Sustainable indicators in desertification phenomena: application to Calabria, Italy

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Abstract

Italy is one of the Mediterranean countries that are menaced by desertification, particularly in the Southern regions: Sicily, Sardinia, Apulia, Basilicata and the Ionian areas of Calabria. In such a scenario it is evident that correct water resource planning is very important: reduced water resources, once considered meaningless, have now acquired notable importance. Environmentally Sensitive Areas (ESAs) [1] to desertification will be described in this paper, with particular reference to the Calabria region. Key indicators for the estimation of soil capacity to resist degradation processes will be found through the MEDALUS methodology (MEditerranean Desertification And Land USE: European Commission, 1999), which allows the assessment of desertification risks on a regional scale. Indicators will be grouped into four classes, on the basis of soil quality, climate quality, vegetation quality and management quality. Each index will be classified into three levels (high, moderate and low) according to the MEDALUS classification, and they will be entered into and employed by a Geographical Information System (GIS), which will define the different layers depending on the quality index considered. In this way, the contribution of each quality index will be defined and intervention and mitigation proposals will be developed through the description of the main sectors (soil protection, sustainable management of agricultural resources, decreased impact of production activities and territory re-equilibrium), allowing the definition of criteria used to limit the effects of the degradation and to allow correct land use.

1 Introduction

In Italy, desertification does not mean that landscape will turn into a desert one, but that it will be characterized by aridity, erosion, salinization, depletion of
vegetable covering and organic substances, pollution and wrong soil use (effects of intensive agriculture on soil, effects of pasturing on vegetation, wood overexploitation in forest, irrigation mismanagement that have wasted land fertility). For this reason it is necessary to develop an efficient system for resources monitoring and models compatible with territory sustainable development. Being mainly a mountainous and hilly country, Italy is particularly vulnerable. Moreover, soil slope and its exposition are a further vulnerability factor in the climatic and geo-morphological context of the regions subjected to water stress conditions. In order to collect data concerning soil degradation and to describe its causes through measurements and observation, some indicators and indexes are employed. They are a whole of aggregated or weighed indicators or data, having great importance in the process that starts from the definition of the phenomenon and leads to decision making [2]. There is not a general consensus regarding the indicators to be used at a national scale. At the Mediterranean Basin scale, there exist many Community research projects. One of these projects, the MEDALUS, was designed to investigate climatic changes in the Mediterranean area, soil degradation in semi-arid areas, vegetation growth, socioeconomic changes and methods useful to integrate these factors through numerical models [3].

2 Project methodology

The methodology developed for the MEDALUS project, and illustrated in previous works [4] provided the definition for ESAs, through the evaluation of the so-called Environmentally Sensitive Areas index. This index is obtained by employing some key indicators grouped in four categories: Soil, Climate, Vegetation and Management. Through them, soil capacity to resist degradation processes or soil suitability to support and sustain specific uses can be evaluated. Each indicator has to belong to a class and each class is given a score varying from 1 (“lower weight”) to 2 (“higher weight”) depending on its influence on desertification process. The geometric mean of the groups of indicators belonging to each of the four categories, provides for four Quality Index (QI) [5]:

1) Vegetation Quality Index (VQI);
2) Soil Quality Index (SQI);
3) Climate Quality Index (CQI);
4) Management Quality Index and anthropic pressures (MQI).

The geometric mean of the four quality indexes gives the ESAs index which is used to classify the areas into four different sensibility categories (critical, fragile, potential, and unaffected by desertification) [6]:

$$ESAI = (VQI \times SQI \times CQI \times MQI)^{1/4}.$$ 

2.1 Vegetation Quality Index (VQI)

The biotic soil component able to contrast the desertification process is vegetable covering. Vegetation Quality can be obtained through indicators that “quantify”
the capacity of each vegetable species (natural or agricultural) to resist to degradation. The key indicators developed for this purpose are:

1) Fire risk and recuperation capacity;
2) Soil protection from erosion;
3) Vegetation drought resistance;
4) Vegetable covering.

By combining these indicators [5] the Vegetation Quality Index (VQI) can be obtained. More specifically:

\[ \text{VQI} = (\text{Fire risk and recuperation capacity} \times \text{Soil protection from erosion} \times \text{Vegetation drought resistance} \times \text{Vegetable covering})^{1/4}. \]

2.2 Soil Quality Index (SQI)

Soil, according to the definition of the Soil Conservation Society of America (1986), is a natural body composed of mineral and organic particles deriving from physical and chemophysical rock alterations and from the biological and biochemical transformation of organic residuals. Capable of supporting vegetation, it is characterized by inner atmosphere, flora and fauna determined by a particular water “economy”. When soil lacks the characteristics necessary to support a vegetable covering (inadequate rooting depth and/or inadequate water capacity and/or lack of nutrients) a degradation process is triggered, leading in the end to land desertification. In this context, quality soil indicators can be related to soil water content and soil erosion through the evaluation of the proprieties or characteristics of the soil [5]. The procedure cannot be strictly applied to Calabria Region because the regional soil map is still missing. This map would have provided for a precise description of soil characteristics, thus giving the tools to estimate, in the totality of the area, the “value” of indicators such as soil depth, drainage, texture, and rock fragments [7]. At present, the indicators considered to represent soil quality are:

1) Parent rock;
2) Soil depth;
3) Slope.

Their combination gives a Soil Quality Index (SQI) equal to:

\[ (\text{SQI}) = (\text{Parent rock} \times \text{soil depth} \times \text{slope})^{1/3}. \]

2.3 Climate Quality Index (CQI)

The spatial distribution of the indicators in the territory is based on the values assumed in measurement stations. Rainfall observation period, for most stations, goes from 1921 to 2000, though in some cases the series are incomplete. Anyway, stations have always been run for more than 40 years, a period largely sufficient to give a very good estimation of the average value of annual total rainfall [8]. Calabria region is particularly rainy (average total annual rainfall is 1176 mm, higher than the Italian average value of 970 mm); the prevailing climate is humid (44%); hyperhumid climate characterizes Sila and Serre
mountain chains, Aspromonte and Pollino massifs; in the areas of Catanzaro, Cosenza and Mileto climate is sub-humid; climate becomes arid in the most Southern areas and in the higher Ionian coastal areas (Villapiana). Irregular annual and pluriannual rainfall distribution, together with the occurrence of extreme events as well as rainfalls and vegetative periods out of season are the main climatic factors contributing to soil degradation in semi-arid and arid Mediterranean areas. According to recent studies [5], global climatic changes will affect the vulnerable Mediterranean areas: in the future, the hydrological deficit might leave the soil naked, thus favoring surface runoff and erosion, factors that may trigger the desertification process. Many proposals have been made regarding a rational classification of climate through the transformation of elementary data into synthetic climatic indexes, which should not consider pluviometry only, but also its relationship with the water need of soil and vegetation, that is real evapotranspiration meaning water quantity passing as vapor directly through soil evapotranspiration or indirectly through plant transpiration [9]. The indicators considered in this paper to represent climate quality are:

1) Climatic Thornthwaite index;
2) Average annual rainfall;
3) Slope aspect.

The combination of these indicators gives the Climate Quality Index (CQI). More specifically:

\[(CQI) = (\text{Clim. Thornthwaite ind.} \times \text{Average annual rainfall} \times \text{Slope aspect})^{1/3}.\]

### 2.4 Management Quality and anthropic pressures (MQI)

Paleoclimatic studies confirmed that the destabilization of natural ecosystems in general, and forest systems in particular, was a consequence of anthropic pressure on environment. In particular, the choice of some areas and not others was possibly a discriminating factor. Moreover, present changes in economic and social structures in some rural areas also have in many cases affected the hydrological cycle, exacerbating erosion phenomena and increasing surface runoff [3]. In the definition of desertification ESAs, the following key indicators regarding management quality and anthropic pressures should be considered:

1) Soil use intensity;
2) Land protection politics.

The highest score to soil use intensity has been given to sowable lands in irrigation areas and to urban areas because of soil subtraction associated with it. A low score for soil use intensity characterizes forested areas, the Tyrrhenian Coastal Chain, the Sila and Serre mountain chains, the Aspromonte massifs. The combination of these indicators gives the Management Quality Index and anthropic pressures (MQI). More specifically:

\[(MQI) = (\text{soil use intensity} \times \text{management politics})^{1/2}.\]
3 Procedures and data

Among the most advanced instruments for the study of environmental variations in general, and desertification in particular, aerospace telemetering and Geographic Information Systems (GIS) are tools with powerful descriptive characteristics. Moreover, when data are introduced in a regional GIS, the immediate analysis and visualization of the phenomenon can be performed. Being relational databases, capable of implementing, manipulating and process any kind of georeferenced information, GIS is by its very nature suitable for the multifactorial analysis of ecological complex processes at a superregional scale. Moreover, ecological processes interact with economic and social factors difficult to quantify and analyze in the decision-making process for a sustainable land development. GIS allows a unitary representation of all these factors by attributing quantitative values to each of them depending on the “weight” that each has with respect to the others. This multidimensional matrical analysis method allows phenomenon interpretation and modeling of future events occurring in predetermined conditions. It can also optimize decision-making regarding environmental management on the basis of a maximum number of factors, thus minimizing the possibility of subjective evaluations [10]. In this paper, GIS ArcView 8.3 and the optional extensions ArcGIS Spatial Analyst were employed for data analysis. This software has many typical functions of the GIS environment, as map creation, data analysis and management. Map calculator function was employed to generate informative layers regarding quality indexes through the spatial distribution of point “values” assumed by the single indicators. The results are made available in a graphic environment, ready to be printed or to be employed for later processing, and in the alphanumerical format for their analysis, to be used in reports, and save the simulated scenario for later confrontation with other scenarios generated by parametric spatial analysis simulations. The following tools were employed in order to determine Desertification Sensible Areas:

1) Calabria Geological Map: scale 1:250.000 (Regional catchment Authority);
2) CORINE Land-Cover: scale 1:100.000 (Italian Geological service) - The surface area of the minimum mapped portion was 25 hectares, corresponding in the reference map (scale 1:100.000), to a square with a 5 mm side or a circle with a 2,8 mm radius;
3) DTM (Digital Terrain Model): square grid with a 250 m side (Italian Geological service).

4 Results and discussion

MEDALUS project methodology was applied to Calabria region. 41% of the area has elevations lower than 300 m.s.l.m. and in the remaining 59% elevations are higher. Mean regional altitude is 556 m.s.l.m. Plains are located near the coasts. Figure 1 shows the map of vegetation quality, which is the synthesis of
the layers referring to fire risk, soil protection from erosion, drought resistance and vegetable covering [4]; Calabria territory resulted to be divided into areas with high (49.9%), moderate (18.4%) and low quality (31.7%). The best conditions characterize Reggio Calabria province; in this area, forested areas and perennial cultivations (olive groves) dominate, and they protect soil from degradation thanks to their resistance to drought, erosion protection and vegetable covering. The provinces of Catanzaro, Cosenza and Vibo Valentia include a higher percentage of areas with stronger tendency to degradation, though the values are less alarming than those reported for Crotone province.

Figure 1: Vegetation quality map in Calabria region [4].

Figure 2: Soil quality map in Calabria region [7].
Figure 2 shows the soil quality map of Calabria region, which is a synthesis of the layers relative to the indicators mother rock, soil depth and slope [7]. Soil results to possess different characteristics estimated on the basis of the indicators considered for the entire regional territory. Good quality soils, having a good
water content and a good resistance to erosion, are located in coastal plains, in some portions of Crati valley where slopes are less than 6% and in most areas of Crotone province. Soils that do not resist well to desertification process (low quality) are located mainly in the Pollino massif.

Figure 3 shows climate quality map in Calabria region, which is a synthesis of the layers regarding the indicators Thornthwaite climatic index, average annual rainfall and slope exposition. A high climate quality characterizes 47 % of the regional area, while in 2% of the areas, located mainly in the most southern part of the region and in the higher Ionian area in Cosenza province, climate quality is low. In these areas, the occurrences of both scarce rainfalls and high evapotranspiration rates at the same time, significantly contribute to land desertification.

![Map of sensible areas to desertification in Calabria region.](image-url)
Figure 4 shows management quality map in Calabria region, which is a synthesis of the layers regarding the indicators soil use intensity, land politics and protection. In most regional areas, management quality is moderate. In particular, almost the entire territory of Vibo Valentia province has a moderate management quality, together with the territory of Reggio Calabria province. Areas with a low management quality are concentrated in a few zones. The theme final synthetic index (ESAI) is obtained by superimposing the theme of quality indexes previously considered. By grouping the results, the Desertification Sensible Areas map is obtained (Figure 5). The unaffected areas in Calabria region is about 26%; in Catanzaro province about 37%, in Vibo Valentia province about 24%, in Reggio Calabria province about 28%, in Cosenza province about 20% and in Crotone province about 26%. Most regional land, however, shows a “fragile” sensibility (41.5%). It should be considered that in “fragile” sensible areas the balance among natural factors and/or human activities is already particularly delicate. Finally, areas with “critical” sensibility are about 10%. These results reflect land geomorphologic characteristics, intensive and careless exploitation, and the presence of few forests, as well as the peculiar pluviometric regime, with rainfall below the seasonal average. For each area determined on the basis of the ESAs index, the quantitative contribution of each quality index can be obtained. For example, in Albidona municipality, there is an area classified as C3 (ESAs index of 1.57) whose contribution is given by a moderate SQI (1.34), a low CQI (1.93), a low VQI (1.68) and a moderate MQI (1.41). Thus, the most critical factors concern climatic conditions and vegetation typology. In this way, intervention politics aiming at solving specific problems peculiar to each area will be developed.

5 Conclusions

In Italy, Southern and insular regions, characterized by environmental stresses (seasonal aridity, several drought events, short and heavy rainfalls, soil erodibility, often unsustainable environmental pressures due to human activities) are menaced by desertification. Water shortage causes unbalances, and adaptation and mitigation measures should be adopted in order to prevent degradation and desertification. As for soil quality index, it is not very detailed because indicators concerning drainage and soil texture are not available due to the delayed publication of the Calabria soil map. Because soil use intensity is important, the indicators capable of representing management quality should be integrated. New thermopluviometric data will increase the network of measurement stations, they will support the analysis of temperature and rainfall trends to forecast possible future projections. By introducing a parameter that will consider fire probability, precious information concerning vegetation quality would be available. As for management quality, great importance should be given to environmental pressure and anthropic factors, fundamental elements in determining Environmentally Sensible Areas (ESAs) to desertification. The proposed methodology, based both on general and local knowledge of environmental processes, would thus be very useful in intervention planning,
aiming at a rational management of the areas subjected to desertification and at the recovery of the menaced ones. After the definition of risk areas, the employment of Regional Indicators would undoubtedly allow planners to make informed decisions.

References


[2] Agenzia Nazionale per la Protezione dell’Ambiente (ANPA) - Centro Tematico Nazionale Suolo e Siti Contaminati, Sviluppo di indicatori per il Suolo e i Siti Contaminati, Roma 2000.


