Soil Erosion Modelling on Arable Lands and Soil Types in Basilicata, Southern Italy

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Abstract. Evaluating the impact and the incidence of the erosive phenomenon affecting the Basilicata region in 2012 - in particular, the agricultural areas used for the arable lands cultivation -, is an important goal aimed at correlating the erosion process – evaluated through the USPED method application (2012) - with the main characteristics related to soil and the areas interested, such as: soil types, with particular attention to two physical-chemical characteristics, such as: total CaCO3 (%) and soil organic matter content (SOM, %) -, land uses and the spatial distribution of arable lands at municipal scale. The correlation is intended to give an overview of geological and agricultural of amount of the areas affected by this phenomenon, since it aims to analyze and evaluate the agrarian framework in relation to the state of erosion in 2012 by assessing the incidence of the erosion process at regional and municipal scale in relation to the different scenarios deriving from the land use and soil types and choosing the most efficient land management strategy in terms of potential policies to communicate to the final decision makers.

Keywords: Soil erosion · USPED method · Soil types · Land use · Arable lands · Basilicata · Southern Italy · Land use policy

1 Introduction

Soil is one of the most important and most complex natural resources, but current developments (climate change, soil erosion and urbanization) increasingly threaten this valuable resource in Europe and worldwide [1]. In addition, it is important to remember that soil is a fragile resource that can be lost by erosion or degrade to such an extent as not to be more useful to support the crops Some analyses carried out by Boardman and Poesen [2] and Benchmann [3] describes erosion process formation events in agricultural lands in European countries. Also, as stated in different sources in literature, the aspect related to the cover crops can improve water infiltration, reduce water runoff, and slow down erosion [4, 13]. Indeed, as argued by Cerdan et al. [14] and Kinderiene, Karcauskiene [15], the soil parameters come into a play – along the factors related to the slope, the incorrect land use and natural rich rainfall – in the induction of the

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erosion process. For this purpose, one of the most interesting aspect to analyze in terms of economic-agrarian impacts, as reported by Dimotta et al. [16], regarding the Bakker et al.'s analysis [17], is fundamental to mention the important role given by the well-known erosion-productivity scenario, characterized by the following effects:

(a) topsoil removal may often result in a nutrient deficit;
(b) erosion may also lead to physical hindrance to root growth.

In addition, as argued by Lal [18] these effects might be induced by several interacting factors, such as reduction of soil organic carbon (SOC), loss of plant nutrients, decline in soil structure, loss of effective rooting depth and decrease in available water capacity (AWC). Another important element coming into a strategic role in the soil fertility consists of SOM (soil organic matter). SOM plays a major role in maintaining soil quality, since it can positively influence a wide range of soil properties such as the provision of nutrients, water retention and release, as well as reducing the risks of soil compaction, surface crusting and soil erosion. In order to describe and define this important element, it is fundamental to mention that well-known factors are able to influence the rate of decline of soil organic matter levels including soil type and physical properties, climate, topography, vegetation and land management practice, as argued in *Maintenance of soil organic matter* guideline – available on www.agriculture.gov.ie [19]. In this regard, as shown by Jenny (1941), the factors affecting SOM consist of the amount of organic matter in surface, mineral soils can vary from less than 1% in coarse-textured, sandy soils to more than 5% in fertile, prairie grasslands [20]. The amount is influenced by all soil forming factors. Jenny arranged the order of importance of these factors in this priority list: Climate > vegetation > topography = parent material. Some general statements about SOM levels in virgin soils can be made based upon Jenny's work [21]:

1. Grassland soils have higher SOM than forest soils.
2. SOM increases with increasing precipitation and decreases with increasing temperature.
3. Fine-textured soils have higher SOM than coarse-textured soils.
4. Somewhat poorly and poorly drained soils have higher SOM than well- drained soils.
5. Soils in lowlands have higher SOM than soils on upland positions. Most SOM is found in the zone of maximum biological activity, the topsoil or plow layer. Anything done to this layer will influence long-term buildup or depletion of SOM (e.g., tillage, crop rotation, erosion, cover crops, crop residue management, fertilization, organic amendments, etc.).

Important to highlight that, as stated by van der Keur and Iversen [22], soil properties can vary over time as a result of impact by climate and land management. That's why two soil characteristics has been chosen in order to characterize the soil types present in the Basilicata region at municipal scale.

In order to reason on a SOM's minimum threshold, as reported by Plunkett and Castle [23], it is very useful to report that the soils characterized by organic matter levels above 3.4% are not considered to be vulnerable. Indeed, as resulting from the

Plunkett and Castle's analysis, various benefits can contribute to making less vulnerable a soil, such as:

1. Enhanced soil fertility
2. Improved in soil structure
3. Ease of workability
4. More active soil
5. Yield benefits.

Considering, now, the Ca-carbonate, as an important chemical factor of soil properties, an analysis carried out by Hassan and Agha [24], the influence of the changes in soil of $CaCO3$ content can cause some changes in soil erodibility factor (K USLE). Soil texture modification due to Ca-carbonate was the main factor affecting soil erodibility.

So, reasoning on the erosion effects on the soil structure and quality, as reported by Guimaraes et al. [25], it is very interesting to focus on the fact that exposing the soil surface to higher levels of energy and erosivity makes them susceptible in terms of structural degradation. This aspect is strictly demonstrated by a Lal's analysis, in which the importance and the related influence of the vegetation have been made evident in the agricultural sector, since the soil is more exposed and susceptible to damage, often resulting in lower SOM levels and lower aggregate stability, depending on the use and management [26]. Logically, maintaining the vegetative cover and/or the addition of organic residues to increase SOM are vital to maintaining soil aggregate stability [25].

The strategic and great importance related to soil resilience in responding positively to the changes of land uses and other aspects coming into a play in the ecosystem context, is well-described by the figure below reported (Fig. 1). Regarding the soil resilience, intended as a potential *soil conservation tool*, it is clearly expressed – by observing the Fig. 1, the balance existing between soil formative and degradative processes, in order to relate the soil properties and the abovementioned balance [27].

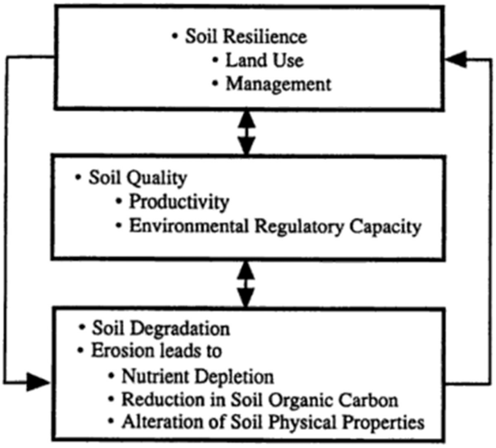

Fig. 1. Interactive effects of soil resilience and degradative processes on soil quality (Lal 1999).

Focusing the attention on the assessment of the soil types, land uses and the areas of the arable lands subjected to the erosion process and putting in relation the soil types and the croplands with this phenomenon at municipal scale, it is possible to obtain an environmental characterization of the territory – by considering geological and agricultural contexts - and the assessment of the areas – at regional and municipal scale – interested and affected by this typology of geomorphologic instability by applying the well-known empirical method - *Unit Stream Power Erosion Deposition* – USPED.

2 Materials and Methods

This section of the work deals with the methods applied in order to assess the quantitative aspect in terms of the arable land areas of the region Basilicata - at municipal scale – affected by soil erosion. The contribute related to the soil erosion derives from a previous output obtained through the USPED method application (Fig. 2). This contribute - taken from a previous study [16] -, has been reclassified into three classes in

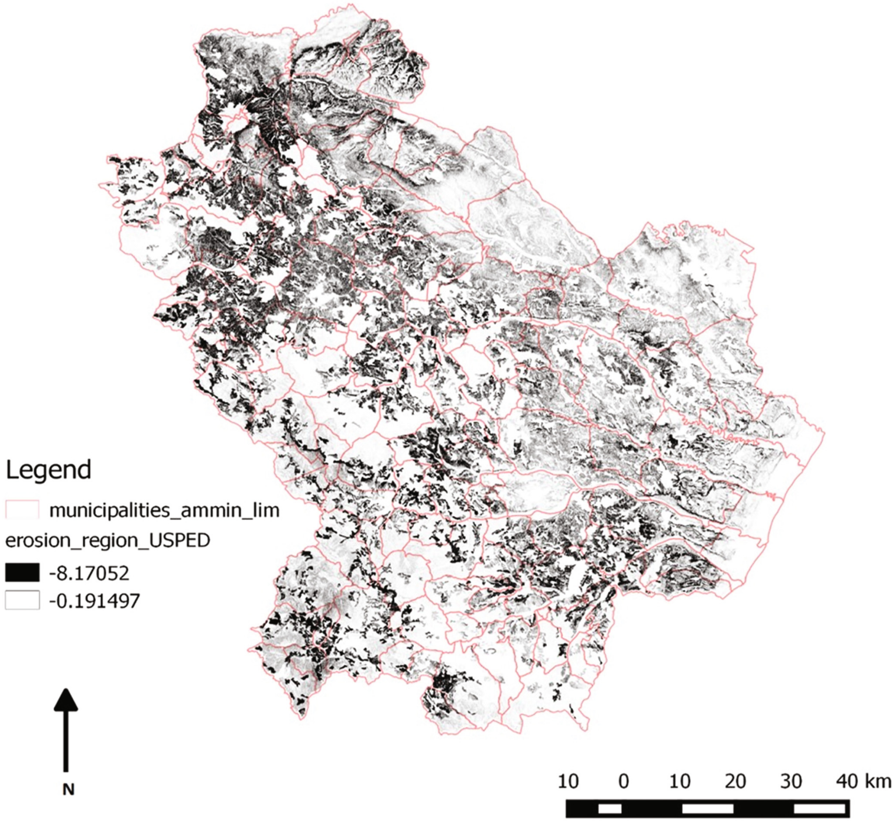

Fig. 2. Spatial representation of the erosive phenomenon affecting the total area size of the Basilicata region (USPED method application) [16].

relation to the potential erosivity (from the highest to the lowest degree), in order to evaluate the areas of arable lands interested by a potential erosion process (Fig. 3). In order to carry out the present analysis, different databases have been used, such as:

a. **Database (1): Utilized Agricultural Area (UAA) and available period:** ***Utilized Agricultural Area (UAA)*** – *Arable lands* - dataset coming from ISTAT – National Institute of Statistics - 6th Italian Agriculture Census, year 2010.
b. **Database (2): GIS geodatabase: Corine Land Cover 2012–4th level –** shapefile coming from ISPRA – Superior Institute of Environmental Protection and Research, Italy.
   Layer derived: layer of the Basilicata region used to extrapolate the different croplands areas/polygons of arable lands designed by the CLC code "*211*".
c. **Database (3): GIS geodatabase: Pedological Map of the Basilicata region 2006** *("I suoli della Basilicata",* http://www.basilicatanet.it/suoli/comuni.htm*)*

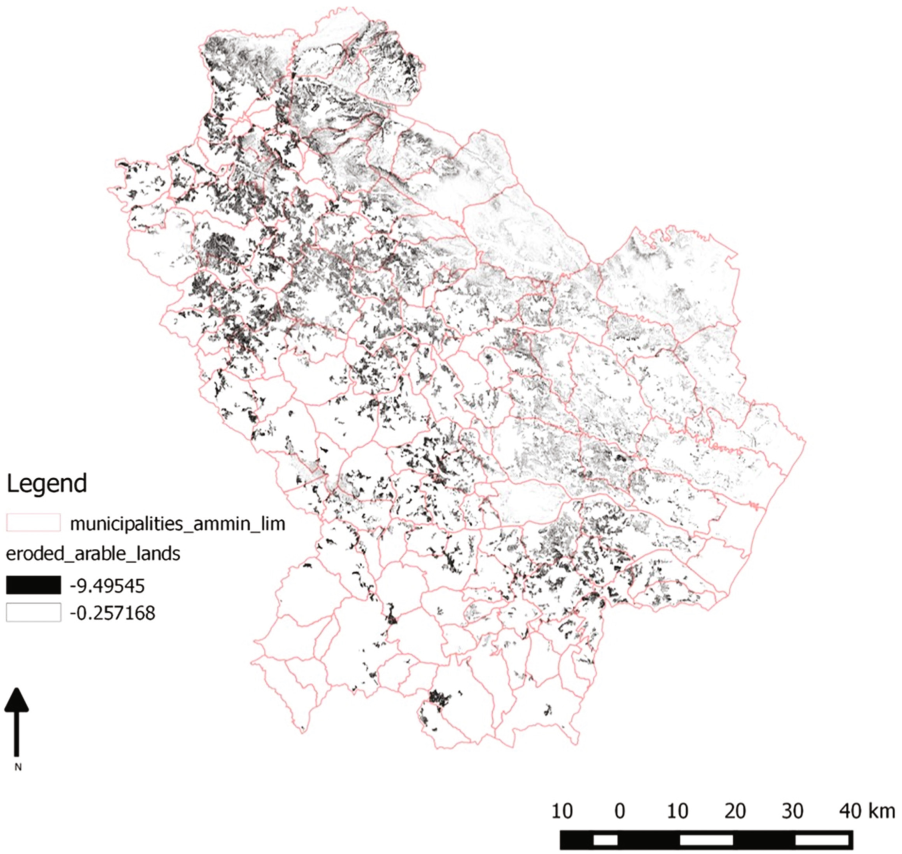

Fig. 3. Spatial representation of the eroded arable lands interesting the municipalities of the Basilicata region (USPED method application).

shapefile coming from Open Source Data by Basilicata Region Office containing spatial information about the soil types in the region (Fig. 4).

d. **Database (4): GIS geodatabases: total and eroded areas of the arable lands at regional scale**.
Layers derived: raster file resulting from the USPED method application of the year 2012 - coming from a previous spatial analysis carried out by Dimotta et al. [16].

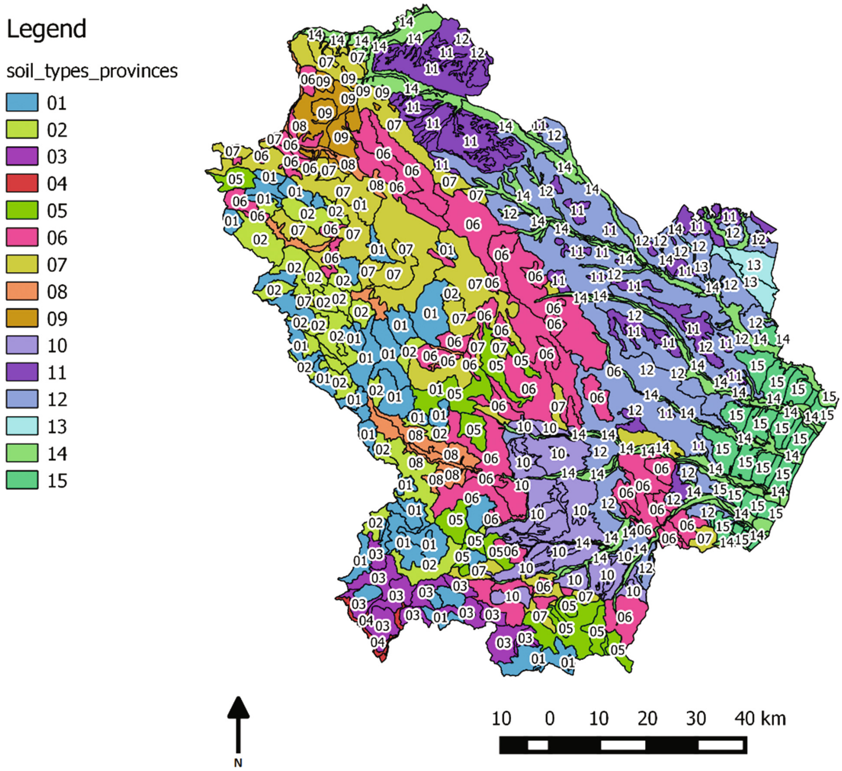

Fig. 4. Pedological characterization of the Basilicata region: soil types provinces [Open source data of the Region of Basilicata http://www.basilicatanet.it/suoli/index.htm]. Legend: (01) Soils of high limestone mountain; (02) Soils of Western inner reliefs; (03) Soils of the Tyrrhenian slope; (04) soils of the foothill area and Tyrrhenian coast; (05) Soils of the high sandstone marly mountain; (06) Soils of central reliefs with rough morphology; (07) Soils of central reliefs with corrugated morphology; (08) Soils of fluvial and lacustrine basins and internal floodplains; (09) Soils of volcanic reliefs of Mount Vulture; (10) Soils of sandy and conglomerate hills of the S. Arcangelo basin; (11) Soils of sandy and conglomerate hills of Bradanica foredeep; (12) Soils of clayey hills; (13) Soils of the Murgia Matera; (14) Soils of floodplains; (15) Soils of the ionic coastal plain and inland marine terraces.

3 Data Analysis

Premised that, as a background of this analysis, two assessments have been carried out by operating the partialization of the areas at municipal scale characterized by a specific land use, such as arable lands.

These assessments have been performed in order to obtain the following outputs:

1. Soil types affected by erosive phenomenon at municipal scale. In order to obtain this output, it has been necessary to use the Regional Pedological Map. This elaboration has been performed in the GIS environment – since it has been necessary to implement the attributes table of the map by adding two data related to the physical-chemical information, such as CaCO3 and SOM content. Then, it has been possible to extrapolate and intersect the different databases coming from different attribute tables: one related to the soil types containing soil characteristics - CaCO3 total and SOM (%) - and the other one containing the dataset of the potential erosivity - interested the areas of the arable land - obtained by the vectorizing process of the raster file generated by the previous application of the USPED method of the year 2012, evaluation deriving from a previous analysis [16].
2. The arable lands areas in hectares – in terms of Utilized Agricultural Area (UAA – source: ISTAT, Italy) - affected by the potential erosion process – classified into the three classes - in each municipality of the Basilicata region.
3. The arable lands affected by soil erosion process at regional scale: this output has been taken through the USPED method application of the year 2012 (Fig. 3) evaluated in the Basilicata region [16].

These outputs have been obtained by operating through two main geoprocessing tools, such as vectorizing and intersection operations followed by appropriate computational operations aimed at calculating the effective areas of interest. Thus, both of these tools allowed to obtain the partialization - in qualitative and quantitative terms -of the areas interested by this analysis.

Describing the steps developed, in order to realize the different scenarios containing the abovementioned results, it has been carried out the following methodologies process:

1. First of all, some data gaps related to the total CaCO3 (%) and the SOM contents (%) have been bypassed by transferring the qualitative data into quantitative terms, by associating an average value aimed at defining the both contents into the correlated value range. Explicating the reasoning: the classes of the value ranges have been considered and the average value has been calculated by applying the well-known analytical relation used for calculating the medium:

$$(max\,value - value\,min)/2 = average\,value$$

2. The utilization of the Corine Land Cover 2012 has made the individualization of the arable lands possible, in order to extrapolate the spatial data related to the areas interested by this specific land use. In fact, this layer has played an important role in

this analysis, by making a biunivocal correspondence evident between the information regarding the land use and the municipal areas interested.

3. The pedological characterization in terms of soil type and the two physical-chemical parameters (total CaCO3 and SOM contents), considered in this evaluation, has been associated to each municipality of the region and, consequently, a sum of the contributes of area - belonging to each soil type - interested to the erosion process, has been calculated. Thus, through this assessment, a *soil type scenario* of the spatial distribution of the areas characterized by different soil types in each municipality and a correlated quantitative result of the areas assessment has highlighted the incidence of the erosion process in the different soil types "districts", by observing the pedological provinces and units more exposed to this phenomenon.
4. The layer "arable lands areas" deriving from the raster obtained through the previous spatial analysis – by USPED method [16] – has allowed to obtain, by a specific assessment, the incidence of the erosive phenomenon in the area interested by arable lands of the Basilicata region (Fig. 3).
5. The operation of intersection, the most strategic '*tool*' used in this analysis, in order to let the different scenarios create geographic, qualitative and quantitative relationships, has been useful to create a complete database – by using the DBF file as a computational sheet in excel environment. This DBF source, taken from the shapefiles generated by the intersection operation, has been used in excel environment, as a computational sheet of great importance aimed at evaluating the different thematisms and parameters coming into a play in this analysis.
6. From the computational operations performed in excel environment on the DBF files deriving from the database generated in the GIS environment, a histogram has been developed in order to illustrate the incidence of the erosion process at municipal and regional scale, in relation to the soil types characterizing the regional and municipal areas affected by soil erosion and a GIS representation related to the incidence of the erosive phenomenon at municipal scale in relation to the land use considered, such as the arable lands.

4 Results

From the analysis carried out, the different outputs resulting have been the following:

1. Assessment related to the areas affected by erosive phenomenon in relation to the soil type more exposed and affected.
2. *GIS elaborations*: a map representative of the erosion process affecting the arable lands evaluated for each municipality and the map representing the erosion process affecting the total pattern of the region, the pedological characterization of the Basilicata's soils and the pedological units interested by the erosion phenomenon affecting the arable lands, the spatial distribution of the SOM and $CaCO_3$ content (%) in the region in relation to the erosion process affecting the arable lands.

By observing the GIS elaboration, deriving from the computational analyses carried out through the attribute table coming from the combination between the municipalities and the excel sheet related to the eroded arable lands evaluated at municipal scale (Fig. 5), it is possible to individuate the most exposed areas to the erosion phenomenon. About the same representation, the intersection tool – GIS operations context – allowed to highlight that the most extensive arable land area affected by soil erosion is the one interesting the territory of Potenza, amounts to 25515.03 ha. On the opposite, the less extensive one amounts to 32.90 ha and is located in Maratea.

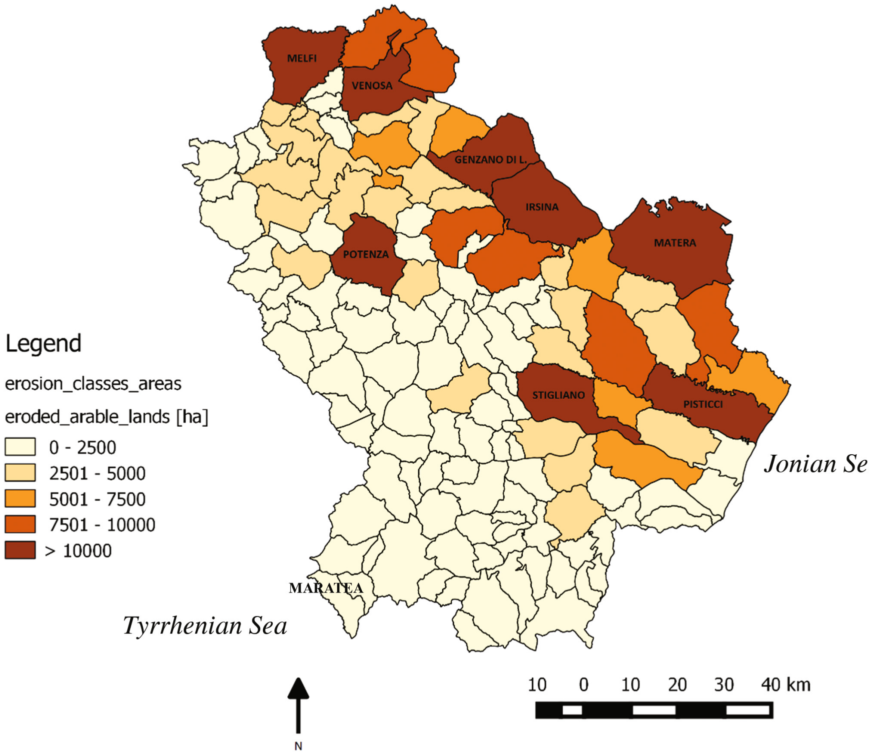

Fig. 5. Spatial distribution of the eroded arable lands evaluated for each municipality in the Basilicata.

By analyzing the assessment related to the soil types more exposed to the erosion process deriving from the histogram – Fig. 6, it is evident to notice that the soil type afferent to the pedologic unit *12.1*, belonging to the pedological province No. 12 defined as “*Soils of the clayey hills*”, results to be much more exposed to this instability. The soils belonging to this soil type are called “*Suoli Elemosina*” and “*Suoli Mattina Grande*”. This soil type interests different municipalities, such as Acerenza, Banzi, Calciano, Forenza, Genzano di Lucania, Grassano, Grottole, Irsina, Matera, Miglionico, Montemilone, Montescaglioso, Oppido Lucano, Palazzo San Gervasio, Pomarico, San Chirico Nuovo, Tolve and Tricarico. The total arable land – belonging to this pedologic unit – subjected to the erosive phenomenon amounts to 46646.89 ha,

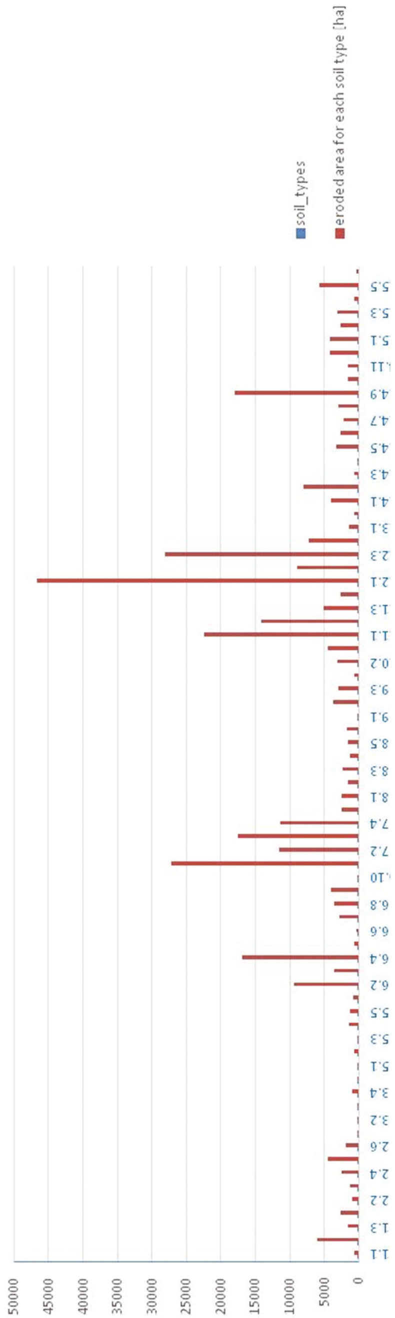

Fig. 6. Eroded arable lands evaluated for each soil type interesting the Basilicata.

calculated by summing the contributions of the eroded arable lands [ha] interesting each municipality characterized by that soil type.

On the other hand, the soil type less exposed to soil erosion consists of the one afferent to the pedological unit *6.10*, belonging to the pedological province No. 6 defined as "*soils of the central mountains in harsh morphology*" characterized by a soil called "*Suoli Arca dei Monaci*" [see "*I suoli della Basilicata*", Pedological Map of the Basilicata region]. This soil type interests the municipality of Rapone and the related area subjected to the erosive phenomenon amounts to 7.45 ha.

The GIS representations of these elaborations has shown by the Fig. 7.

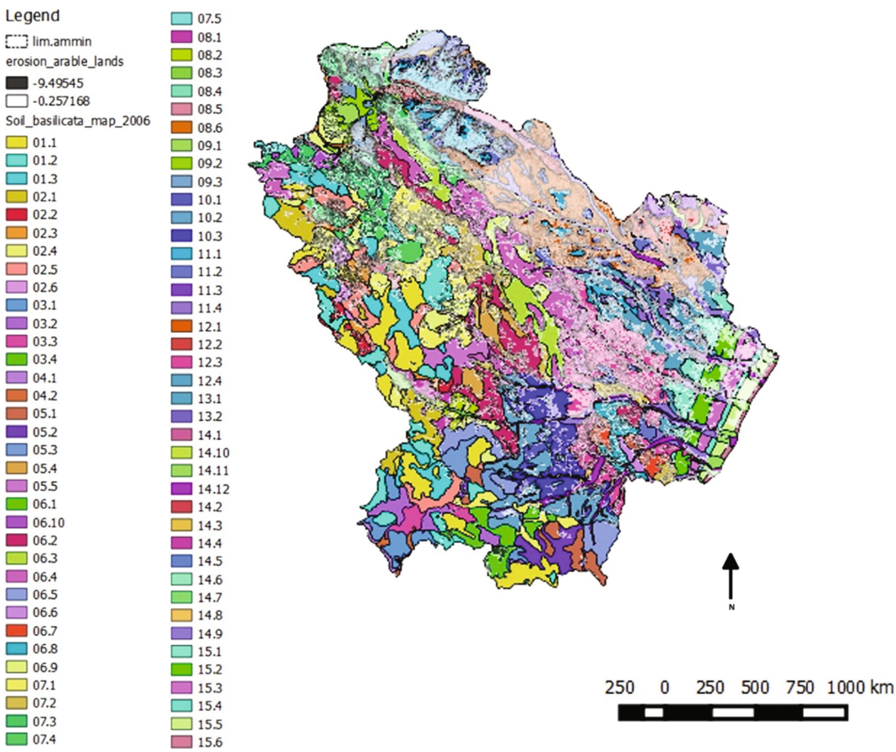

Fig. 7. Spatial distribution of the erosive phenomenon affecting the arable lands in relation to the soil types of the region

The characteristics, emerging from these soil types, highlight a different percentage between both of them: the soil type more exposed to the erosion phenomenon (soil type 12.1) results to contain a total $CaCO_3$ content of 3.7% and SOM of 1.9%; while, the soil type less exposed to the same phenomenon (soil type 6.10) is characterized by a total $CaCO_3$ content of 9.9% and a SOM content of 1.2%.

In relation to the assessment of the areas more exposed and affected by the erosion process, at municipal scale, it is possible to notice and highlight that, in correlation to the total area of each municipality and the area affected by soil erosion, the incidence of the occurrence of the phenomenon is correlated to the aspect related to the soil type characterization (Fig. 8).

This difference of the total $CaCO_3$ content (%) and the SOM content (%) in the two soil types reports a strong correlation with the amount of the areas interested by the land cover considered (arable lands) and the area size in relation to the municipality areas. It is evident that the soil characterized by a SOM content <1.9% is affected by a higher erosion.

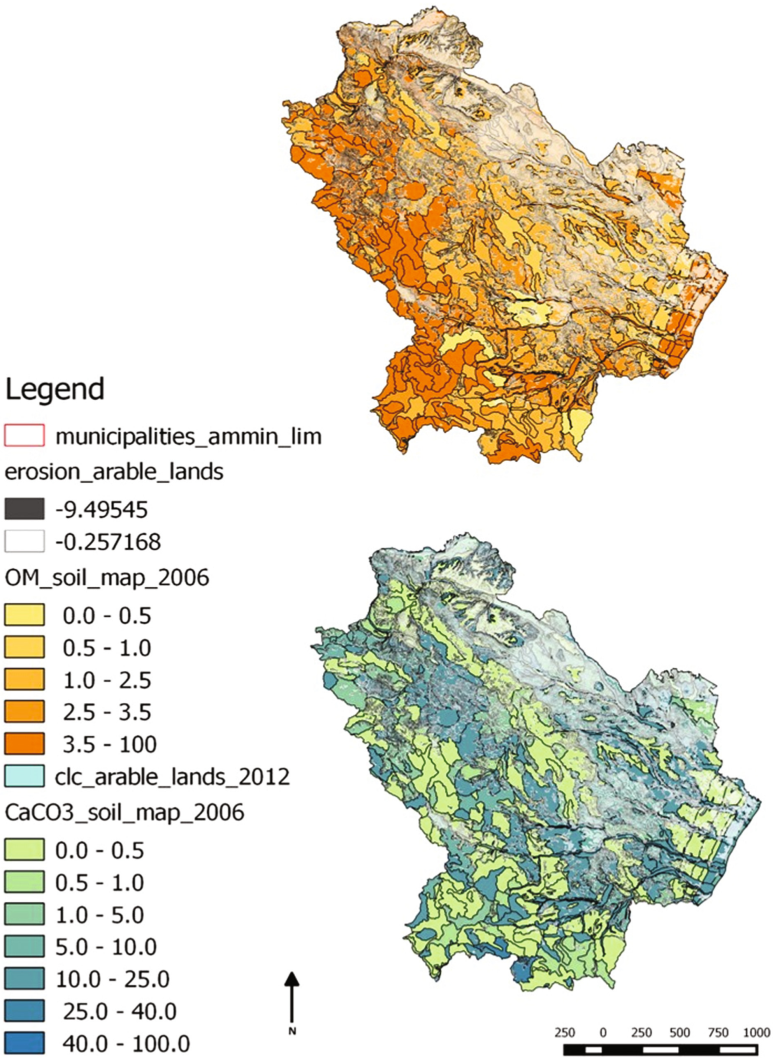

Fig. 8. Spatial distributions of the SOM content (%) and CaCO3 content (%) – respectively - in the Basilicata region in relation to the arable lands affected by soil erosion.

5 Discussion and Final Remarks

From this analysis carried out on different thematisms resulting from different aspects considered, it was possible to make this vision emerge: the areas interested by the erosive phenomenon, both in relation to its own geographical area and the magnitude of the erosion process, belong to a pedological framework that, in relation to the topographic, climatic and land cover features, need to be monitored through a singular and strategic territory monitoring plan, aimed at preventing the potential erosive phenomenon and, if it has already happened, able to mitigate it by reducing the direct and indirect effects on the regional environment.

As the literature demonstrates, the erosion process is able to change soil physical properties, mainly because of the removal (soil profile truncation) of surface soil rich in organic matter and exposure of lower soil layers [28]. Arriaga (2003) indicated that the bulk density and hydraulic conductivity of saturated soil increased slightly with erosion severity [29]. In relation to the soil organic matter influence, it is interesting to mention, as stated by Boyle (2002), this soil parameter, in eroded soil, decomposes at a greater rate than in intact soil. [30]. Numerous field and laboratory studies have shown that soils with low SOM contents are more erodible than soils characterized by a high SOM content, and generally soils with <2% SOM content by weight are highly erodible [31]. Obviously, this aspect can not be considered by itself, given that the various relationships and interrelations among the different land managements and conservation strategies focus on several contributes deriving from the most influencing factors, such as physical, hydrological, geological and pedological characteristics of the area considered.

In the literature, regarding the mitigation of land degradation, several studies have indicated that application of suitable cropping systems (crop rotations) significantly can mitigate this phenomenon of instability in sloping areas [14, 32]. One of the most influencing factors enable to mitigate the land degradation process activated by soil erosion, is the vegetation cover, because it is able to reduce runoff and nutrient losses [33]. For this purpose, it is very important to consider that different plant covers are characterized by different resistance to erosion and can afford soil protection differently [34]. Thus, a constant conservation of these vital resources needs to receive high priority to ensure the effective protection of managed and natural ecosystems [35].

The best management practice in crop and land management is important because, in this way, it is possible to reduce the soil erosion and minimize the leaching of nutrients and increase soil productivity [36].

For this purpose, it is very interesting to focus on one of the most efficient environmental approach described by applying the ratio of *engineering resilience* and *ecological resilience.* Two mean concepts - belonging to this approach -, play an important and strategic role in this context: *recovery duration* (RD) – defined as a measurement of the capacity of land to recover its original state when disturbed – and *recovery effort* (RE), considered in terms of social-ecological resilience, is characterized by the measurement of the land's anthropogenic potential to recover its original state or to prevent damage caused by the same type of disturbance in the future [37, 38].

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