sandstones and sands) and an intrusive granodiorite.

The soils of the island have a quite strong dependence on geology but they have also experienced a long influence of human activities. They are represented by three main typologies: soils on marbles (mainly syrosem, rendzina and red rotlehme soils), soils typical of schist outcrops (mainly ranker and dark-brown Mediterranean soils) and terraced soils, typical of agricultural areas at low or medium slope steepness (terraced colluvial soils, gley soils, pararendzina and alluvial soils).

The development of soil horizons already slowed down and limited by the water deficit typical of Naxos climate, is further hampered by the wind (during the summer *meltemi*-wind season) and water erosion (in autumn and winter). The most developed soils are those of terraced type, which are preserved by agricultural practices such as terracing, nowadays at risk given the steady trend of decrease in land utilization by farmers.

Vegetation, as already seen, is scarce and of typical arid Mediterranean variety. Only a few areas in the interior (e.g. Chalki community) exhibit a small wood with prevalence of oaks (*Quercus ilex* and

Quercus coccifera). The dominant vegetation (Paoli, 2004) is bush with a typical association (*Pistacia lentiscus, Erica manupuliflora, Rhamnus alaternus, Phillyrea latifolia, Calycotome villosa, Sarcopterium spinosum, Euphorbia acanthothamnos, Thymus capitatus, Cistus creticus, Genista acanthoclada*). The presence of vegetation cover is, however, extremely discontinuous, mainly due to grazing activity on pasture lands. In the very few humid areas along the temporary streams the most common species is the oleander (*Nerium oleander*).

This leaves a lot of space to accelerated erosion processes acting on the fragile soils of the island.
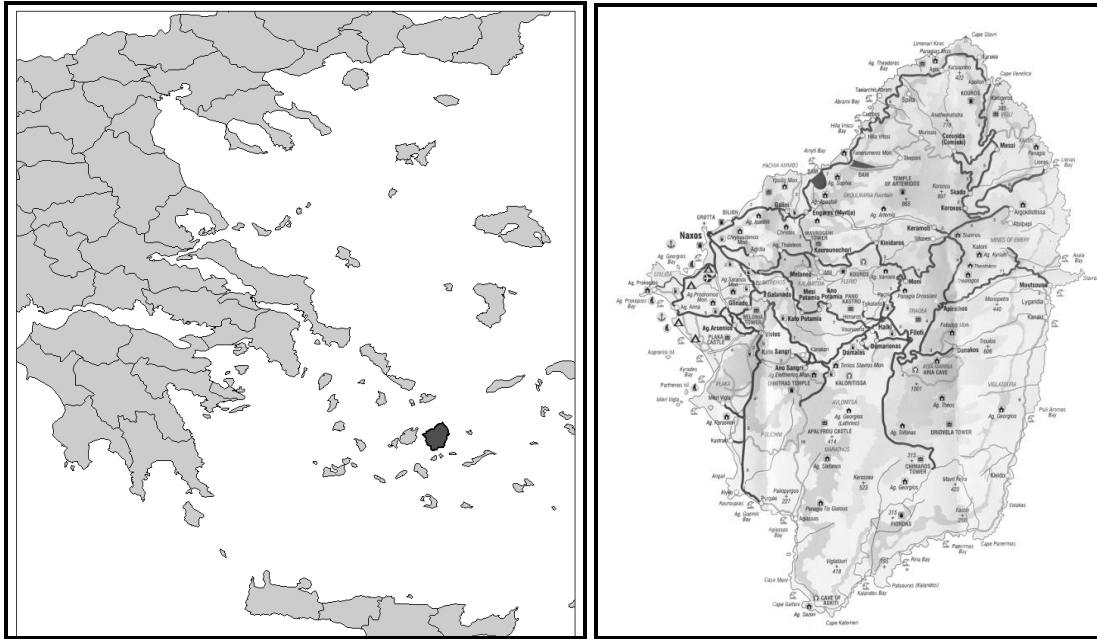

Figure 1: The Cyclades Islands (Greece). Naxos (in Darker Tone in the Left Image) is the Largest Island and has a Central Position. Its Complexity and Variability make it an Ideal Test Site Representative of the Entire Central and Eastern Mediterranean

3. Materials and Methods

The attempt carried out in this research work is the application of a simple yet spatially distributed and multitemporal approach to the definition of soil erosion hazard for the whole island using a combination of field and remotely sensed data. This would lead to the definition of maps of potential soil losses for the studied area which will be useful for the definition of land sustainability policies and planning.

The model that has been applied is a modified version of the widely used USLE (Universal Soil Loss Equation, Wischmeier and Smith, 1958, 1965, 1978). The USLE model has been preferred here over the PESERA specific-point application (or other similar process-based methods) because of the unavailability of the input data at the required resolution in the studied environments. For example, the PESERA model application requires data on cultivation practice (planting month, planting marker, dominant arable crop and so on) that have to be derived from low-resolution EU databases such as the Farm Structure Survey (FSS, Eurostat) or the Planting Dates Database (Van Orshoven, 1999) or data on soil properties (crust storage, effective soil water storage capacity, soil water available to plants and so on) that are reported for all Europe in the European Soils Data Base (ESDB, http:eusoils.jrc.it) at regional scale (usually at scales smaller than 1:250,000). The application of PESERA-like models at higher resolutions (around 1:25,000 to 1:10,000) would require a huge effort to directly measure or derive such parameters, an effort that cannot be done widely over large areas due to time and economic constrains, especially in Mediterranean island environments. Therefore, we

attempted the application of a specific modification of the traditional USLE approach (Wischmeier and Smith, 1958, 1965, 1978), whose needed parameters are often available or that can be easily derived from simple field campaign and basemap data. To adapt the USLE approach, defined and calibrated at the land parcel scale, we used a spatially distributed definition of the main parameters in which variation in both space and time can be embedded.

Remote sensing and GIS mapping techniques can be of great help in such applications for at least three reasons: i) in the application of hydrological-erosive models at the basin or regional scale it is very crucial to work on homogeneous terrain data having the same scale of survey and the same level of accuracy; ii) it is also very important to collect the data over the entire investigated surface, avoiding parameter interpolation typical of spot-like or gridded field surveys (this is even more true when dealing with areas with problems in the availability of geographic information); iii) finally, the dynamical analysis of surface processes must be inherently multitemporal and hence the parameter estimation procedure should rely on remote sensing methods at least for those more subjected to change.

The material needed and the subsequent relevant operational steps are clearly dictated by the form of the USLE equation translated towards a spatially distributed concept. In particular, the original equation A=RKLSCP can be expressed in a spatially distributed form, where A is the annual soil loss per hectare (Mg/ha y), R is rainfall erosivity (MJ mm ha^{-1} h^{-1} y^{-1}), K is soil erodibility (ton h MJ^{-1} mm^{-1}), L is a quantity proportional to the slope length, S is a parameter proportional to slope gradient, C is an adimensional parameter (values from 0 to 1) reflecting the soil protection by vegetation cover (and including crop seasonal variability) and P is a second adimensional quantity (values from 0 to 1) expressing the effect of soil conservation practices, where present.

The contribution of remote sensing and GIS to this computation can be very comprehensive and can cover the whole set of parameters. In the following, the spatial definition of each USLE variable will be considered as well as the contribution of remote sensing and GIS to its estimation.

3.1. Rainfall Erosivity

The R factor, expressed as in the original formulation of the authors (Wischmeier and Smith, 1958, 1965, 1978), represents the energy of rainfall at ground level. The correct profile-scale procedure for its estimation would be through direct measurement of the product of the average kinetic energy of rainfall (mainly dependent upon raindrops mass since velocity at ground is practically constant) times the average maximum rainfall intensity over 30 minutes time intervals. Such method, quite easy to apply to single slope profiles in selected experimental plots, is very expensive and impractical to use for large areas. A simplified approach has been used in this study in substitution for the energy computation technique, based on the widely accepted assumption that rainfall erosivity is proportional to average annual rainfall H. In particular, we used the expression proposed by Wischmeier and Smith (1978) and Roose et al. (2006) for Mediterranean-type areas, where:

(1) R = 0.5H

The value of H, however, must be computed according to local variations in annual rainfall quantities. As already seen, Naxos has a rather variable rainfall pattern with a strong difference between the coasts and the interior. For this reason, we studied the distribution of average rainfall data over a 20 years period for the four main rainfall gauge stations and found a logarithmic relationship (correlation coefficient: 0.98) between H and elevation z above sea level of the form:

(2) H = 95.38Ln (z) + 147.48

The spatial mapping of R values on the studied area was thus obtained substituting equation (2) into (1) and applying a distributed computation scheme in a GIS environment at 20 m spatial resolution.

3.2. Soil Erodibility

The potential erodibility of a bare soil is dependent upon specific quantities that can be estimated by field surveys and laboratory analysis and then generalized in space with the help of soil maps and remote sensing techniques giving information on bare soil spectral properties.

In the classical application for single profiles the suggested expression for K is:

(3) $100 K = 2,1 M 2,14 (10^{-4}) (12-a)+3.25 (b-2)+2,5 (c-3)$

Where M is dependent on soil texture, *a* on organic content, *b* on soil structure and *c* on permeability. The main supporting data for the determination of spatial distribution of K was a soil map produced during the research by means of the integration of field surveys, laboratory analyses, geological mapping and remote sensing. The soil survey showed the presence of 6 different types of coverages in connection with source rocks (schists soils, marble soils, terraced soils, colluvial soils, sand dunes and rocky outcrops). For each one (with the obvious exception of rocky outcrops where erosion is clearly zero in absence of soils) a series of samples were taken and analyzed whose average properties are summarized in Table 1.

Table 1: Soil Properties Used for the Computation of K Factors. Parameters are not defined for Rock Outcrops since they Lack a Soil Coverage

Soil Class	%Silt + %Very Fine Sand	%Sand	%Clay	%Org.Cont.	Structure	Permeability	K
Terraced	37.46	46.30	7.60	3.55	3	2	0.027
Schists	26.13	49.64	5.80	1.84	4	3	0.028
Marble	36.68	39.25	10.73	4.12	2	3	0.021
Colluvial	30.92	48.27	7.46	4.35	3	2	0.019
Sand dunes	7.40	92.00	0.60	0.50	2	1	0.020
Rocky Outcrops	-	-	-	-	-	-	-

3.3. Morphometric Factor LS

The two morphometric factors, proportional respectively to slope length and slope gradient, are usually directly measured on single slope applications and taken constant for small experimental plots of a few tens of meters in length. In the case of basin scale applications, though, this is clearly not feasible and oversimplified.

For this reason, we adopted a distributed approach proposed by Moore et al. (1993) that relies on the fact that the contribution of topography to soil erosion is reflected by the relative stream power exerted by running (or overland flow) water on land. In turn, this stream power can be computed by a series of suitable elaborations of a DEM. The final form of LS factor is therefore:

(4) $LS= (As/22.13)^{n} (sin\beta/0.0896)^{m}$

Where As is the specific contributing area (m^2/m) of the selected land parcel (a DEM cell in our case), *β* is the slope gradient (m/m) for the same cell and n and m are two adimensional empirical constants that in our case were selected to be n=0.4 and m=1.3 by direct calibration in test areas.

The computation of contributing area and slope gradient is carried out by standard DEM analysis codes in a GIS environment (Tucker et al., 2001) starting from a 20 m DEM derived by the combination of topographic maps at the 1:25.000 scale with an ASTER derived DEM. Two ASTER images were

acquired and the best one, selected for absence of cloud cover and quality, used to generate a 25 m resolution DEM using NASA-USGS specifications. The interpolation technique contained in the *topogrid* code (Hutchinson, 1989) was used on contour line derived information and the resulting preliminary DEM was afterwards completed by grid matrix integration with ASTER data. A geostatistical autocorrelation analysis was carried out to locally weight the two different contributions and to compute the optimal values for elevation. The final resulting DEM was validated by GPS direct measurement over about 50 target locations scattered within the studied area. Average errors and accuracies are compatible with a 1:20.000 scale and with a cell resolution of 20 m.

3.4. Cultivation Practices and Conservation Measures

The two parameters C and P are non-dimensional quantities that reduce soil erosion in presence of a vegetation cover and measures of soil protection. In the case of Naxos island, and in general for all the Mediterranean island environments, the correct estimation of both C and P is of critical importance due to the high vulnerability of soils and to the intensity of human impacts. Whilst the definition of C is complex due to the differences in land cover existing in the study area and to the dynamic nature of vegetation presence (both on short and long term), the assessment of P is easier. This is mainly due to the fact that in Naxos the sole conservation practice which is widely used is the construction of terraces by local farmers, a practice broadly adopted in the entire Mediterranean area. A simple approach in the spatial estimation of P is thus based on the mapping (mainly through satellite imagery interpretation backed by field control) of terracing over the hillslopes. Where terracing is present, the P factor can be assumed as being lower than 1 whilst where absent equal to 1. In particular, in this research we also tried to evaluate the state of conservation of terraces, nowadays endangered by the lack of maintenance in several parts of the island, a common problem in the Cyclades islands (Figure 2). For damaged terraces we selected a value P=0.5 whilst for well-preserved terraces we adopted a value of P=0.1 (Lehman, 1993).

Figure 2: Naxos Terracing Systems in Different State of Conservation. From Left to Right, Clockwise: a Completely Disrupted Terracing; a Poorly Maintained One Which Still Retains Some Protection Efficiency; a Well Maintained System Newly Restored in the Apirathos Area

The assessment of C values was strongly connected with the multitemporal mapping of land cover. Using two satellite images of May 1987 (Landsat 5 TM) and April 2003 (Landsat 7 ETM), the CORINE land cover map (updated 1989) and field surveys carried out by the authors in the spring of 2003, we performed an accurate analysis of land uses that resulted in the production of two maps (relative to the years 1987 and 2003). First of all we compare the CORINE land cover classification (European Commission, European Environment Agency, 1997) with the multispectral TM data set, through several basic analyses such as different color composites (457, 432, 321) and NDVI. Afterwards we proceed to update the third level of CORINE database with two different approaches: on the one side we compare the land use classes with the newer status offered by ETM Landsat image and on the other side we use a field survey carried out in 2003, same period of the satellite acquisition date. The adopted methodology for the updating of 19 different classes present on the Naxos Island was based on the methodological guide by Perdigao and Annoni (1997). The field survey provided the basis for supervised Maximum Likelihood classification of ETM image. Finally, both products were integrated in a GIS system in order to generate an updated land cover.

The comparison of the land cover of 1987 and 2003 shows a series of changes mainly linked to urbanization (e.g. the construction of the new airport and of two artificial water reservoirs) and agriculture. According to literature data and to an empirical relationship linking the C factor and the Landsat-based NDVI, that we hypothesized valid for most of the vegetated parts of the island (land cover classes 333 and 323), we assigned C values for each land cover class for both 1987 and 2003.

4. Results and Discussion

The final computation of soil erosion potential according to the spatially distributed USLE model is a matter of a few simple mathematical grid overlay operations in a GIS environment. We repeated the procedure for three different values of P (0.1, 0.5 and 1) for both analyzed years so that we ended up with two sets of 3 maps, giving an estimation of erosion in Mg/ha y.

The most relevant information that can be deduced by a first look at the general results is that soil losses have increased from 1987 to 2003 of about 7%. The Figure 3 shows the spatial distribution of expected soil losses for the six scenarios whilst Figure 4 presents a quantitative comparison between the worst case scenarios (P=0) in 1987 and 2003. The latter reveals that only limited areas experiences a decreasing erosion trend while for the most part we register increments in soil losses. Such losses seem to be mainly connected with land use changes.
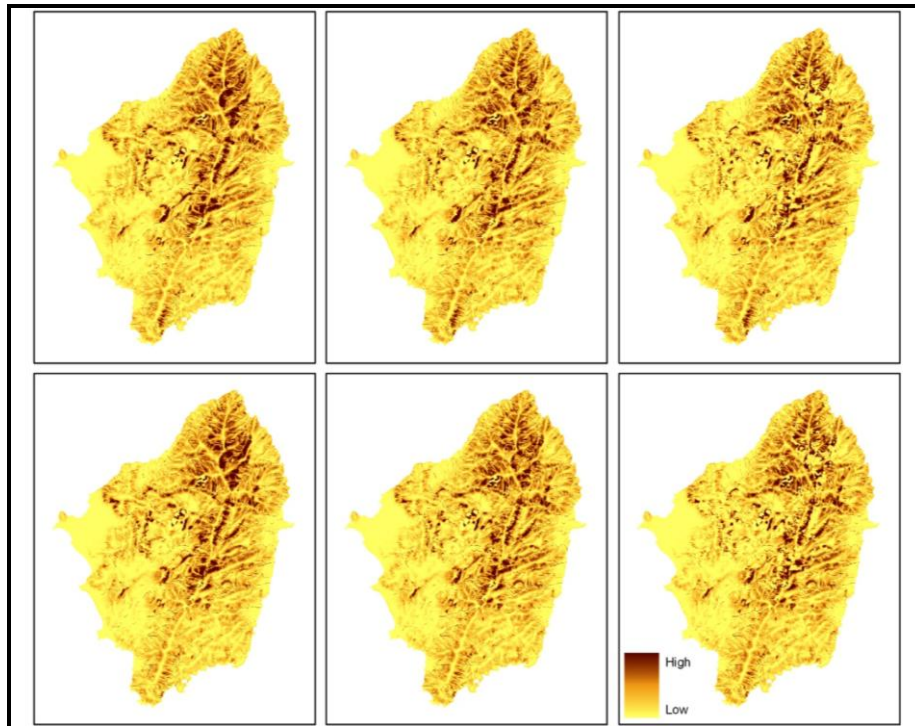
Figure 3: *Soil Erosion Maps for the Year 1987 (Top Row) and 2003 (Bottom Row). For Each Year the Three Different Scenarios for Terracing Maintenance are Shown (P=1 Left, P=0.5 Center, P=0.1 Right)*
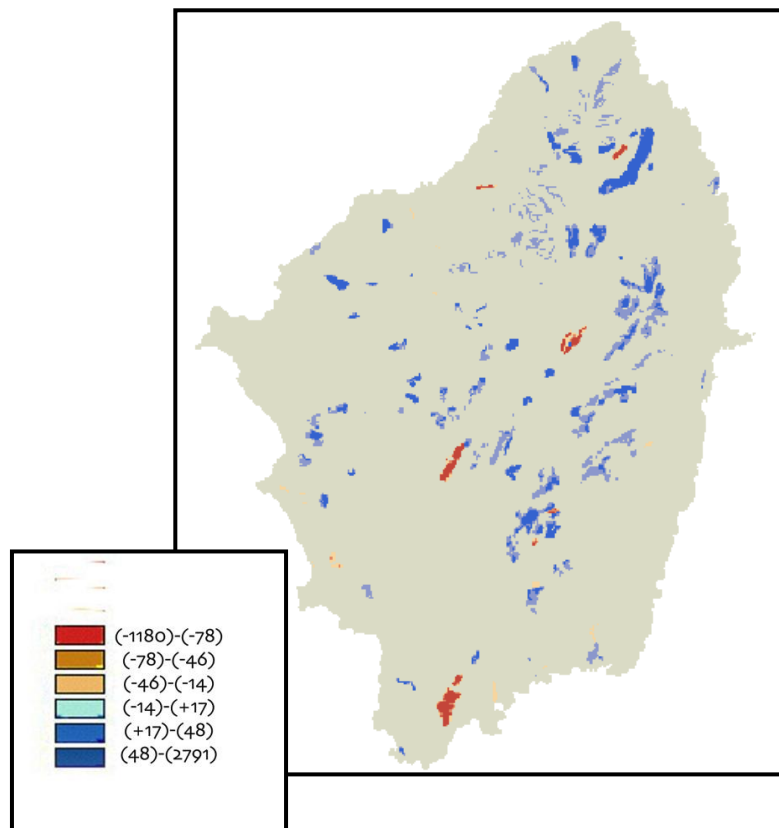

Figure 4: *Differences in Erosion Potential (in Absence of Protection Measures) between 1987 and 2003. Negative Values (Red) Shows Locations in Which Erosion Exhibits a Decreasing Trend Whilst Positive Values (Blue) Shows Location Where Soil Losses Have Increased Mainly Owing to Land Use Changes*

However, the quantitative results provided by USLE-based models are very sensitive to local variations. Furthermore, the adoption of empirical estimation for parameters which were adapted for areas with similar but not identical climates imposes caution on the use of the values of soil losses generated by the model. For this reasons, it is usually advisable to rely on classes or ranges of values rather than on exact figures. This is even more true in cases in which no field validation data are available concerning long term soil losses. The results of the analysis carried out in Naxos must thus be regarded as a multitemporal mapping of the soil erosion proneness over the island territory and of the impact of land use practices on it.

Another problem that is not considered in the spatially distributed application of USLE-like models is that there is no explicit accounting for soil transport and deposition after erosion. A realistic distributed model for the prediction of sediment budgets at the regional scale should consider this aspect. The definition and application of such models, requiring a large number of field and laboratory parameters, was not within the scope of this research. Furthermore, at present, dynamic hydrological-erosive rainfall-runoff sediment transport models are difficult and very expensive to apply over extensions larger than a few squared kilometers.

However, an average measure of soil loss for the whole island can be obtained using a constant sediment delivery ratio (SDR). An acceptable general value for Mediterranean areas that accounts for the typically convex topography of the islands is proposed by Giordani and Zanchi (1995) as equal to SDR=0.22. If we apply this correction the total erosion in the 6 different scenarios computed is as depicted in Table 2.

Table 2: Final Figures for Soil Losses for the Three Different Conservation Status of Terraces after the Application of SDR=0.22. Units are in Mg/y

1987 P=1	721,425	2003 P=1	769,695
1987 P=0.5	638,400	2003 P=0.5	678,286
1987 P=0.1	592,660	2003 P=0.1	625,114

The impact of the potential soil losses computed by the model can be quantified more precisely if we compare the results with the local depth of the soil itself. It is obvious, in fact, that erosion rates unsustainable for a thin layer of rendzina on marbles can be perfectly compatible with the rate of soil formation in an alluvial area. For this reason, a soil depth map was elaborated for Naxos using a recently developed methodology based on topography and basic field sample measurements (Catani et al., 2010). The final result shows that the thickness of the regolith over the island has an average value of about 0.8 m. Maximum values of about 3 m can be found on the alluvial plains in the western part of the island whilst several areas in the mountains have no soil at all and expose bare rock. If we assume an average bulk density of about 2.0 Mg/m^3 for the regolith terrains, we have that an erosion of 1 (Mg/ha y) will detach 0.05 mm of soil each year. We recomputed the erosion maps and evaluated the time needed for completely eroding the soil layer in each scenario (Figure 5). According to our computations, at the present stage 9.9% of the island (42.3 km^2) will be bare rock in less than 200 years and 1.6% (6.8 km^2) in less than 100 years (Figure 6). Soils are considered a non-renewable resource since their development rate from source rocks is very slow and incomparable to accelerated erosion processes such as those revealed by the analysis. Usually, a depletion time smaller than 100-200 years can be considered catastrophic and in need of urgent mitigation measures. For this reason, and also because the most endangered areas are in locations where very thin soils support grazing as the second important local income source after tourism, this results are not encouraging and should draw the attention of local administrators towards erosion protection systems such as micro-damming and terracing. One such experimentation was carried out successfully in the Apirathos area from 1992 to 1994 but remained a confined exception so far (Lehman, 1993).
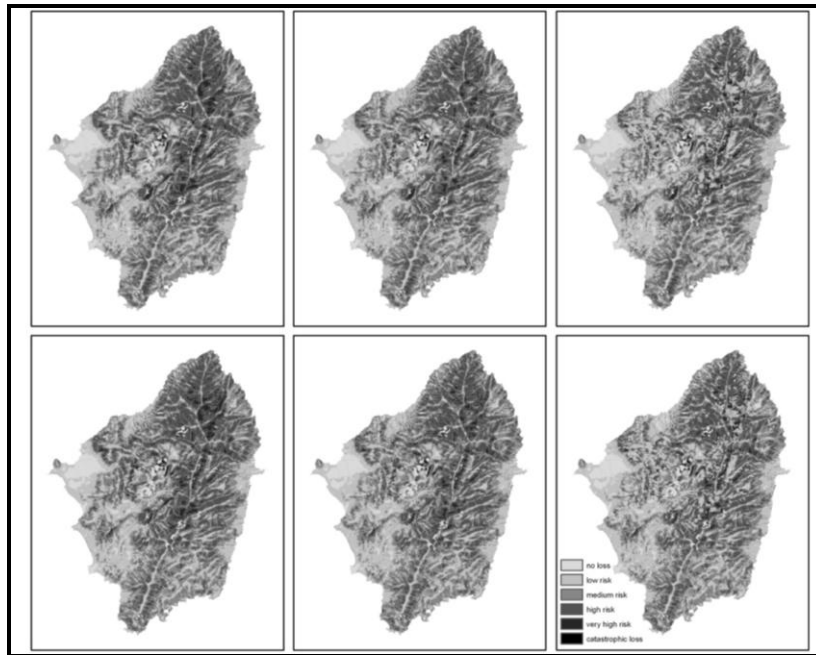
Figure 5: Soil Erosion FAO Classes after SDR Correction for the Year 1987 (Top Row) and 2003 (Bottom Row). Again, Three Different Scenarios for Terracing Maintenance are Shown (P=1 Left, P=0.5 Center, P=0.1 Right)
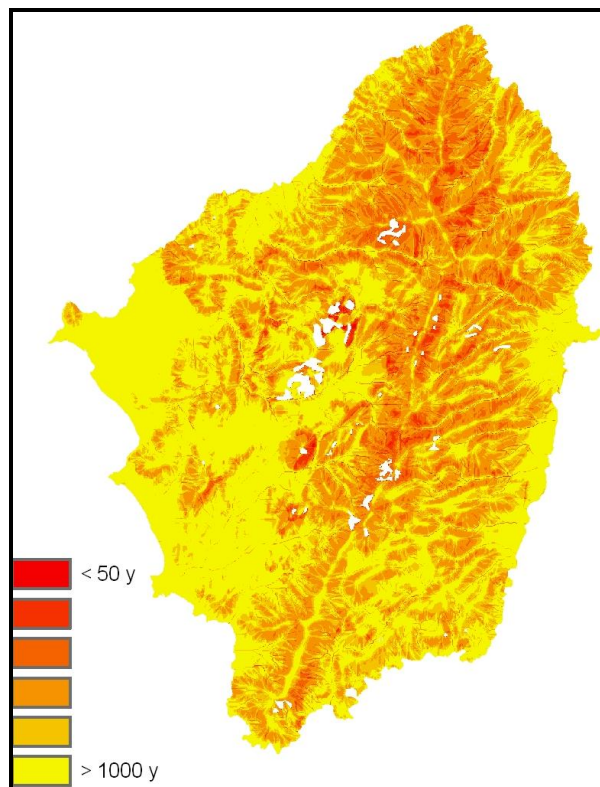

Figure 6: Expected Time to Attain Complete Soil Depletion in the Hypothesis of Lack of Protection Measures on Hillslopes. Soil Erosion Rates have been assessed with the Approach Described in the Text, Using an Average Bulk Density of 2.0Mg/m³. This Value has been Slightly Overestimated to Indirectly Take into Account the Possible Positive Contribution of Soil Forming Processes

A partial confirmation of the spatially distributed results obtained by the application of USLE model comes from the study of the effects of the recent storm that affected the entire Aegean Sea in October-

November 2006. We acquired two ASTER images from July and November 2006 and we analyzed the differences through change detection. The impact of the storm is wide and clearly visible. Its impact on sediment erosion and transport can be appreciated if we look at the two main artificial water reservoirs in the north-western Naxos. The water of both looks clear in the July image whilst suspended sediments are visible in the November image. Furthermore, as a partial validation of the soil loss mapping, the northernmost reservoir, draining a basin for which we predicted above 40% of land under severe erosion risk, presents a much higher amount of suspended load than the other, which is located at the closing section of a less steep valley in which we forecasted no more than 15% of soils under severe threat.

5. Conclusions

The research has concerned the processes relative to, and the quantification of, the soil erosion within the territory of the island of Naxos. In summary, we collected the necessary parameters with a combination of field surveys and remote sensing techniques, we applied a spatially distributed modification of the USLE equation and we analyzed the significance of the results under the assumption that in the Mediterranean environments soil losses are an irreversible process.

We found that, according to the FAO classification, in 1987 about 27% of the island (115 km^2) was subjected to erosion greater than 30 (Mg/ha y) whilst in 2003 the situation had worsened, despite some conservation attempt carried out in the nineties, with 29% of land (123 km^2) over the 30 (Mg/ha y) limit (Figure 3). Following a simple approach that makes use of a soil depth map and the estimated rates of erosion, we also obtained a forecast of probable depletion time for soils. This information tells us that in short times a large proportion of Naxos pedologic environment will be lost forever. This figure could be even worsened by the possibly increasing trend of extreme hydrological events due to climate change (Nunes et al., 2008).

At present, only about 10% of the island territory is protected by terraces and most of them are in a poor maintenance status. If this protection system could be extended over another 10% of land, precisely the one which is under the strongest risk of erosion today, we will have a reduction of soil loss rates of about 90% locally, with an increase of depletion time well over security levels.

Further studies are needed in order to: i) properly validate the model using a combination of field measurements (possibly combined to the setup of experimental parcels) and remote sensing, such as the one proposed in this paper; ii) understand the still poorly documented relationship between short intense rainfalls and soil losses; and, iii) devise possible countermeasures among which the construction of micro-dams on steep channels and the construction/maintenance of terraces over all the endangered areas.

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