Insight desertification process: Bio-physical and socio-economic drivers in Italy

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INSIGHT DESERTIFICATION PROCESS : BIO-PHYSICAL AND SOCIO-ECONOMIC DRIVERS IN ITALY

COMPRENDERE I PROCESSI DI DESERTIFICAZIONE IN ITALIA: IL RUOLO DELLE VARIABILI BIO-FISICHE E SOCIO-ECONOMICHE

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Abstract
Since some decades, land degradation and desertification became one of the most severe threat for environment and human survival. In the World nearby 70% of useful drylands for agriculture has suffered soil erosion and degradation. In more than 100 countries, nearby 17% of world population is affected by desertification, forcing people to leave their farms or their villages. By now many other Countries, like Italy, although do not suffer explicit consequences, show environmental fragility induced by bio-physical (especially climate) and socio-economic causes. CRA-CMA took part in Country efforts to evaluate this issue and specifically to develop an objective methodology of land vulnerability assessment. By using several elementary variables, environmental indicators (climate characteristics, soil qualities, human pressure, economic activities), setting up through statistical methods (multidimensional analysis), and GIS tools, CRA-CMA has implemented a synthetic index, defined Land Vulnerability Index (LVI) which follows DPSIR scheme. LVI classifies the national territory in terms of exposure to land degradation and desertification risk.

Keywords: land degradation, risk, degradation systems, vulnerability index, Italy

Riassunto
N*egli ultimi decenni, degrado dei suoli (*land degradation*) e desertificazione sono divenuti una delle maggiori minacce per l'ambiente ed il benessere umano. Nel mondo circa il 70% delle terre coltivabili è colpito da erosione ed altri fenomeni di degrado. Complessivamente, tali fenomeni coinvolgono in forma diretta o indiretta circa il 17% della popolazione mondiale contribuendo, nei casi più gravi, ad aumentare il numero dei cosiddetti "rifugiati ambientali". Oggi, molti altri Paesi, fra cui l'Italia, sebbene non patiscano in modo conclamato ed esteso di processi di desertificazione, evidenziano una graduazione di fragilità ambientale dovuta sia a cause bio-fisiche (specialmente climatiche), sia di natura socio-economica. Il contributo del CRA-CMA all'interno di questa tematica ambientale è stato quello di sviluppare una metodologia oggettiva di valutazione della vulnerabilità del territorio a livello nazionale. Attraverso l'utilizzo di numerose variabili elementari, indicatori ambientali (caratteristiche climatiche, qualità dei suoli, pressione antropica, attività economiche), metodologie statistiche (analisi multidimensionale) e strumenti GIS, il CRA-CMA ha implementato un indice sintetico di vulnerabilità ambientale, definito* Land Vulnerability Index *(LVI), sulla base di uno schema DPSIR (*Driving Forces-Pressures-State-Impacts-Responses*). Attraverso l'indice LVI è stato classificato il territorio nazionale in termini di sensibilità alla* land degradation *ed al rischio di desertificazione.*

Parole chiave*: degrado del territorio, rischio, sistemi di degrado, indice di vulnerabilità, Italia*

Introduction
Since the 1970s, desertification has gained growing attention of the international community about its devastating and destabilising potential on the natural environment and the human society. According to the United Nation Convention to Combat Desertification (UNCCD), desertification was defined as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. In other words, worsening environmental conditions is well express by serious or complete loss in soil fertility. Based on United Nations estimates, the phenomenon has interested nearby 70% of arid lands, amounting to about 30% of the world cultivable land. The problem is particularly severe in Africa and in several developing countries in Asia, South America and the Caribbean, but it interests also the United States, Australia and Southern Europe (especially Greece, Spain, Portugal and also Italy). According to OECD, the main processes of soil degradation are due to erosion, submersion, acidification, salinisation, soil compaction, surface crusts and compact layers along the profile, loss of organic matter, deterioration of the soil structure, accumulation of toxic substances, as well as loss of nutrients. Desertification is often triggered by initial conditions of environmental fragility. Causes are linked to several underlying factors (of both natural and anthropic nature) that work as a complex system of interactions. In this context, climate change makes ecosystems even more sensitive and fragile because it increases the pre-existing climate aggressiveness. The socio-economic causes, instead, are generated from the impacts of anthropic pressure linked to urban expansion and economic activities, especially when the above factors involve an unsustainable exploitation of natural resources. Each of these environmental haz-

Tab. 1 – Example of DPSIR framework to evaluate land degradation and desertification processes.
Tab. 1*- Esempio di schema DPSIR per valutare i processi di degrado del territorio e la desertificazione*

DRIVING FORCES	PRESSURES	STATE		IMPACTS	RESPONSES
climate change	precipitation temperature	rainfall evapotranspiration drought run-off aridity		soil moisture depletion, soil erosion	irrigation, land amelioration
climate change, agriculture	climate aggressiveness, grazing, fire, soil management	soil characteristics	soil depth soil texture AWC soil parent material stoniness soil drainage organic carbon content	soil erosion	agro-enviromental policies, agronomical tecniques, sustainable crop production
		vegetable land cover			protected areas
		human activities	over-grazing forest fires soil compaction		
agriculture	water over-exploitation	groundwater use for irrigation inefficient irrigation systems		soil salinisation	irrigation source/system diversification
	intensification or marginalisation of agriculture	land use	crop intensification settlement of rural areas crops suitability	loss of cultivable land	sustainable agriculture
		farm management strategies	type of farm management farms granted in leasing diversification of farmer activities	crop diversification	diffusion of integrative economic acivities (e.g., rural hospitality)
		socio-economic system	people employed in agriculture farmers ageing farm marginalisation	agricultural efficiency	policies for young farmers
population growth	urbanisation	population density characteristics of human settlement tourism concentration		soil sealing	sustainable urban planning
economic development	pollution	quantity of pollutant emission mining		excess of wastewater	limitation to polluting

ards, even if not immediately producing observable desertification effects, can create an instability in the ecosystem equilibrium. Therefore, changed environmental conditions may lead to land vulnerability. That is to say a decreased resilience of the ecosystem which can ultimately causes a real damage. In Italy desertification shows effects on limited areas of southern regions (Basilicata, Apulia, Calabria, Sardinia and Sicily) where, in addition to arid conditions, unsustainable anthropic pressure on the natural environment occurs. As a consequence the same environment reduces its biological and agricultural productivity and shows a progressive loss of biodiversity. In other Italian regions, where by now land degradation processes are not evident, the potential risk of desertification is increasing. This is in turn due to worsening hydro-meteorological conditions caused by decreasing amounts of precipitation, more frequent heavy rain events, intensification of soil erosion, intensive crop systems, urbanisation (e.g., Salvati *et al.* 2005; Perini *et al.* 2006). The circumstances above show that desertification concerns not only arid and/or marginal areas, but it can affect any agro-eco-system (Pearce 1993).

Materials and methods

Despite the considerable number of issues at stake, at the moment land degradation and desertification (LD&D) investigations are based on qualitative or semi-quantitative methods that produce relative or empirical classifications. All methods use elementary indicators to build-up composite indexes (Kosmas *et al.* 1999, Montanarella 2001, Giordano *et al.* 2002, DISMED 2003,

Tab. 2 – List of selected indicators to evaluate land degradation and desertification processes.
Tab. 2 *- Elenco degli indicatori selezionati per valutare i processi di degrado del territorio e la desertificazione.*

Indicator	**link with LD&D**	**H/S**	**Indicator**	**link with LD&D**	**H/S**
Average year rainfall	☺	H	*Water soil erosion*	☹	H
Seasonality rainfall index	☹	S	*Slope*	☹	H
Concentration rainfall index	☹	S	*Drought resistance index*	☺	H
Rainfall variability	☹	S	*Modified drought resistance index*	☺	H
Effective rainfall (by standard water balance)	☺	S	*Fire risk index*	☹	H
Effective rainfall (USDA)	☺	S	*Soil erosion protection index*	☺	H
Growing degree day (T_{base} = 10°C)	☹	S	*Land cover index*	☺	H
Growing degree day (T_{base} = 15°C)	☹	S	*Agro-Forest soil utilization index*	☺	H
High temperatures (T>35°C)	☹	S	*Grazing index*	☹	H
ET_0	☹	S	*Wooded areas burnt / Municipal areas*	☹	H
ET_R	☹	S	*Wooded areas burnt / Total burnt areas*	☹	H
Dry spells period	☹	H	*Replacement costs of wood fires*	☺	S
Drought index (freq. SPI < -0.99)	☹	H	*Soil compaction index*	☹	n.a.
Runoff	☹	S	*Number of beneficiary farms (Reg. 2078)*	☺	S
Aridity index (UNEP)	☹	H	*Number of beneficiary farms (Reg. 2079)*	☺	n.a.
Corrected aridity index	☹	S	*Environmental protected areas*	☹	H
Water deficit	☹	S	*Soil phosphorus total contamination*	☹	n.a.
Soil moisture	☹	S	*Soil nitrogen total contamination*	☹	n.a.
Angle	☹	H	*Mining*	☹	S
Population density	☹	H	*Soil organic content*	☹	H
Population growth	U	H	*Agricultural intensification inex*	☹	H
People living in urban areas	☹	S	*Agricultural utilised area (% on municipality surface)*	☹	S
Touristic activities	☹	S	*Agricultural total area (% on municipality surface)*	☹	S
Building areas	☹	H	*Wooded area index*	☺	S
Farms with groundwater exploitation	☹	S	*Familiar farms (number)*	☺	S
Farms with obsolete irrigation system	☹	n.a.	*Farms granted in leasing (surface of)*	☹	H
Areas with primary salinisation risk	☹	H	*Full-time farmers*	☹	S
Areas with secondary salinisation risk	☹	S	*Agricultural workers*	☺	n.a.
Irrigation sources diversification (Shannon index)	☺	S	*Farmers ageing (older than 55 years)*	☹	H
Soil deep	☺	H	*Economically marginalised farms (smaller than 2 ha)*	☹	S
Soil texture	😐	H	*Agricultural land surface variation*	U	H
Available water capacity (AWC)	☺	H	*Crop diversification index (by Shannon and Pielou formulas)*	☺	S
Soil parent material	😐	H	*Land profitability index*	☺	n.a.
Stoniness	☹	S	*Organic farming surface*	☺	S
Surface soil stoniness	☹	S	*Tourism rural hospitality*	☺	S
Soil drainage	☺	S	*Irrigated agricultural areas*	☺	S
Soil content of organic carbon	☺	S	*Irrigable agricultural areas*	☺	S

Motroni *et al.* 2004, Ceccarelli *et al.* 2006). In order to overcome the actual methodological limits, linked to the choice of significant indicators and to the attribution of coherent weights, we have carried out an original approach to the problem. The methodology uses the framework DPSIR (Driving Forces, Pressures, State, Impacts, Responses) as proposed by the European Envi-

ronment Agency to describe the interactions between society and environment (EEA, 1995).
DPSIR is widely adopted as a scheme for a large number of environmental processes including desertification (Gentile 1999). The model assumes a causal sequence among each element where determinants (e.g., human behaviour consequents to economic processes, production and consumption) generate pressures (e.g., polluting emissions, overexploitation of resources) that, producing environment changes, in turn generate a negative impact on living conditions. The economic system reacts through responses including incentives/ disincentives policies, environmental legislation, geared towards all the other elements of the sequence.
The choice of DPSIR was supported by a preliminary analysis on methodological and cartographic experiences carried out at national and international levels (see Ceccarelli *et al.* 2006). A simple model (Pressure-State-Response), was initially developed to highlight possible, causal chains among anthropogenic pressures, impacts and responses to mitigate themselves (OECD, 1994). Experimental studies on LD&D investigations are quite abundant and well documented, but there is often an insufficient understanding of causes, effects and processes. In many cases there is even disagreement to set indicators and, generally speaking, causes appear difficult to quantify. Furthermore, despite a clear interpretation of environmental phenomena made possible by the application of the DPSIR framework, many indicators can be considered at the same time as determinants, pressures or impacts. Finally, in some cases, responses are difficult to identify and quantify.
The application of DPSIR to the study of LD&D processes implies, at the first stage, the identification of each element of the model and, subsequently, the development of a procedure to derive a synthetic index. Starting from the previous assumptions and definitions regarding LD&D and environmental vulnerability, we identified six interacting degradation systems. Systems are analysed in accordance with the framework DPSIR as follows:

- climate change,
- urbanisation,
- salinisation,
- soil erosion,
- soil pollution,
- agricultural impacts.

For each of the above mentioned systems a number of indicators were selected which describe the corresponding process of degradation. Some indicators could be related to more than one degradation system. However, in order to avoid redundancy in information, we opted for operating univocal attribution. Tab. 1 shows the DPSIR scheme adopted in this study.
A particular aspect, related to the indicator choice, concerns the integration of information from different data with various formats, spatial resolution, and units of measurements. This aspect arose the need to overcome data dishomogeneity.
In this respect an useful approach to build-up synthetic indexes envisages the application of objective methods as multidimensional analysis (Trisorio, 2005). This method is useful to reduce the complexity of data array, providing an implicit assessment of the quantitative importance of each variable considered (Salvati *et al.* 2005). It is also advisable to elaborate separately socio-economic indicators and bio-physical indicators in relation to their different nature and information content.
In order to implement the DPSIR framework we operated in accordance with existing literature, particularly related to MEDALUS and DESERTLINKS projects (Enne e Zucca 2000, Brandt *et al.* 2003, Brandt 2005, Ceccarelli *et al.* 2006). We selected 74 indicators covering all six systems of degradation (18 for climate change, 5 for urbanisation, 5 for salinisation, 23 for erosion, 4 for soil pollution, and 18 for agriculture). A relationship between each indicator and its impact in the LD&D processes (positive or negative) was established (Tab. 2).
The information provided by each indicator was established analysing the conceptual relationship (direct or indirect) with the LD&D process (eg, Low *et al.* 1999, Giordano *et al.* 2002, Brandt *et al.* 2003, Motroni *et al.* 2004, Salvati *et al.* 2005, Ceccarelli *et al.* 2006) also distinguishing hard and soft indicators. This classification is meaningful to assemble the final index because it highlights two different groups: (i) hard indicators are those showing a clear connection with LD&D and are generally well documented and confirmed by field experiences, (ii) soft indicators are those usually not included in multi-dimensional models (e.g., MEDALUS/ESA). These indicators, with indirect links to LD&D, could be defined as context indicators. Soft indicators are useful in defining the environmental conditions of land vulnerability (Tab. 2).
In order to develop an evaluation model with intrinsic spatial dimension, it is necessary to analyse the geographical pattern of LD&D processes. This approach highlights basic problems linked to different accuracy of data sources (heterogeneous spatial resolution) and to the application of downscaling criteria in order to obtain comparable data. As an example, in this work the following spatial units had to be harmonised: two soil grids (1x1 km and 8x8 km), a climate grid (30x30 km), a digital terrain model (75x75 m), and several information layers (generally related to human impacts) having the municipality area as the spatial reference unit. The use of appropriate GIS functions has been instrumental in finding a common spatial reference: a cell size of 1x1 Km was finally adopted following Basso *et al.*(2000). GIS was used also to extract data for statistical analysis. This original approach is characterised by (i) mapping variables obtained by a transformation in ordinal scale (with scores ranging between 0 and 1), (ii) evaluating the importance of each variable through multidimensional statistical analysis (PCA) and elimination of eventual redundancy of information, (iii) calculating a synthetic index of land vulnerability obtained by weighted average of variables as resulting from the PCA.

In details, the technical steps can be described as follows:

- choice of variables and drafting thematic layers,
- transformation of thematic layers,
- extraction of data elements for each layer by using a regular grid,
- construction of analysis matrix of "k" variables and "n" geographical units,
- application of PCA to analyse data matrix,
- identification of the most relevant variables to calculate the synthetic index.

In order to compare variables, a normalisation was adopted by using the following formula:

$$\mathbf{x_i' = (x_i - x_{min}) / (x_{max} - x_{min})}$$

The procedure allows to assess a direct relationship between variables and land vulnerability.

a) Degradation system: climate change

Climate is one of the most important determinants in the desertification processes. The aggressiveness of climate is the main cause of soil erosion, landslides and floodings. Climate is an important resource but it can be also regarded as a limiting factor for plant growth: inadequate temperatures and/or insufficient precipitations may limit vegetation covering of soil and may be a constraint for profitable agriculture. Generally speaking, climate change worsen environmental conditions and this, assuming as constant the other factors of pressure, can easily lead to overexploitation of natural resources. (e.g. increasing water consumption for irrigation as a consequence of more severe and more frequent drought periods). In this study all elaborations were carried out separately for two long periods (1961-1990 and 1971-2000) in order to verify possible differences related to climatic changes. In brief, concerning this degradation system, we have considered the following indicators:

- Average annual precipitation – the rainfall amount gives a reliable indication about the water availability for the environment and human needs (eg., agriculture). In accordance with Kosmas (1998), values of annual precipitation under 300 mm are associated with significant loss of soil as consequence of water/wind erosion due to a more rarefied vegetation. Small precipitation quantities, generally combined with high rates of evapotranspiration, drastically reduces the soil water content (eg., Perini *et al.* 2004), the production of biomass and, at last, the soil content of organic matter which is directly linked with soil properties (aggregation and stability) acting against surface erosion. The indicator was calculated as the average value of total annual precipitation.
- Indexes of rainfall seasonality and concentration – in the Mediterranean basin, the rainfall distribution is not uniform along the year. Monthly or seasonal differences , determine different water availabilities leading to wet or dry periods. A first indicator was calculated as the average ratio between spring-summer precipitation (summed-up over April to September) and autumn-winter precipitation (summed-up over October to March). The second indicator (concentration of precipitation) was calculated as the average ratio between the annual rainy days and the correspondent annual amount of precipitation.
- Rainfall variability – Precipitation was also analysed through the coefficient of variation (CV) to highlight particular differences in the climatic behaviour.
- Effective rainfall – this indicator was calculated following USDA method (Patwardhan *et al.*, 1990) and also expressed as percentage of annual precipitation amount.
- Growing degree days (sum of GDD) – the indicator expresses the environmental potential to promote development and growth of plants. The calculation of GDD was made using two temperature thresholds: 10 °C and 15 °C (Perini *et al.*, 2004). The corresponding indicators were obtained as average annual sums of GDD.
- High temperatures – extreme temperature values can adversely affect plants and fertility of the soil and can accelerate the processes of LD&D. We calculated the indicator as average annual frequency of temperature events > 35 °C.
- Soil water balance - The need to consider the water cycle from several point of views (e.g., meteorology, hydrology, hydrogeology) and through various field of application (e.g., agriculture, industry, tourism), involves a systematic and integrated evaluation of multiple sources of information and environmental data. For example, the erosive potential of rain, mainly depending on its intensity, affects the ability to manage water surpluses and preventing soil erosion, especially in case of non-irrigated agricultural system. In order to consider an exhaustive approach coherently with the available dataset, we implemented the Thornthwaite-Mather soil water balance (Legates, 2005). This simple procedure allows to determine the soil moisture (SM) which represent a good indicator for planning irrigation volumes. The other basic parameters of this balance used as indicators are (i) reference evapotranspiration (Et_0), (ii) real evapotranspiration (ET_r), (iii) water deficit (D), and (iv) excess water/runoff (S). Et_0 was calculated using the Penman-Monteith formula (Allen *et al.*, 1998).
- Dry spells periods - Uninterrupted sequences of days without precipitation are important climatological indicators with significant consequences for the ecosystem. Long periods of absence of rain (Cortemiglia 2002) can be considered as drought periods (Arlery *et al.* 1973). In accordance with literature, we defined "dry day" a day with less than 1 mm rainfall (Arlery *et al.* 1973) and "dry period" a period of at least 10 dry days. We computed the average annual number of dry days belonging to dry periods accordingly.
- Standardized Precipitation Index (SPI) - The Standardized Precipitation Index (McKee *et al.*, 1993) is a very much used index to verify abundance or deficit of precipitations on different time scales. In this work, using a time step of three months, we calculated the frequencies of SPI values < -0.99, wich correspond to dry conditions.

- Aridity index (AI) - The normal lack of water (aridity conditions) is the main factor limiting biological processes. There are many criteria to define or classify arid conditions, but one of the most common approaches is through the Aridity Index, which is simply the ratio between mean annual precipitation and mean annual potential evapotranspiration (Türkes, 1999, Aslan and Tokgözlü, 2000). This indicator is widely adopted by UNEP and FAO. In this work, we also used a modified index (correct aridity index) where precipitation is replaced by effective precipitation and potential evapotranspiration by effective evapotranspiration.
- Slope exposure - In accordance with the MEDALUS/ESA approach (Kosmas *et al.*, 1999), this indicator was included among the climatic indicators. The slope exposure, in fact, affects the soil microclimate through a specific sunshine intensity and duration. This can result, for example, in higher evapotranspiration rates on southern compared with northern exposures. Other indirect effects refer to soil retention of water and development of vegetation related to different soil erosion rates (Motroni *et al.* 2004).

b) Degradation system: urbanisation

In this context, with the term "urbanisation", we indicate both soil sealing by cementation and the complex impacts on the natural ecosystems originated by anthropic presence and related activities. This kind of environmental pressure is very relevant for LD&D processes, because it seems to be directly related to the dynamics of population, extension and diffusion of villages, roads, highways, railways, a large number of economic activities, fragmentation of the landscape, pollution from diffuse sources, etc. (CNLD 1999, DISMED 2003, Salvati *et al.* 2005, Ceccarelli *et al.* 2006). For the representation of this system of degradation, we have considered 5 indicators selected by the General National Census of 1990 and 2000 carried out by the National Statistics Institute (ISTAT): demographic density, demographic variation, urban sprawl (derived from CORINE land cover), number of inhabitants in urban centres, touristic activities density.

c) Degradation system: salinisation

Salinisation is a process by which water-soluble salts (sodium, magnesium, calcium, chloride, sulphate, carbonate and bicarbonate) accumulate in the soil. Salt in soils decreases the osmotic potential of the soil so that plants have increasing difficulties to take up water from it. Salts can also have a direct effect being toxic for plants. In any case, the consequence is a serious reduction of soil fertility (Eckelmann *et al.*, 2006). Salinisation may occur naturally or due to conditions resulting from management practices. This process generally appears together with an increase in the severity of erosion, as well as changes in groundwater and surface water quality. It should be noted that hydrological processes are a key determinant of the increase of erosion. For example the reduction of plant cover permits the increase of soil exposed to extreme precipitation, conducing in turn to high runoff rates and sediment transport (Van-Camp *et al.*, 2004).

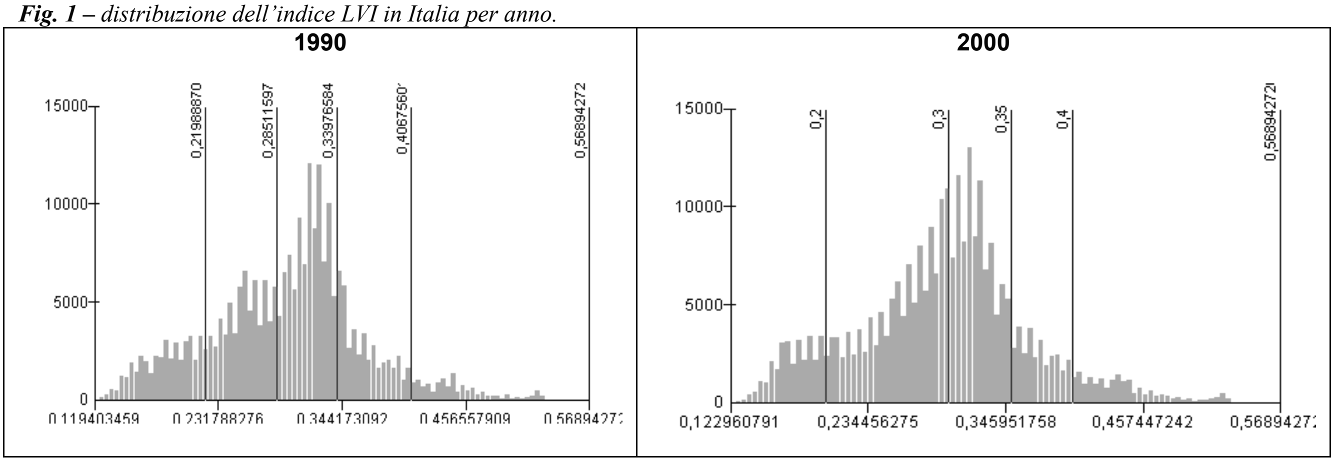
Generally, there are limited and localized data concerning the mentioned process. Therefore at a national scale, often proxy indicators are used for the definition of areas with potential salinisation risk due to groundwater overexploitation (Costantini *et al.*, 2007). In this work 5 indicators were used: farms with irrigation by groundwater (ISTAT census), farms with obsolete irrigation systems (ISTAT census), areas with primary salinisation risk (Carta geologica d'Italia 1:500.000 and distance from the sea coast), areas with secondary salinisation risk (land use derived by CORINE land cover), Shannon index applied to irrigation sources data.

d) Degradation system: soil erosion

Soil erosion is the wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere (Eckelmann *et al.*, 2006). Soil erosion, under normal circumstances, can be considered as the evolutionary dynamics of soils. More recently, it has been perceived as a real process of degradation due to the fact that its natural rate has significantly increased due to human activities and climate aggressiveness. Moreover, soil formation is a very slow process: any soil loss of more than 1 t/ha/yr could be considered as irrecoverable within a time span of 50-100 years. Losses of 5-20 t/ha/yr can have serious effects, both on- and off-site (Gobin el al., 2002). Higher soil losses (up to 100 or more t/ha/yr) can have catastrophic effects at local level and serious off-site consequences. In order to better represent this complex phenomenon we preliminary considered a group of 23 indicators related to (i) soil properties, (ii) vegetation/crop cover, (iii) anthropic pressure, (iv) soil protection actions. Unfortunately, a sufficient national covering for all selected indicators was not available. Only a subset could therefore be used. Regarding the first category (soil properties) the data source was the National pedological cartographic centre in Florence , which is part of the Research Institute for agro-biology and pedology (CRA-ABP). For the others indicator categories (ii), (iii) and (iv) we derived the data from CORINE land cover maps, the Map of soil erosion produced by the Joint Research Centre and from the National Censuses (of agriculture, population, etc.) produced by ISTAT. A brief description of some of the most important indicators elaborated is given below :

- Soil depth - The unconsolidated material immediate the surface of the earth serves as natural medium for the growing plants. Soil depth defines the root space and the volume of soil from where the plants fulfil their water and nutrient demands (Kosmas *et al.*, 1999). Greater soil depth generally means better plants covering against erosion processes. This indicator and the soil characteristics discussed below were obtained by the Centro Nazionale di Cartografia Pedologica del Centro di ricerca per l'agrobiologia e la pedologia (CRA-ABP) in Florence.
- Soil texture - Soil texture is a term commonly used to designate the proportionate distribution of the differ-

Fig. 1 – LVI distribution in Italy by year.
***Fig. 1** – distribuzione dell'indice LVI in Italia per anno.*



ent sizes of mineral particles in a soil. Using the USDA method (Brown, 2003) we classified the whole Italian soil dataset and, with reference to the criteria used in MEDALUS/ESA (Kosmas *et al.*, 1999, Salvati *et al.*, 2005), we evaluated the vulnerability of soils to LD&D processes: higher (soil class: 2), medium-high (soil class: 12 and 13), medium-low (soil class: 5), lower (soil class: 3, 4, 6, 8 and 10).

- Available water capacity – Soil available water capacity (AWC), which is the difference between field capacity and wilting point, was used in this work as another index to evaluate the degree of soil resistance to LD&D processes. Simulation results showed that AWC determines the partitioning of precipitation among runoff, deep flowing, water soil storage and evapotranspiration (Weng & Luo, 2008) . The fractions of precipitation used by plants (evapotranspiration and soil moisture) increased with AWC values but decreased in relation to runoff and deep flowing. AWC, therefore, regulates ecosystem responses and the soil plants covering.
- Soil parent material – The primary material from which the soil is formed. Soil parent material could be bedrock, organic material, an old soil surface, or a deposit from water, wind, glaciers, volcanoes, or material moving down a slope. The Carta geologica d'Italia (1:500.000), was used for a classification of several lithological categories based on their tendency to promote erosion. Other indices used were: Erosivity index (obtained as esteem of annual soil loss), Drought resistance index, Vegetation land cover, index of soil use intensity and protection against erosion (obtained as reclassifications of the Corine land use cartography), Fires risk (obtained as percentage of forest fire in respect to the whole municipal area), Overgrazing, Protected areas (e.g. Natural Park).

e) Degradation system: soil pollution

Contaminants are a severe hazard of soil quality. Often the presence of contaminants refers to punctual and/or diffuse pollution sources linked to resident population (e.g., urban waste water contaminated by organic substances and/or chemical agents), agriculture (e.g., chemical fertilizers and pesticides, livestock waste), industrial activities (e.g., issue of production waste), extractive activities, illegal landfill, etc. Environmental restoration leads to a complete recovery of soil functionality only in few cases. In spite of the importance of this soil degradation causes, there are some difficulties in organising homogeneous and useful datasets at national scale. Therefore, in order to analyse this particular aspect we considered the total organic pressure calculated as equivalent inhabitants (Barbiero *et al.*, 1998). This includes three components: resident population, zoothecnical and industrial activities.

Tab. 3 – LVI average values by NUTS-2 region.
***Tab. 3**- valori medi dell'indice LVI per regione.*

Italian Regions	Land Vulnerability Index (LVI) weighted mean values 1990	2000	variation (%)
Sicily	0.328	0.358	9.1
Apulia	0.320	0.347	8.3
Sardinia	0.285	0.320	12.2
Emilia Romagna	0.296	0.305	3.0
Veneto	0.294	0.305	3.7
Marches	0.280	0.300	7.1
Calabria	0.274	0.296	8.2
Latium	0.284	0.296	4.1
Basilicata	0.272	0.293	7.7
Campania	0.272	0.288	5.9
Tuscany	0.275	0.288	4.5
Molise	0.276	0.284	3.1
Umbria	0.261	0.276	6.0
Lombardy	0.268	0.274	2.3
Piedmont	0.256	0.263	2.6
Liguria	0.235	0.258	9.9
Abruzzo	0.244	0.258	5.4
Friuli Venezia Giulia	0.238	0.250	4.9
Aosta Valley	0.178	0.187	4.9
Trentino Alto Adige	0.165	0.182	10.5

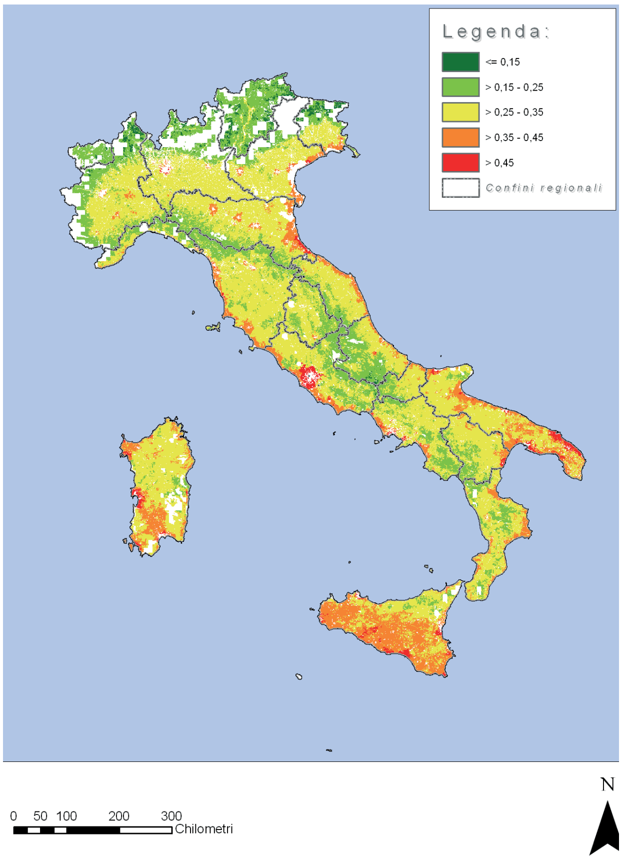


Fig. 2 – Land Vulnerability Index (LVI): map of Italy referred to year 2000.
Fig. 2 *– Land Vulnerability Index (LVI): mappa dell'Italia del 2000.*

f) Degradation system: agricultural inpacts

Environmental hazards from agriculture are mainly caused by unsustainable management, often forced by reasons of economic convenience. On the one hand, where the natural resources are relatively abundant and the technologies are easily available, it a progressive intensification/specialisation of crops production can be observed with an associated high risk of ecosystem overexploitation. On the other hand, when conditions of depopulation and marginalisation take place, the consequent abandonment of lands may contribute to deteriorate further the environment. The possibility of balancing agricultural activities and ecological suitability is linked to the ability to adopt production strategies compatibles both with the environmental sustainability and the economic interests. By the ability to balancing these opposite interactions derive the contribute (positive or negative) of agriculture to LD&D processes. The considered indicators were:

- Intensification of agriculture – In developed countries agriculture is generally very efficient: it requires few people to produce food in large quantities and of high quality. However, the environmental externalities of this production system can easily exceed the sustainable limits in terms of use of natural resources (mainly soil and water) and application of pollutant inputs (fertilizers, pesticides, etc.). Therefore, intensive agriculture can be a factor of environmental pressure (ANPA, 2001) and thus of vulnerability to LD&D. Through a review of literature (Ceccarelli *et al.*, 2006, Motroni *et al.*, 2004), we defined as indicator of agricultural intensity the ratio between areas intensively cultivated

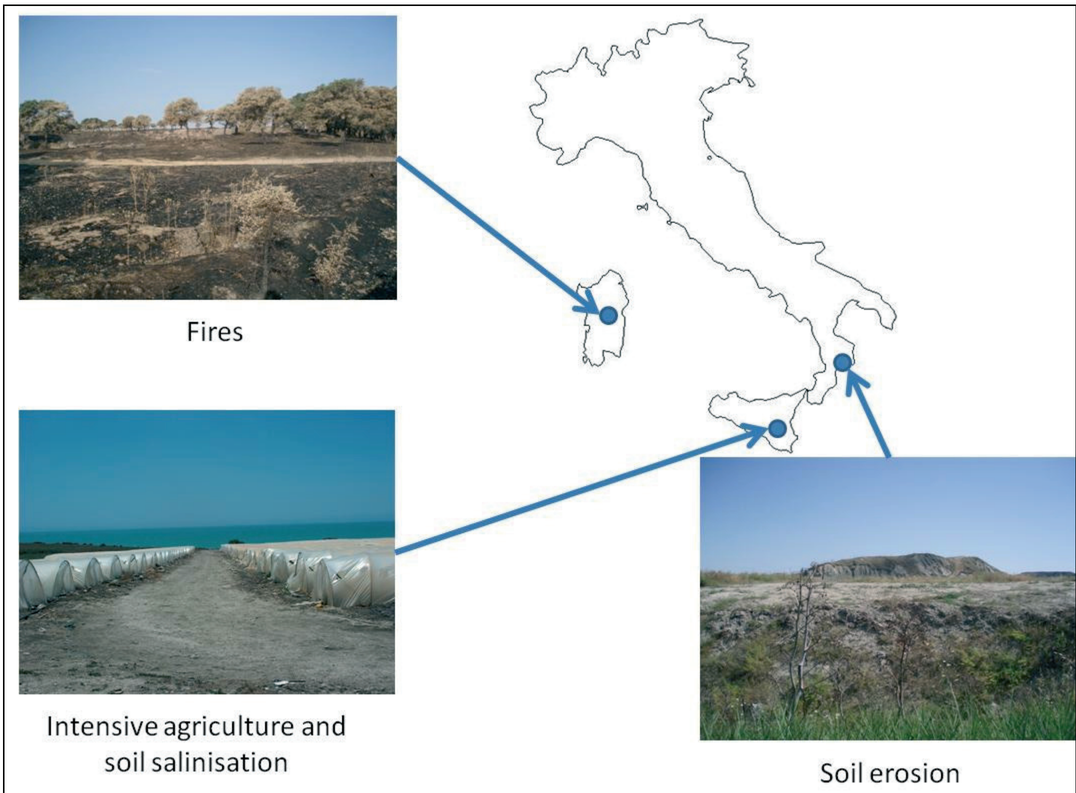


Fig. 3 – Examples of pictures as part of field documentation about land degradation and desertification processes.
Fig. 3 *– Esempi di documentazione fotografica di campo relativa ai processi di degrado del suolo e desertificazione.*

(arable crops and orchards) and total agricultural areas (SAU).

- Farms granted in leasing – Farm management can influence greatly the environmental equilibrium. Field experience show that the lack of long time perspectives (needed to adopt strategies to preserve the natural resources) addresses exclusively the immediate gain with serious ecological consequences over the long period. Under this point of view, we considered, as proxy indicator, the ratio between areas of farms leasing land and the total of agricultural areas (SAU).
- Farmer ageing - The age of farmers influence strongly the pattern of farm management, for example, through the choice of crops, of cultivation methods, adoption of innovation processes, activity diversification (e.g. agricultural tourism), etc. Usually, younger farmers show more entrepreneurial dynamism, better level of instruction and closer attention to environmental aspects than old farmers. Hence, considering the incidence of ageing rural population, we quantified for each municipality the ratio between agricultural workers with more than 55 years and the total number of agricultural workers.
- Abandonment of cultivated areas - The reduction of cultivated land involves social and economic aspects with serious environmental consequences (Khanal and Watanabe, 2006). Since about the 1940's, following a global trend, in Italy a progressive abandonment and depopulation of agricultural areas has been observed. This is especially true especially in rural mountains and other marginal contexts where the human presence allowed effective territorial control against land degradation processes. In this work we selected as an indicator the variations of agricultural areas between 1990 and 2000, at the municipality level.

Many other indicators were collected but not used in this work, due to their lack of temporal and/or spatial coverage. For detailed list see Tab. 2 the indicators classified as not applicable (n.a.).

Statistical analysis

The matrices obtained have been analysed through the principal components analysis (PCA), a method which allows to explore relations between various and numerous (quantitative) variables. As a first step was calculated an array of correlations among variables using the Pearson's coefficient. High values of the coefficient highlight variables strongly correlated with each other and, therefore, redundant. As the next step, we extracted the principal components, that are latent variables obtained as linear combinations of primitive variables through the maximisation of each singular variance compared to the whole variance of the data matrix. The new variables can be ordered according to the proportion of explained variance. The interpretation of the results is obtained from the correlation that each primitive variable presents with the new variables. Positive correlations between variable i and the component j indicate that the component j is well represented by variable i, vice-versa for negative correlations. Considering the part of variance explained by each component and the contribution of each variable to the definition of the various components, it was possible to calculate the relative importance of each elementary variable, then used as weight in the subsequent processing.

The variables processed in the manner described above and weighed on the basis of the results of PCA are at this point summed to obtain a index defined Land Vulnerability Index (LVI):

$$LVI = \Sigma_j \, p_j \, V_j$$

where:

V_j = value associated with j variable included in the model

p_j = weight of j variable by statistical analysis.

Results and discussion

The proposed methodology allows to evaluate the degree of land vulnerability to degradation and desertification processes by means of scores from 0 (max vulnerability) to 1 (no vulnerability), these are derived by a weighted combination of several elementary indicators. Elaborations were carried out for the whole national territory for two periods (1990 and 2000) in order to highlight possible temporal variations.

Both periods investigated (1990 and 2000) present frequency distribution of LVI (Fig. 1) with shapes slightly asymmetric (positive slope) and mean values respectively equal to 0.277 and 0.294. This result shows increasing pressure on environment which are contributing to the processes of land degradation.

The national trend is also confirmed at local scale. Tab. 3 shows mean values and percentage variations of LVI for each Italian Region. The most vulnerable regions are mainly located in the southern-central part of Italy (including the great islands Sicily and Sardinia) where the climate seems to play a very important role to determine conditions of environmental vulnerability, especially when it is associated to human activities not compatible with sustainable management of natural resources (e.g. introduction of intensive cultivation methods). Unfortunately, as was mentioned above, the comparison between 1990 and 2000 shows positive changes everywhere, even in regions less affected in absolute terms such as Trentino Alto Adige.

Results were finally mapped by means of GIS. Fig. 2 shows a representation of vulnerability to land degradation processes for the reference period (2000) at country level.

By a comparative examination of the maps (relative to the synthetic index and to elementary indicators) it is possible to observe the accurate spatial distribution of land vulnerability and the predominant type of pressure on the environment. Generally speaking, the most problematic areas seem to be located mainly along the coasts and the flatlands where population, economic activities, pollution, etc. are mostly concentrated. A high degree of vulnerability, however, is also observed in areas characterized by unfavourable climatic conditions and/or geomorphologic features usually related with land degradation (e.g., land gullies, low land cover, slopes). These conditions are often associated to inappropriate exploitation of agriculture, tourism etc. Low vulnerability, on the contrary, is usually found in inland, especially mountainous areas, where ecosystems are less affected by human presence and, at the moment, less exposed to climate change. Preliminary validation of LVI was approached through some field inspections in order to check the correspondence between LVI classification and local observed conditions. Each field observation, adequately documented and classified on the basis of the more evident (or probable) process of land degradation, was compared with the results of the methodology and the elementary indicator values. Pictures of landscape and descriptions were acquired to form an initial probative documentation about morphology, land use, human pressures, environmental damages, etc. (Fig. 3). The work, however, cannot be considered as concluded because the results must still be confirmed by further direct checking, field measurements and other analytical approaches (e.g., remote sensing) that can validate results and methodology.

Conclusion

As already observed in the paper, land degradation is a complex environmental process with rapidly increasing impacts on natural and agro-ecosystems over the whole Mediterranean basin. The need to set-up reliable procedures to assess changes in land quality and thus vulnerability appears as meaningful in such a environmental context. In fact, it be should be noted that land degradation is not static but dynamic and diverging at different scales of observation. This assessment can therefore benefit of a multidimensional analysis aimed to integrate several indicators from different sources. LVI represents a preliminary contribution in this research field.

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