Soil Ecosystem Services and Sediment Production: The Basilicata Region Case Study

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Abstract. The conservation of soil and multiple ecosystem services it provides, is crucial for human well-being, for pursuing many of the Sustainable Development Goals and for addressing some of the most important challenges of our society. However several factors contribute to soil degradation, including climatic characteristics, lithological and morphological features and transformation processes. Only the last ones can be governed and that is the reason why spatial planning needs tools and analyses to interpret the role of land use changes in complex dynamics such as the erosive phenomena. This work presents the results obtained from the implementation of the InVEST SDR module on the territory of Basilicata Region and considering the evolution occurred between 1990 and 2018. Our outcomes show an intensification of erosion phenomena mainly along the Apennine chain and the coastal area of the Tyrrhenian Sea. Although this area corresponds to the higher average rainfall erosivity over the entire period, the most significant soil loss occurs in correspondence with unfavorable land use changes. The negative connotation typically associated with deforestation, conversion of agricultural soils to arable lands and thinning or total loss of vegetation becomes a measurable quantity, at least from one of several points of view.

Keywords: Soil ecosystem services · Land degradation · Soil conservation · InVEST SDR module

1 Introduction

Soil is the core of terrestrial ecosystems and the provider of most of ecosystem services (ES) [1]. Even if the type, the intensity and the quality of these ES depends on the specific environmental characteristics [2, 3], soil is essential for agricultural production and plays a key role in regulating carbon cycle [4] and in preserving biodiversity [5, 6].

Contributing in the removal of significant topsoil and, consequently, in the loss of nutrients and carbon stock and in porosity variations, erosion is actually recognized as one of the most critical threat to soil properties and functions [7]. Unfortunately a detrimental mix of morphological, climatic and soil characteristics [8], makes the Mediterranean basin particularly exposed to erosive phenomena [9]. Furthermore, because of increasing anthropic pressures, land use changes and climate conditions under actual global changes, the Mediterranean basin is expected to be a critical desertification hotspot [10].

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Although it is recognized that soil functions must necessarily be preserved in order to pursue sustainable development [11] and despite soil scientists have highlighted for decades the need to overcome the piecemeal legislative approach [4], nowadays a fully integration of soil ES into decision-making processes at different levels of governance regarding land use and management [12] is still missing.

The purpose of this work is to evaluate the differences in terms of sediment generation occurred in the Basilicata region between 1990 and 2018 considering both land use and climatic changes. According to the European Soil Bureau [13] the study area, whose territory is characterized by a predominantly mountainous morphology and the widespread presence of clayey hills, includes many catchments that fall within the highest erosion risk classes. Some areas of the region, where erosion phenomena are so evident that they represent a threat to settlements and infrastructure, have been the focus of a number of studies aimed at investigating the role of agricultural policies [14, 15], the increase in the frequency of heavy rainfall events [16] or in inter-annual precipitations variability [17].

The Region's attitude to land degradation [18], the expected climate changes and ongoing land-use modification trends require a regional study to be carried out in order to define a basis for monitoring future erosion trends and design policies aimed at preserving soil ES provision.

We used Sediment Delivery Ratio (SDR) InVEST module [19], a spatially-explicit tool able to model soil erosion and sediment transport and deposition phenomena. The results of the elaboration are precisely related to changes in land use, in order to highlight the domains in which spatial planning can act on the regional scale.

2 Materials and Methods

Erosion is a natural phenomenon to which a number of factors contribute: morphological and soil characteristics, climate, vegetation cover, fire occurrence, land management and cultural practices, land use changes. As the topic is considered of relevant importance in order to support the most basic ES for the survival of humankind [20], it is important to carry out assessments at the regional scale.

The difficulty in finding detailed and spatialized data related to each of the above mentioned quantities, has led to the increasing usage of models that are both simple and scientifically credible such as the SDR InVEST module, useful to represent the spatial variability in sediment retention service also considering non-linear responses to land use changes [21].

The study area, the model on which the tool is based and the phases of data collection and processing of the layers needed for the model running, are described below.

2.1 Study Area

The soils of Southern Italy, as well as most of the Mediterranean lands [9], are prone to erosive phenomena so that Rendell, 1986 [22] defined them as *the inevitable results of a combination of high relative relief, erodible soils and climate.*

The Basilicata Region (Fig. 1), which covers a total area of about 10,000 km^2, is more than 46% mountainous and just over 45% hilly, while only 8% is characterized by a flat morphology.



Fig. 1. Basilicata region's physical map

Analyzing the changes in land use in the Basilicata region from 1990 to 2018 (Fig. 2), it emerges that the most significant losses occurred in woodlands (−12,500 ha), agricultural mosaic (−27,500 ha) and meadows (−5,500 ha). On the other hand, an increase has been recorded in the classes related to bare lands (+13,600 ha) and shrublands (+7,000 ha) but, above all, from arable lands (−21,400 ha). Less significant on the regional scale were the transitions towards residential and industrial land uses which, however, due to their dynamic characteristics have been studied by the authors in several works [23–25].

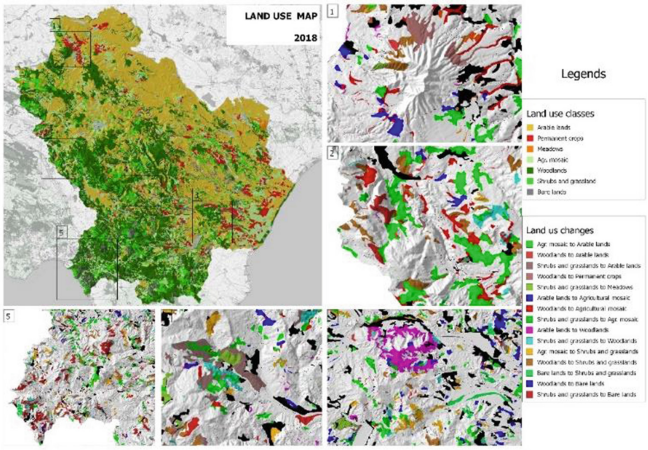

Fig. 2. Land use map at 2018 for the Basilicata region. The detail boxes represent the main land use changes in some areas of the regional territory

Altogether the territory, which from both the geological and structural points of view represents one of the most complex and varied among the Apennine regions [26], is composed of a western sector, on average more elevated due to the presence of the Apennine Chain and an eastern area, mainly characterized by the hilly morphology and often subject to erosive phenomena which, in some territorial areas, have given rise to

badlands [27]. The flat areas can be identified mainly along the Ionian coast, originating from the continuous build-up of eroded material carried downstream by the branched and dense hydrographic network [28].

The topographic complexity of the study area inevitably influences its climatic features, characterized by contrasts [29] where the Apennine reliefs intercepts the Atlantic perturbations and affects the precipitation distribution [30]. In fact, the territory falls partly in the temperate and cold climate, and partly in the Mediterranean, linked to two distinct pluviometric regimes: the Ionian side, characterized by perturbed fronts less frequent and with a lower intensity; and the Tyrrhenian side exposed instead to perturbations, coming from the west and north-west, and affected by greater rainfall.

The average annual precipitation varies between about 500 mm and over 2000 mm and has a typically Mediterranean seasonal distribution: generally about 35% of rainfall is concentrated in winter, 30% in autumn, 23% in spring and only 12% in summer. The trend of rainfall during the year is subject to strong variations with a considerable part of the precipitations concentrated in a few days and characterized by very high intensity.

The temperature trend is also characterized by strong excursions with very hot summers and cold winters. The average of the minimum temperatures varies between about −10 and −2 °C while the average of the maximum temperatures is between 31 and about 39 °C. A recent study [29] revealed an increase in both minimum and maximum temperatures during the 1951–2010 period, leading to an average growth in minimum temperature of approximately 1.1 °C and a raise in the number of very warm days per year that became markedly stronger since 1971. It is worth considering that this increase in temperatures correspond to a downward trend in precipitation total amount [30], implying conditions conducive to aridity and all consequent processes such as landslides [31], gully [32] and badlands [33] erosion. Some of these areas have been the subject of in-depth study by the scientific community, which has extensively documented the role of changes in land use and management. In some cases this growth in territorial vulnerability was due to the introduction of Common Agricultural Policy (CAP) measures that favored the recovery of shrubland and badlands for wheat cultivation [34] or the implementation of some measures included in the Reg. CE 2078/92 that which implies a 20-year period of set-aside for remodeled areas [35].

To further man-driven pressures in degradation prone areas, linked for examples to deforestations [36] and overgrazing [37], has to be added the increasingly relevant threat of wild fires [38–40].

2.2 Methodology

Although the scientific bibliography is rich in relationships and models for the evaluation of soil loss [41, 42], an increasing attention [43, 44] is paid to tools and models capable to assess not only on-site effects but even off-site impacts [45], strengthening a more systemic approach to territorial governance [46]. The understanding of these dynamics constitutes the necessary basis for the design of policies and strategies aimed at ensuring the delivery of the above mentioned ES by the landscape.

The tool used in this work, the InVEST Sediment Delivery Ratio (SDR) module, allows the spatially-explicit representation of the annual average soil loss and then to

compute the sediment delivery ratio which is the part of the soil loss that actually reaches the hydrographic network.

For each of the i-pixels, the annual total amount of soil loss - expressed in $tons \cdot ha^{-1} \cdot yr^{-1}$ - is assessed using the Revised Universal Soil Loss Equation (RUSLE) [47]:

$$usle_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i$$

where R_i is the rainfall erosivity ($MJ \cdot mm(ha \cdot hr)^{-1}$), K_i is the soil erodibility ($ton{\cdot}ha \cdot hr\ (MJ{\cdot}ha{\cdot}mm)\ -\ 1$), LS_i is the slope length gradient factor, C_i is the crop management parameter and P_i is a factor depending on support practices.

The SDR ratio is then calculated following the following expression [46]:

$$SDR_i = \frac{SDR_{max}}{1 + exp\left(\frac{IC_0 - IC_i}{k}\right)}$$

where SDR_{max} represents the maximum theoretical SDR set by default equal to 0.8 and IC_0 and k are calibration factors set by default equal to 0.5 and 2, respectively. IC_i, according to Borselli et al. [48], constitutes a measure of the connectivity assessment based on landscape's information and it's useful to describe the hydrological linkage between sediments' sources and destinations, among which hydrographic network's components.

Although SDR module is scientifically based on the theory of hydrological connectivity [49], it requires a small number of input layers and provides ease of implementation for this reason proving to be useful in predicting the impacts related to land use changes [50]. Data needs for running SDR model are indeed a Land Use/Land Cover (LULC) map, the Digital Elevation Model (DEM) of the study area, two raster dataset with the rainfall erosivity (R) and the soil erodibility (K) indexes for each pixel and a biophysical table summarizing the values of the C and P parameters assigned to each land use class.

The detailed building of the dataset is described below.

Rainfall Erosivity (R)

R factor is a parameter significant of the rainfall energy as an erosive agent [51] and it represents the rain potential ability to cause soil loss [52]. As stated by Diodato, 2004 [53], its assessment is tedious and time-consuming because it accounts for the product of the total kinetic energy of a rainfall multiplied by its maximum intensity of 30 min of rain [54].

However, since the purpose of this work is to define the changes that occurred in the period 1990–2018 and the necessary data are not all available for this time series, an experimental relationship [55] was used:

$$R = 0.0483P^{1.61}$$

where P is the average annual precipitation in mm.

These datasets were made available by the Basilicata Civil Protection Functional Center in relation to the pluviometric stations located within the regional territory and

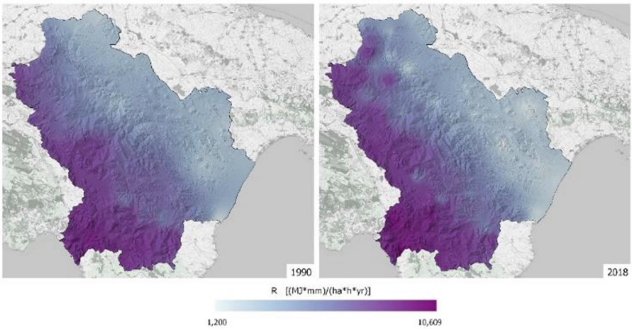

Fig. 3. Rainfall erosivity maps related to 1990 and 2018

those ones located in Calabria, Campania and Apulia Regions closer to the regional borders. Results can be seen in Fig. 3. *Rainfall erosivity maps related to 1990 and 2018*

Soil Erodibility Factor (K)

The K factor is significant of the soil erodibility (Mg·h·MJ − 1·mm − 1), that is a measure of the susceptibility of soil particles to detach from the ground and be transported by rainfall and runoff [54]. Being representative of the susceptibility to soil erosion, the K-factor is a complex synthesis of a combination of phenomena such as the splash during rainfall and intensive events, runoff along the upper soil layer - including transportability of sediments - and seepage into the soil [56]. For these reason, *K* factor is a function of the soil structure [57], the permeability [58], the total amount of organic matter [59], the granulometry [60], the water contents in topsoil [61], and a number of quantities that vary over time even in response to major upheavals such as fires [62–64]. An accurate estimation thus requires intensive and time-consuming field measurements [65] that have resulted in a continuous investigation and testing of experimental methods and estimation procedures based on a limited number of soil features [66].

In this work, the raster dataset of K-factor was provided by the JRC's European Soil Data Centre (ESDAC) [67] as a result of a study aimed at generate a harmonized high-resolution soil erodibility map for EU-25 member States.

Biophysical Table: The Crop Management (C) and the Support Practice (P) Factors

As already mentioned in the methodology, one of the inputs required by the model is a table specifying the *C* and *P* parameters' values for each land use class.

C-factor represents a ratio between soil loss from a certain LULC class and the fallow condition [68] and it's useful to consider differences in infiltration capacities between vegetated and tilled bare fallow areas. Limiting the rainfall impact on soil surface, vegetation cover and an appropriate crop management thus influence runoff and soil erosion [69]. RUSLE original model [56] consider *C*-factor as a product of following variables: land use, soil moisture, canopy cover, surface's cover and roughness. Its value ranges from 0, corresponding to non-erodible surface, and 1, that represent bare land with no vegetation. In the present work, given the regional working scale and the lack of detailed data related to the type of management of agricultural practices (e.g.

conservation/ridge tillage, no till practices), it was decided to adopt the values proposed by Panagos et al., 2015 [70], which are variable according to LULC.

P-factor is significant of the adoption of supporting agricultural management practices, such as fields contouring, terracing and strip cropping, that contribute in reducing the runoff and, consequently, limit the soil erosion [71, 72]. Since the model requires only one value for each land use class and not a spatially distributed value layer, it was decided to use the values calculated for Italy, and equal to 0.9519, as part of work carried out on the European scale [73].

3 Results and Discussion

The first result obtained from the implementation of the SDR module is a map of the spatial distribution within the regional territory of the annual soil loss gradient (t/ha).

Figure 4 shows through a color gradient representing the intensity of erosive phenomena, the comparison between the outcomes obtained in 1990 and 2018. Uncolored portions of land correspond to land use classes that do not contribute to sediment production (watercourses and bodies of water, artificial surfaces) [74, 75]. Both maps highlight the areas that show a greater attitude to give rise to erosive phenomena: the northern part of the regional territory, the south-western part overlooking the Tyrrhenian coast and the slopes located along the eastern part of the Apennine chain, corresponding to the middle valleys of the main rivers of the Basilicata region. Our outcomes, furthermore, confirm what assessed by European Soil Bureau [13] that declared an average annual soil loss ranging from 5 and 10 t/ha in the province of Potenza and ranging from 3 and 5 t/ha in the province of Matera. Although the analysis carried out at the regional scale necessarily uses less detailed dataset than the studies at the basin scale, the maximum value obtained, equal to 282 t/ha/yr, is comparable to what found in the Candelaro basin (Apulia Region) in which a maximum equal to 210 t/ha/yr was assessed [76]. In fact, it should be noted that the western part of the regional territory falls entirely within the first province and that, as can also be seen from our results, the area along the Ionian coast contributes very little to erosion phenomena, also thanks to the very low slopes that compensate for the negative role of intensive agriculture.

An useful comparison can be made with outcomes derived from Morgan, 1992 [77] which assessed average loss in an individual rainstorm, throughout the European territory, ranging from 20 to 40 t/ha with a frequency of once every two or three years and in more than 100 t/ha during extreme events. However, the comparison suggests an intensification of the intensity of erosion processes above all along the Apennine chain.

Based on the analysis of the values measured by primary catchment area (Table 1), it can be seen that the maximum value of annual soil loss has increased in all basins falling in the Basilicata region, excluding the Cavone catchment. However, these increases do not always correspond to a growth in the average value: this is the case for the Bradano, and Basento basins. On the other hand, erosive phenomena seem to be attenuating in the Cavone basin, which is the only one to record a decrease both in the average and in the maximum value.

In order to understand the changes that have occurred in terms of the intensity of erosion phenomena, a map has been produced representing the difference between

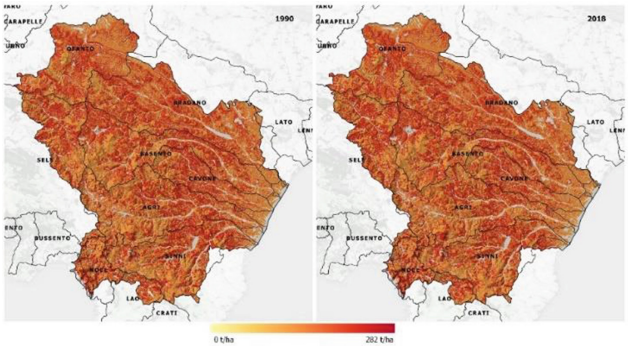

Fig. 4. Comparison between the distribution of annual soil loss (t/ha) in 1990 e 2018, respectively

Table 1. Soil loss values (t/ha/yr^{-1}) for 1990 and 2018 resulting for each of the river basins of the Basilicata region

Catchment	Maximum value		Mean value		Standard Deviation		Variance		Median value	
	1990	2018	1990	2018	1990	2018	1990	2018	1990	2018
Ofanto	215.3	240.6	2.2	2.4	4.4	4.6	19.6	21.6	0.7	0.8
Bradano	231.4	241.3	2.3	2.1	4.4	4.0	19.0	16.2	0.8	0.7
Lato	7.0	7.7	0.3	0.3	0.5	0.5	0.3	0.2	0.1	0.1
Sele	336.9	512.1	3.1	3.6	6.6	7.6	43.7	57.1	0.5	0.8
Basento	332.6	400.3	2.6	2.5	5.5	5.2	30.0	27.4	0.5	0.6
Cavone	307.4	286.0	3.0	2.7	6.1	5.5	36.7	30.7	0.8	0.7
Agri	378.2	744.2	2.7	3.0	6.4	8.7	41.1	76.1	0.3	0.3
Sinni	640.9	955.9	3.3	3.5	8.1	10.2	64.9	103.9	0.3	0.3
Bussento	58.1	80.5	1.3	1.8	6.3	8.8	40.2	77.2	0.0	0.0
Noce	990.7	1377.9	5.3	11.0	13.0	32.6	169.2	1059.7	0.5	0.6
Lao	537.0	1305.7	5.3	7.1	13.8	20.6	190.9	424.9	0.4	0.4

2018 and 1990 soil loss (Fig. 5). A positive difference corresponds to a worsening of the conditions predisposing to erosion (red gradients), while a negative difference is significant by a decrease in soil loss (green gradients). For the areas where this difference is most evident, more detailed boxes have also been set up. The first detail window (Fig. 5 - box 1) frames the area of the Vulture Mount where the increase in soil loss mainly concerns the sectorial side of the Mount. To this worsening in terms of soil conservation, the deforestation of large areas changed into permanent crops, arable lands, shrubs and grasslands has been determinant. More heterogeneous is the change in the most western part of the region (Fig. 5 - box 2) where three types of changes have contributed most to the increase in soil loss: from shrubs to bare lands, from woodlands to agricultural

mosaic and from this last class to arable lands. A substantial improvement in soil stability conditions is shown by detail window 3 (Fig. 5 - box 3), which frames a portion of territory between the Sinni and Agri river basins. In the more northern part of the box, the decrease in soil loss is related to a change from arable lands to woodlands while in Southern part, it is more linked to a transformation from agricultural mosaic to shrubs and grasslands.

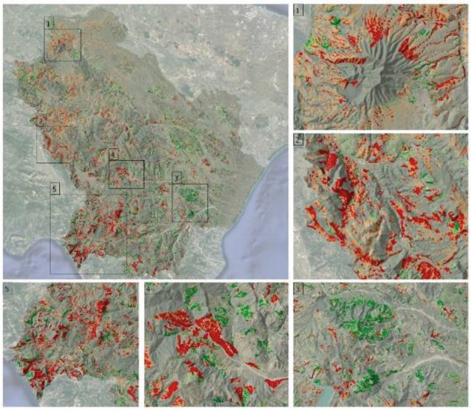

Fig. 5. Differences in annual soil loss occurred between 2018 and 1990. Green graduation represents an improvement (i.e. a decrease in erosion intensity), red graduation represents an increase in erosive phenomena. (Color figure online)

Figure 5 - Box 4, shows an area belonging to a mountainous catchment area where changes in land use have brought about changes in erosion phenomena that vary according to altitude. Along the slopes, in fact, the changes have led to the reduction of shrubs and stable grassland in favor of agricultural classes of land use (arable lands, meadows and agricultural mosaic). This has led to an increase in soil loss. In the riparian lands, closer to the watercourses, the establishment of agricultural mosaic and the evolution of bushes in the woods has led to a stabilization of the slopes with consequent improvement of erosion phenomena. The area overlooking the Tyrrhenian coast (Fig. 5 - Box 5), finally, appears to be strongly affected by an increase in erosion phenomena and soil loss linked to the decrease of wooded land and vegetated areas (mainly shrubs and meadows) that covered the highest part of the reliefs characterized by relevant slopes.

4 Conclusions

The need to protect the soil and its functions is all the more evident as not only does the provision of many ES depend on them [78], but they are considered crucial for obtaining many of the UN 2030 Sustainable Development Goals [79] and relevant keys for the most important challenges for our society such as poverty alleviation, mitigation of regional disparities and climate change mitigation [2, 80]. The importance of the issue of soil protection and limiting land degradation is particularly crucial for spatial

planning, as it is in charge of the governance of land use change. The results obtained for the Basilicata Region indeed confirm that, despite the intensity of erosion phenomena are significantly influenced by the characteristics linked to the pluviometric regime and the rainfall erosivity, the soil use and coverage play an important role.

As highlighted by Mallinis et al. [81], mapping the spatial distribution of erosive processes and the consequent assessment of the soil loss in relation to different time extents, constitute the starting point for the implementation of erosion control measures and the design of policies oriented to soil ES conservation.

In this regard, since the issue of land degradation is complex and transversal with respect to different sectors, it is considered particularly useful to deepen it through the ES approach [82–86], capable of supporting a comprehensive, dynamic and scalable assessment framework to support and to make more operational the Sustainable Planning [87–91].

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