A Modified Soil Quality Index to Assess the Influence of Soil Degradation Processes on Desertification Risk: The Apulia Case

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Received: 23 January 2010. Accepted: 8 May 2010.

Abstract

Apulia is one of the most prone Italian regions to soil alteration phenomena, due to geographical and climatic conditions and also to human activities' impact. In this study, in order to investigate regional soil degradation processes, following the "European Directive for Soil Protection", the ESA's method has been adopted. It is based on the use of an indicator's set to assess the desertification risk. This approach simplifies the diagnosis and monitoring of soil degradation processes, defining their status and trend. Special attention has been given to Soil Quality Index (SQI) determined by six predisposing indicators (parent material, soil texture, rock fragment, soil depth, drainage and slope grade). The integration in the SQI calculation of two additional soil parameters (organic matter content and soil salinity) has been considered particularly significant. In fact, through the evaluation of a so "modified SQI" and the Apulia land use too, it could be possible to assess the role of agriculture management on soil degradation processes, which predisposing regional area to desertification threat. Moreover this approach provides short, but accurate, information thanks to GIS integration, which defines phenomena in detail, offering helpful planning tools.

Key-words: desertification risk, ESA's method, modified Soil Quality Index (SQI), soil degradation processes, Apulia region.

Introduction

Soil degradation is a serious problem in Europe because this area is more affected by intense human activities such as inadequate agricultural and forestry practices, industrial activities, tourism, urban and industrial sprawl and construction works. These activities have a negative impact, preventing the soil from performing its broad range of functions and services to humans and ecosystems (COM (231) 2006). Moreover, especially for the countries of the Mediterranean area, adverse climate conditions such us drought, which stressed soil composition and structure predisposing it to alteration processes, play an important role in soil degradation occurring. These causes result in loss of soil fertility, carbon and biodiversity, lower water-retention capacity, disruption of gas and nutrient cycles and reduced degradation of contaminants. Consequently, soil degradation has a direct impact on water and air quality, biodiversity and climate change. Furthermore it can impair human health and threaten food and feed safety.

The European Environmental Agency (EEA) realized on 2001, in collaboration with ENEA (Italian National Agency for new Technologies, Energy and Sustainable Economic Development), a map of Mediterranean basin countries sensitive to desertification, in which an alarming Italian vulnerability emerged. It has been also confirmed in subsequent researches (Ceccarelli et al., 2006). In particular, studies realized by ENEA, for RIADE project, revealed that in Italy desertification processes affecting southern regions, especially along the coasts and in level lands, were due to climate conditions worsening and to human activities intensifica-

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tion. In fact, an increment of natural resources (soil, water and plant ecosystems) degradation has been registered on last 40 years (Iannetta, 2007).

Among these regions Apulia is widely affected by soil alteration processes, in fact, several studies, conducted in order to evaluate its vulnerability to desertification risk, showed that different soil degradation processes occur in this region. In detail, MEDALUS (Mediterranean Desertification And Land Use) project (Kosmas et al., 1999), enacted by the Environment DGXII, developed a methodology for the individuation of Environmentally Sensitive Areas to desertification (ESA's) based on multi-factorial approach, now well-established and shared, which had in Apulia many applications (Regione Puglia, 2000; Montanarella, 2001; Ladisa, 2001; Magno, 2001; Dipace and Baldassarre, 2005). This region is a very important agricultural area, characterized by a high and changeable human impact due to a large employ in crop management of chemicals (fertilizer, pesticides, herbicide, etc.), low quality irrigation water, heavy and frequent tillage operation.

Desertification processes represent a widespread threat for the environment. The UNCCD (United Nations Convention to Combat Desertification) asserted that desertification is the extreme deterioration of land in arid and dry sub-humid areas due to loss of vegetation and soil moisture; desertification results chiefly from man-made activities and influenced by climatic variations. Great attention has been given towards this phenomenon that provokes a high alteration of soil properties traducing in a loss of soil quality. It as well known that soil quality consists of the capacity of a soil to sustain biological production, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994). Subsequently, Karlen et al. (1997) defined soil quality as "the capacity of a soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation". The concept of soil quality includes assessment of soil properties and processes as they relate to ability of soil to function effectively as a component of a healthy ecosystem (Schoenholtz et al., 2000). The Directive of European Parliament and of the Council, establishing a framework for the protection of soil and amending Directive 2004/35/EC (COM (232) 2006), focuses on the importance of several factors into defining a strategy of soil defence. This can also offer useful tools to combat desertification, improving soil resistance to this threat and increasing the quality of soil.

As well known, soil degradation processes include organic matter decline and soil salinization phenomena because they strongly influence chemical, physics and functional soils characteristics (Chhabra, 1996; Tsutsuki, 2003*)*. In regard of the first one, around 45% of soils in Europe have a low or very low organic matter content (meaning 0-2% organic carbon) and 45% have a medium content (meaning 2-6% organic carbon), (the problem exists in the Southern countries, but also in parts of France, the United Kingdom, Germany and Sweden.) This is a serious problem because soil organic matter (SOM) plays a major role in the carbon cycle of the soil. Indeed, soil is at the same time an "emitter" of greenhouse gases and also a major "store" of carbon containing 1,500 gigatons of organic and inorganic carbon. Moreover, the second one, which consists in Soluble salts accumulation (mainly sodium, magnesium and calcium), affects around 3.8 million ha in Europe. Most affected are Campania in Italy, the Ebro Valley in Spain and the Great Alföld in Hungary, but also areas in Greece, Portugal, France, Slovakia and Austria (SEC (1165) 2006).

Therefore in this work, in order to investigate the Apulia soil characteristics involved into soil quality establishing, we have given particular importance to Soil Quality Index (SQI) evaluation. This is one of the indices used in ESAs methodology for individuating Environmental Sensitive Risk Areas to desertification (Kosmas, 1999). In particular, to calculate this index, some specifically soil properties (texture, parent material, rock fragments, slope, soil depth, drainage) have been considered since they are related to soil quality indicators considered in ESAs method, which regard water availability and erosion resistance, and they are also fundamental for reacting against deterioration processes. According to ESAs methodology, organic matter content and soil salinity parameters were considered in the SQI assessment only indirectly, including soil intrinsic characteristics correlated to them (e.g.: drainage capacity to salt content and soil texture to organic matter content). But, having a large and updated data set, it should be useful to consider directly the values of these two soil variables.

Therefore, the aims of this work were: (a) to apply the Soil Quality Index (SQI) calculation for the Apulia region, as indicated in ESAs method; (b) to modify the SQI calculation procedure, considering organic matter content and soil salinity like further parameters; (c) to compare the "not modified SQI" with the "modified SQI"; (d) to assess the influence of Apulia land use in soil quality worsening in order to individuate the causes of Apulia soil degradation which predispose this region to desertification risk.

Materials and method

The ESA's (Environmentally Sensitive Areas to Desertification) methodology, based on the employment of key indicators (or indices), has been successfully applied in many arid and semi-arid areas (Greece, Iran, Italy, Portugal, Spain, etc.) because it results efficient in risk area individuation and, at the same time, easy to apply (Kosmas et al., 1999; Roxo et al., 1999; Montanarella, 2001; Sepehr et al., 2007; Lavado et al., 2009). This approach includes parameters, which can be easily found in existing environmental reports (Kosmas et al., 1999).

In detail, the ESA's are defined through an algorithm that combines four different indices (concerning soil, climate, vegetation and land management) in order to obtain a final value indicating the overall sensitivity of an interest area.

The methodology is structured in the following way:

- in a first stage, to each parameter (or variable) involved in the indices calculation are attributed different class-values through a standardization process which transforms all the variables in pure adimensional numbers (class-values);
- successively, the 4 indices, are obtained averaging the groups of standardized variables by a geometric mean;
- finally, the 4 indices just obtained are themselves averaged by means of another geometric mean, which represents the final index.

The adimensional values of each parameter class employed in the calculation vary, naturally, in function of the examined area characteristics. In particular, the index-value assigned to every class is inversely proportional to the soil desertification resistance, then the diffuse presence of high index-values represents a diffuse conditions of low soil quality.

In this study the attention has been focused especially on the Soil Quality Index, which has been calculated adopting this formula:

(Eq. 1) Soil Quality Index (SQI) = (parent material x soil texture x rock fragment x soil depth x drainage x slope grade)$^{1/6}$.

Successively, a modification of SQI calculation procedure has been realized using a new formula:

(Eq. 2) Modified Soil Quality Index (mod SQI) = (parent material x soil texture x rock fragment x soil depth x drainage x slope grade x organic matter content x soil salinity)$^{1/8}$.

Subsequently for each parameter has been implemented, using GIS tools, a raster map representative of all different class-values, in order to apply the calculation formula and then to realize the map of "not modified SQI" and "modified SQI" too.

The single parameters employed in "not modified SQI" and "modified SQI" calculations were defined in the following way:

Parent material

The information required to define the class-values concerning Parent material issued from the Lithological Map of Apulia Region realized in the context of ACLA2 Project (Regione Puglia, 2001). In this case, the standard ESAs methodology has been adopted and class-values have been assigned as indicated in Table 1.

Table 1. Classes and assigned weighing indices for "Parent material" parameter used for assessment of SQI.

Class	Description	Parent material	Index
1	Good	Schist, basic, ultrabasic, conglomerate, unconsolidated. etc.	1.0
2	Moderate	Limestone, granite, rhyolite, gneiss, ignibrite, sandstone. etc.	1.7
3	Poor	Marl, Pyroclastics	2.0

Soil texture

The values assigned to soil texture classes, after the analysis of the ACLA2 pedological map (Regione Puglia, 2001), are shown in Table 2.

Rock fragments

Rock fragments parameter has been defined, also in this case, by the observation of the ACLA 2 pedological map (Regione Puglia, 2001), and their related indices are shown in the Table 3.

Soil depth

The class-index attribution defined following the ESAs methodology (Kosmas et al., 1999) has been reported in Table 4.

Drainage

The map of drainage, obtained using 3 class-indices classification, as indicated in standard methodology, showed generic and not detailed data and also largely uniform in areas characterized by different drainage capacity (data not showed). Therefore, 6 indices have been proposed, in order to obtain a map more conform to Apulia soils (Tab. 5).

Slope grade

The slope gradient has been defined, by means of GIS tool, using the Apulia DEM (Digital Elevation Model). Table 6 highlights slope classes and their relative index.

Organic matter content

To define the class-values of this soil parameter the organic carbon content data of ACLA 2 Project (Regione Puglia, 2001) have been employed. Four parameter-classes have been defined (Cassano et al., 2007), considering the content percentage of organic matter. The values attributed to each class are showed in Table 7.

Soil salinity

Soil salinity values have been determined using available data of soil electrical conductivity (Farifteh, 2008). These data result from a soil sampling activity conducted, from 2005 to 2008, all around the Apulia Region (250 sampling sites) by Water Research Institute of the National Research Council during the Regional Project "Improvement of regional agro-meteorological monitoring network".

In function of soil EC (ds/m), 4 parameter-

Table 2. Classes and assigned weighing indices for "Soil texture" parameter used for assessment of SQI.

Class	Description	Texture	Index
1	Good	Loam, Sand-Clay-Loam, Sand-Loam, Loam-Sand, Clay-Loam	1.0
2	Moderate	Sand-Clay, Silt-Loam, Silt, Clay-Loam	1.2
3	Poor	Silt, Clay, Silt-Clay	1.6
4	Very poor	Sand	2.0

Table 3. Classes and assigned weighing indices for "Rock fragments" parameter used for assessment of SQI.

Class	Description	Rock fragments cover (%)	Index
1	Very stony	> 60	1.0
2	Stony	20-60	1.3
3	Bare to slightly stony	< 20	2.0

Table 4. Classes and assigned weighing indices for "Soil depth" parameter used for assessment of SQI.

Class	Description	Depth (cm)	Index
1	Deep	> 75	1.0
2	Moderate	30-75	2.0
3	Shallow	15-30	3.0
4	Very shallow	< 15	4.0

Table 5. Classes and assigned weighing indices for "Drainage" parameter used for assessment of SQI.

Class	Description	Index
1	Very good drainage	1.0
2	Good drainage	1.2
3	Medium drainage	1.4
4	Imperfect drainage	1.6
5	Poor drainage	1.8
6	Very poor drainage	2.0

Table 6. Classes and assigned weighing indices for "Slope grade" parameter used for assessment of SQI.

Class	Description	Slope (%)	Index
1	Very gentle to flat	< 6	1.0
2	Gentle	6-18	1.2
3	Steep	18-35	1.5
4	Very steep	> 35	2.0

Table 7. Classes and assigned weighing indices for "Organic matter content" parameter used for assessment of SQI.

Class	Description	Organic content (%)	Index
1	Very high	> 3.5	1.0
2	High	2.0-3.5	1.5
3	Medium	1.0-2.0	1.8
4	Low	< 1.0	2.0

Table 8. Classes and assigned weighing indices for "Soil salinity" parameter used for assessment of SQI.

Class	Description	EC (ds/m)	Index
1	Low	< 0.2	1.0
2	Medium	0.2-0.5	1.5
3	High	0.5-1.0	1.8
4	Very high	> 1.0	2.0

Table 9. Classes and assigned weighing indices for SQI.

Class	Description	EC (ds/m)	Index
1	High quality	< 0.2	< 1.13
2	Moderate quality	0.2-0.5	1.13 to 1.45
3	Low quality	0.5-1.0	> 1.45

classes have been defined (Cassano et al., 2007) to employ in the calculation, such as described in Table 8.

Soil quality Index (SQI)

As reported in ESAs methodology, three classes have been defined for SQI, such as indicated in Table 9.

Apulia Land use

Apulia land use data have been obtained from technical regional map realized in range of "Apulia Region Landscape Plan" by Territory Organization Department of Apulia region.

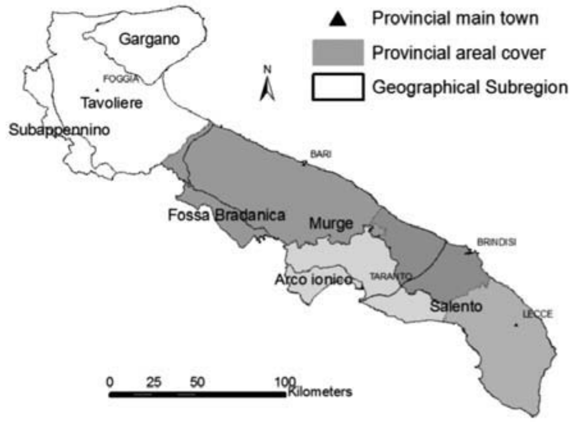

Figure 1. Apulia provinces areas and subregions placement.

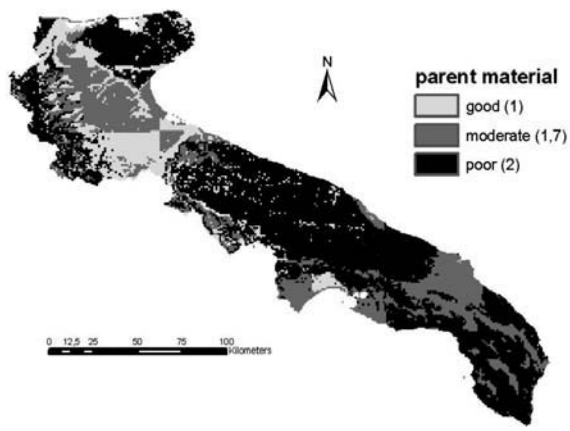

Figure 2. Parent material Map.

Results

In Figure 1 the main geographical and administrative areas referred to the region are presented. The regional distribution of each soil parameters has been considered as by ESA's methodology indicated to determine both SQIs ("not modified" and "modified").

Parent material

Chemical and physical properties of parent material have great relevance on general characteristics of soil, specifically on its strength to erosion and relating to hydrologic processes. Therefore, in presence of different lithological matrices can be observed different degrees of soil desertification (Kosmas et al., 2001).

Figure 2 shows a good parent material quality into Foggia province only; in fact, in the whole region, the prevalence of soils with poor quality emerges. This is due to the large presence of a limestone matrix, from which soils particularly prone to erosion processes arise. Moreover, these soils aren't favourable to rapid recovery of vegetation after critical events.

Soil texture

Soil texture characteristics are essential to define important peculiarities of a soil, as the organic matter content and the water retention and drainage capacity. This property influences the prevalence of deep infiltration and surface run-off with related erosion phenomena (Kosmas et al., 1999). The map (Fig. 3) shows index values assigned to texture classes awarded on the basis of soil capabilities to erosion resistance and water retention. The analysis of the texture classes' distribution in Apulia region shows the dominant presence of good and moderate soil

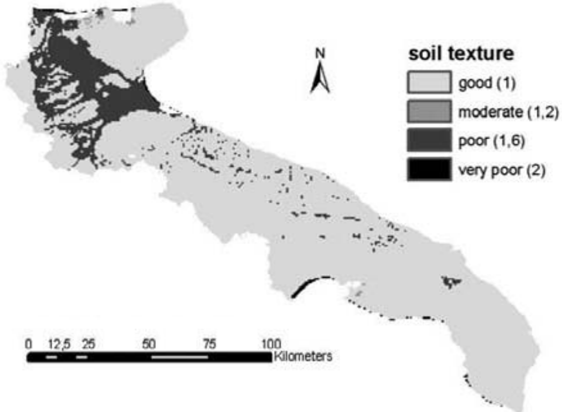

Figure 3. Soil texture Map.

quality. It is explained by the widespread of loam soil type (in particular, sandy-loam, clay-loam and loam) having physical properties more suitable to contain the degradation processes than purely clay, silt or sandy soils.

Rock fragments

The presence of rock material on ground surface assures a protective action against soil alteration processes, especially related to run-off erosion. Thus, it is considered by ESAs methodology in SQI calculation. Rock fragments classes and their indices are shown in the legend of Figure 4. A widespread critical situation emerges, especially in areas characterized by intensive agriculture (Tavoliere plane, Bari province, Salento and Arco Ionico), where soil tillage is intense and mechanical removal of debris is more frequent. Instead, the situation in marginal agricultural areas characterized by extensive production (Gargano, Murgia and Sub Appennino Dauno), appears less critical.

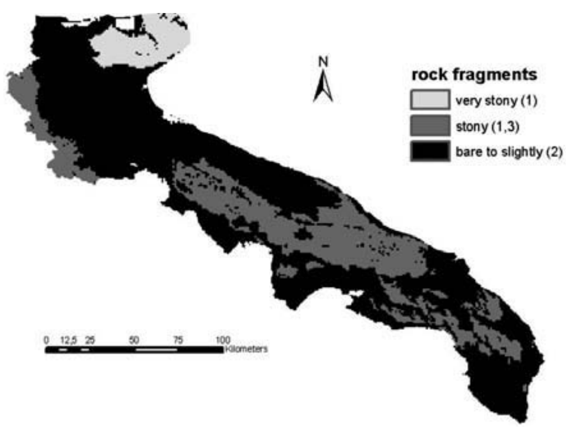

Figure 4. Rock fragments Map.

Soil depth

Soil depth is an important parameter in the SQI evaluation, since as well as to influence the water availability and the run-off effect; it furthers the growth of vegetation and its soil protective action. The map of Figure 5 shows zones with different soil depths and their relative index values. Analysis of this parameter shows the widespread prevalence of soils with high thickness (class-index 1), particularly in the Tavoliere Plane and Fossa Bradanica. Areas with shallow and very shallow soil depth (class-index 3 and 4) are typically karstic (Gargano promontory, Murgia and Salento).

Drainage

Soil drainage capacity acts especially toward possible salinization phenomena, hence in soil profile salts transport and concentration depend on soil water balance and groundwater level (Motroni et al., 2004). Drainage map (Fig. 6)

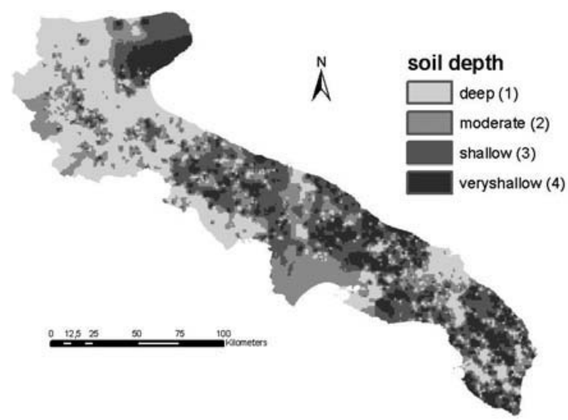

Figure 5. Soil depth Map.

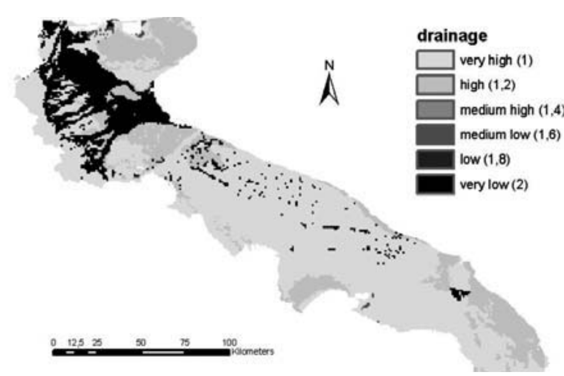

Figure 6. Drainage Map.

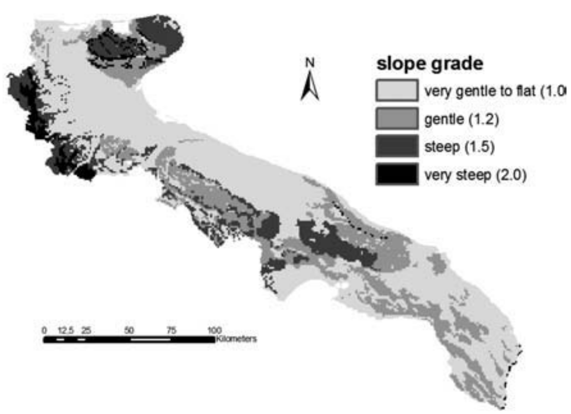

Figure 7. Slope Map.

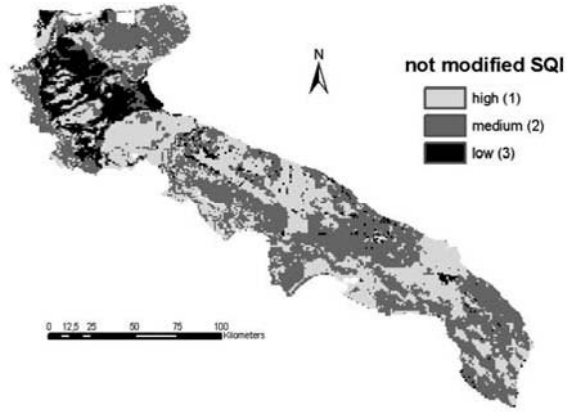

Figure 8. Not modified SQI Map.

highlights that "very high" and "high" classes have been marked in the whole region. Their prevalence is linked to the prevailing silt-clay soils and to the intermediate ones. Moreover, "very low" class is concentrated on Foggia province.

Slope grade

Slope is one of the main factors of soil erosion and sediment transport processes (Wischmeier and Smith, 1965), because it influences both water (surface runoff) and soil (cohesion) dynamics.

The examination of the map in Figure 7 reveals that slope grade classification is coherent with regional topography. The steeper slopes are individualized on Gargano promontory and Sub Appennino Dauno, where heights are higher. Moreover, considerable slopes emerge in northwest and southeaster sectors of the Murgia also.

Not modified SQI

This map (Fig. 8) indicates that medium SQI (class-index 2) is uniformly predominant (954.153 ha of areal cover). The highest class (class-index 1) is mainly localized on Brindisi and Bari provinces and to the south of Foggia ones. On the whole, this class covers 723.810 ha of regional land. The low SQI (3) is represented in the Sub Appenino Dauno and occasionally on the rest of the region with an overall areal cover of 213.810 ha.

Organic matter content

The map relative of organic matter content evidences an high value (> 3,5%) in limited areas of territory (Sub Appenino Dauno, South eastern Murgia, South Salento); a medium and low classes characterize Tavoliere plane, great part of Bari, Brindisi and Taranto provinces, and also part of Lecce ones. A global exam of data could suggest that organic matter content impoverishment, detected diffusely in Apulia soils, could be due to different agricultural activities.

Soil salinity

Primary soil salinity depends on chemical structure of parent material on high groundwater level and on evapotranspiration rate higher than rain contribute. Instead, human factors that contribute to increase the salinity of determined soils are: unsuitable irrigation methods, insufficient drainage, hydrologic balance alteration caused by human impact. All these factors are responsible of space-temporal dynamics of soils salinity (Amezketa, 2006).

On the basis of the EC (electrical conductivity) values distribution, is possible to know that the medium and the high classes, which in-

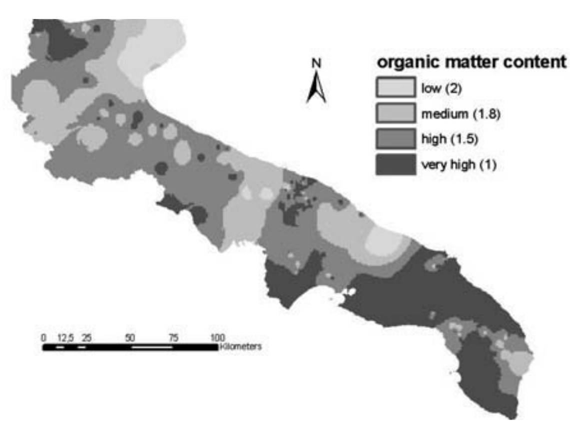

Figure 9. Organic matter content Map.

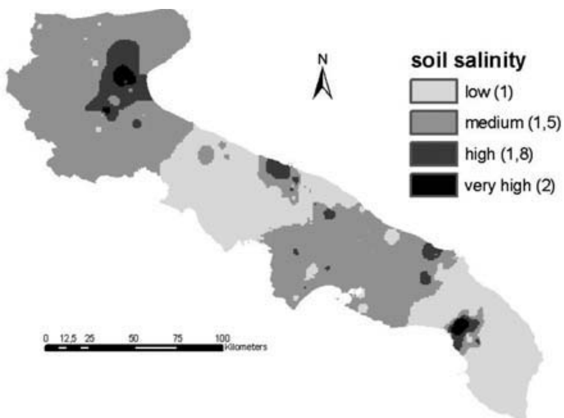

Figure 10. Salinity Map.

teresting in full provincial territories of Foggia, Brindisi and Taranto and partially the Bari and Lecce ones, are the most widespread (Fig. 10). A widespread critical situation appears, especially affecting areas characterized by intensive agricultural activities and coastal ones, probably for effect of the seawater intrusion phenomena.

A particular attention is due to Tavoliere plane and Salento areas, in which the class "very high" is present.

Modified Soil Quality Index

The Map (Fig. 11) shows that "modified SQI" is almost everywhere higher than 1, except for a negligible area equal to 0,14%. Generally, a medium quality situation prevails, characterizing diffusely the 79,23% of the area. It spreads, without continuity solution, from Cape of Leuca (Lecce province) to South Tavoliere, affecting also part of the Sub Appennino Dauno and part of Gargano promontory. The sizeable presence of areas with low soil quality (class-index 3) could be a serious problem because it affects the 20,63% of region. In detail, these areas have been identified with great part of Tavoliere plane, southern sector of Murge Plateau, eastern slope of Sub-Appenino Dauno, part of Salento peninsula and part of Bari and Brindisi's coast.

Discussion

The fundamental soil characteristics are determined by complex interactions of physical, chemical and biological processes, so soil quality expresses the continuous exchanges between soil and surrounding environment. This is also increasingly proposed as an integrative of environmental quality (National Research Council, 1993; Monreal et al., 1998) and it would appear to be an ideal indicator of sustainable land management (Herrick, 2000). Indeed, indicators can be easily communicated to the public or to policy-makers. Also these indicators can be used as easy synthetic information in geographic information systems (GIS) to: (i) determine spatial extension and geographic distribution of degraded areas and (ii) relate human actions to environmental conditions (Rubio and Bochet, 1998).

In order to understand soil management influence on soil alteration grade it could be important to compare different SQIs ("not modified" and "modified") calculated considering regional land use too.

The graph in Figure 12 reports the areas expressed in hectares (ha) for each class of Soil quality Indicator for both SQIs. These results

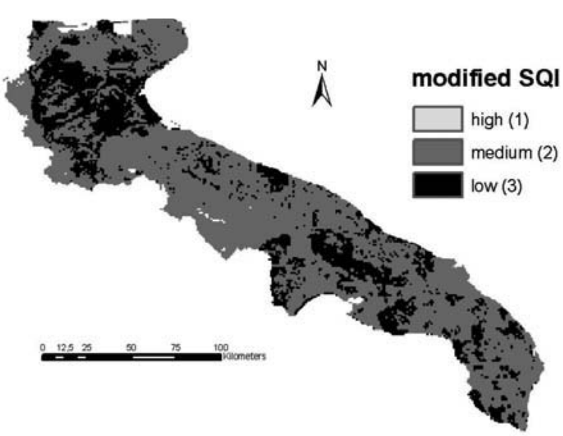

Figure 11. "Modified SQI" Map.

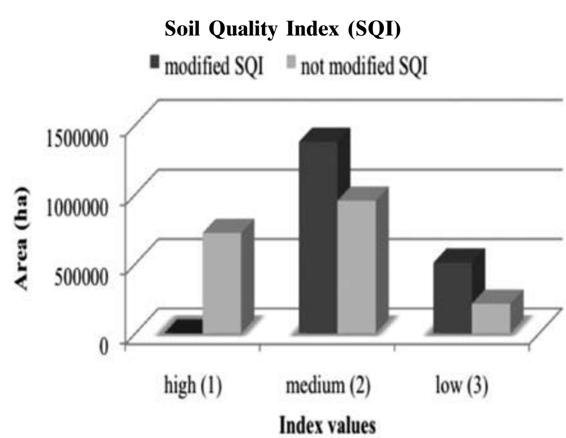

Figure 12. Areal cover comparison between each class of "not modified SQI" and "modified SQI".

evidence that a high increase of class 2 and 3 has observed considering also "organic matter content" and "soil salinity" parameters, indeed, soils quality decreases considerably.

The area related to a medium soil quality (1.377.408,31 ha) is higher than that detected without modifying SQI calculation (954.153,07 ha). The class index 3 (low soil quality) affects 508.187,76 ha, twice over the area involved in "not modified SQI".

The graphs reported in Figures 13 and 14 present the areas characterized by medium (class-index 2) and low (class-index 3) modified SQI, classified on the basis of regional land use. In both cases arable lands and olive grove predominate on the other ones. In detail (Fig. 13), for medium SQI area, arable lands are the 30,24% (415.458,69 ha) of the whole area whereas olive groves cover the 26,55% (364.716,58 ha). Instead, for low SQI area, arable lands cover 211.435,46 ha and olive groves 117.065,17 ha, representing the 41,75% and 23,12% of the whole area respectively (Fig. 14).

Figure 15 shows the overlap of "modified SQI" and regional land use, which indicates only the widespread typologies of land use (arable lands and olive groves).

Low class of "modified SQI" is mainly concentrated on northern part of Tavoliere plane, characterized by arable lands. Hence, this modified index highlights the presence of a serious problem in the Foggia province; instead, remain areas are affected occasionally.

The identification of this sector as a great fragility area has been determined by high values of the indices of drainage, soil texture, and rock fragments. Moreover, on Tavoliere plane soil salinity and organic matter content play an important role. In fact, on Foggia province a medium and low content of organic matter has been observed. In this zone characterized by intensive productions, more frequent and heavy

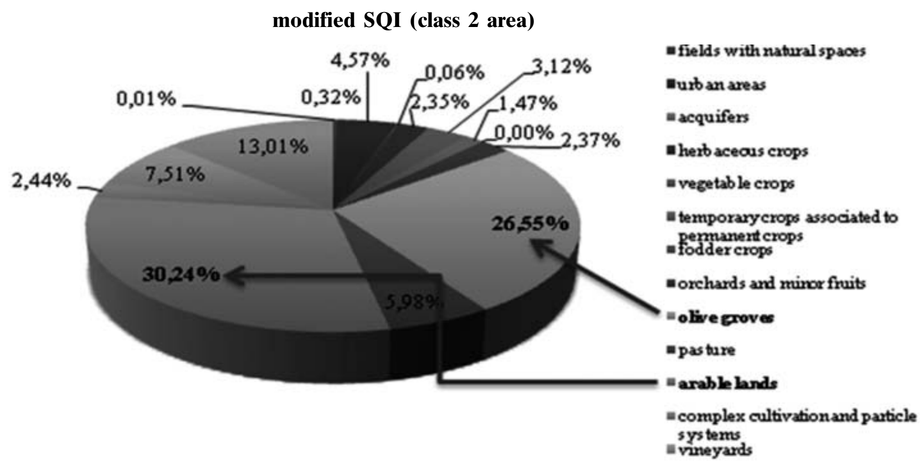

Figure 13. Distribution of different types of land use for "modified SQI" (class 2 area). Arrows indicate corresponding percentages for particular land use types.

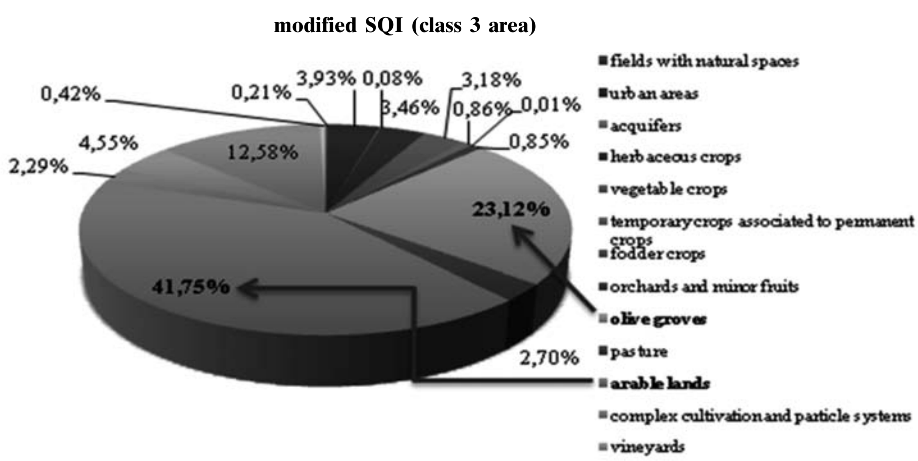

Figure 14. Distribution of different types of land use for "modified SQI" (class 3 area). Arrows indicate corresponding percentages for particular land use types.

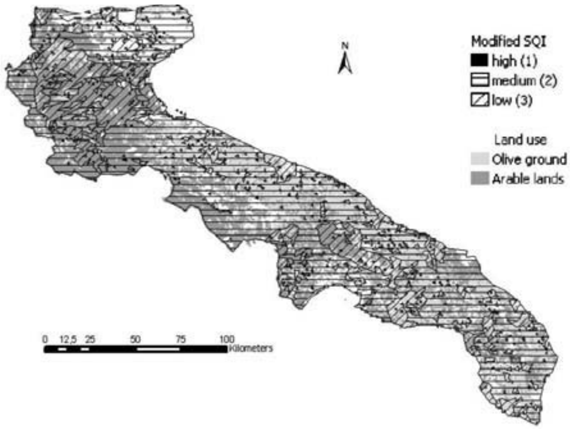

Figure 15. Principal land use typologies corresponding to classes 2 and 3 of "modified SQI".

tillage operations are adopted and the use of chemicals nutrients is preferred to organic fertilizer in crop management causing, in the long period, soil characteristics alteration. The excessive application of fertilizers (including quantity and frequency of application) usually exceeds the functional soil abilities (Zalidis, 2002). Also in regard of soil salinity parameter, a critical situation has been registered in this same zone; in fact, very high salinity values characterize this area (Fig. 10). The increasing conductivity and associated soil salinization and also the intrusion of seawater into the groundwater aquifers near the coast represent a fundamental impact of agriculture on soil quality and water resources in Mediterranean area (Zalidis, 1999). Salinization has a direct negative effect on soil biology and crop productivity, and an indirect effect leading to loss of soil stability through changes in soil structure (Szabolcs, 1996).

Concluding, maps analyses suggest that in Apulia region a soil quality alteration process is occurring activated by several factors (natural and human ones). This phenomenon can expands itself uncontrollably, in favor a more intensive desertification process. Thus, these results recommend a revision of Apulia crop and land management strategies in order to mitigate the soil degradation process. For example, it could be useful a large adoption by farmers of Best Management Practices (BMPs), such as irrigation practices rationalization, respect of natural productive cycles, higher use of organic fertilizers, and reduction of chemical and energetic inputs, supported by Regional Authority.

Acknowledgments

This work has been realized in range of an Italian national project "Attuazione sperimentale della nuova direttiva per la protezione del suolo finalizzata alla lotta alla desertificazione in Puglia" sustained by MATTM (Ministero dell'Ambiente e della Tutela del Territorio e del Mare), CNLSD (Comitato Nazionale per la Lotta alla Siccità ed alla Desertificazione), Apulia Region and developed in partnership with ARPA Puglia (Regional Agency for environmental protection of Apulia), MAIB (The Mediterranean Agronomic Institute of Bari), and ENEA (Italian National Agency for new Technologies, Energy and Sustainable Economic Development).

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