



Osservatorio Nazionale sulla Desertificazione

**INDICATORS FOR ASSESSING
DESERTIFICATION
IN THE MEDITERRANEAN**

Proceedings of the International Seminar
held in Porto Torres, Italy 18-20 September, 1998



*Nucleo Ricerca Desertificazione
Università di Sassari*



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Degradation processes in the Agri Basin: evaluating environmental sensitivity to desertification at basin scale

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Abstract

The estimation of Environmental Sensibility to desertification at basin scale requires the setting up of elaboration and updating methodologies capable of handling considerable amounts of data in an integrated approach. This would allow evaluating the different stages of environmental degradation as well as the existing interactions among the singular components of the territory.

The present paper proposes a new methodology on evaluating Environmental Sensibility of an environment at basin scale that foresees the integration of alphanumeric and cartography data with remote sensed images, using Geographic Information Systems. This approach does not only guarantees easy management of the data collected, their continuous updating and their rapid interpretation but it also offers the possibility to analyse the factors causing the phenomena in progress.

Key words: Desertification, land degradation, GIS, RS, indicators, Mediterranean area.

1. Introduction

The abandonment of large hilly and mountainous areas and the incorrect management of agronomic and forest surfaces in recent decades have brought about an increase of erosion phenomena and soil degradation, never seen before in the Agri valley (Basso, 1995); (Thornes, 1995); (Basso *et al.*, 1997); (Ferrara *et al.*, 1997). Therefore, knowledge of environmental and economical factors of a territory, their interrelationships and the setting up of systems capable of analysing and elaboration of such data becomes a fundamental requirement to carry out a correct planning of the available resources in order to avoid that present situations become worse. The identification of a precise and objective framework allows reaching two aims: (i) to optimise the use of resources compatible with the environment and (ii) to supply indications for an adequate planning of social and economical development to the local administrations.

This research study presents a imple methodology that allows identifying the different stages of Environmental Sensibility of large environments with respect to soil degradation processes as well as desertification by the use of existing territorial

information that can be easily acquired and successively elaborated through Geographic Information Systems.

2. Materials and methods

2.1. The study area

The Agri basin is located in Southern Italy, in one of its smaller regions called Basilicata. The 1763 Km² hydrographic basin (figure 1) is characterised by marked morphological, vegetation, climatic and environmental variability. The basin can be divided in three large zones differing in their susceptibility to erosion, to disorder and naturally to environmental sensibility (Basso *et al.*, 1996):

- Upper Val d'Agri, 60,000 hectares, made up of 12 municipalities located above 600 m a.s.l.;
- Middle Val d'Agri, 91,000 hectares, made up of 17 municipalities located between 200 and 600 m a.s.l.;
- Lower Val d'Agri, 22,000 hectares, made up of 6 municipalities all under 200 m a.s.l.

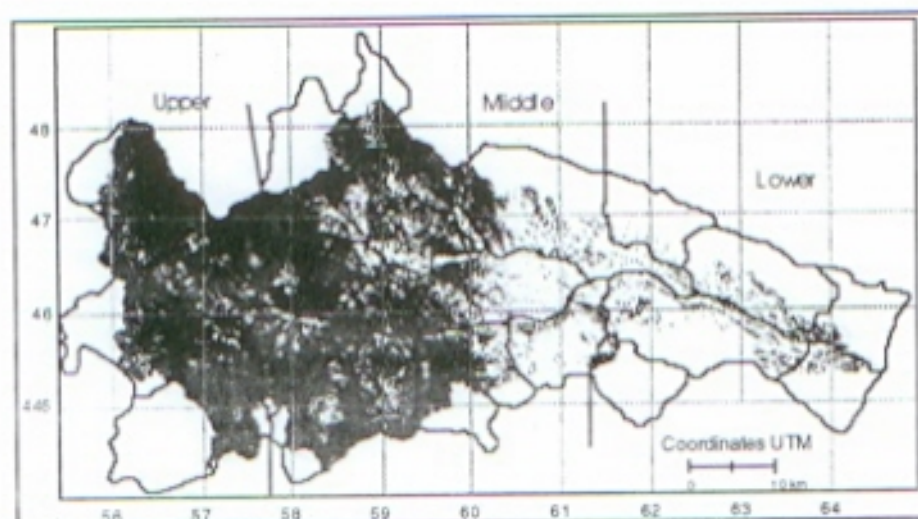


Figure 1: The Agri river hydrographic basin with its municipality boundaries. Landsat TM images with false colour (the vegetated areas are represented with dark grey tones).

The valley has particular climatic conditions that are influenced by its orographic nature and by its proximity to two seas: Tirreno and Ionio. There is a typical Mediterranean climate along the Ionio coast up to 500 - 600 m a.s.l., characterised by scarce rainfall concentrated during the autumn-winter period and by heavy summer drought. Above these altitudes and up to 1200 m there is a temperate-cold climate, with mild dry summers, while a cold and rainy climate is found at the higher zones and towards the Tirreno Sea.

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The geomorphologic aspect of the basin reflects its geologic and lithological nature. Calcareous mountains and plains made up of gravel, sand, clay and flysch dominate the upper part. The middle valley is made up alluvial plains, fluvial terraces and alluvial cones with abundant gravel and clay-silt deposits. The lower part of the middle valley is characterised by clayey-silt formations undergoing Calanchi erosion and alluvial deposits. This type of soil erosion called Calanchi occurs on clay formations triggered by the combined force of runoff and dynamic landslides making difficult the survival of protective vegetation cover. A lacustrine coastal environment with sand sedimentation and heavy salinity also characterises the lower valley.



Photo 1: Calanchi areas near Aliano, Matera

Regarding vegetation cover, beech and oak forests (*Quercus cerris* and *Quercus pubescens*) dominate the mountainous part with specialised crops (fruit orchards, corn, etc.) on the plains. The hilly middle part of the valley with vast pastureland is made up of chestnut groves, vineyards as well as olive groves in its lower area. Fertile terrain along the Agri river not subject to harshness of the winter are cultivated with citrus and specialised fruit orchards, whilst cereals are cultivated on the less favourable zones of this lower part of the valley (Cantore *et al.*, 1987).

Its economic and environmental importance is reflected by its nomination as a future Natural National Park. This is a representative area to deeply analyse the components

interested in the different stages of Environmental Sensibility, on account of its complex alternating situations ⁽¹⁾.

2.2. Methodology

Environmental Sensitivity of an area is a wide concept and not yet completely defined, both for its different features that it assumes with respect to environments and for the elements taken into consideration. An Environmental Sensitive Area (ESA) can be considered as a *specific territorial entity where environmental, social-economical and agronomic management factors are not in equilibrium among themselves or are not sustainable for that particular environment*.

Environmental Sensitivity can also be seen as the result of the interactions among elementary factors relative to soil, climate, vegetation and socio-economic aspects, that are linked individually or together to environmental and management degradation. For example, the combination of critical environmental factors such as accidental morphology, the presence of soils subjected to heavy erosive phenomena, unfavourable climatic trend, scarce vegetation cover together with non optimal socio-economic factors, identifies and characterises a high Environmental Sensitivity (Basso *et al.*, 1996); (Ferrara *et al.*, 1997).

In this ambit, in order to identify and quantify the different levels of Environmental Sensibility at basin scale, the following is needed:

- Information relative to elementary factors (soil, climate, vegetation cover, and socio-economic aspects) that is uniformly and continuously collected in the area under examination. The information is chosen according to their availability and possibility of updating.
- Cross analysis procedures and methodologies on the available data foresees the integration of vectorial and raster information with the connected archives.
- Suitable instruments to manage the massive amount of data and interactive system capable of acquiring, elaborating, recording and visualising the different territorial information (Toccolini and Angileri, 1992).

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Quality	Layer	Source
Soil	Parent material, Soil Texture, Rock Fragments, Soil Depth, Drainage, Slope Angle	Published data at various scales and field samplings
Climate	Rainfall, Aridity index (Bagnouls e Gaussen), Aspect	Published data at various scales, field samplings and DEM
Vegetation	Fire risk, Erosion protection, Drought resistance, Plant cover	Landsat TM, published data at various scales and field samplings
Management	Elderly index, Illiteracy index, Retirement index, Employed index	Statistical data (ISTAT)

Table 1 - Information layers used in evaluating ES in desertification risk areas.

Three essential considerations were taken into account in selecting the information layers:

- their correlation to degradation phenomena or environmental critical state;
- their availability of large areas;
- their possibility of being easily and economically updated.

The setting up of analysis systems based on information difficult to obtain with high updating costs, even though very important, would be impossible to use in larger environments or in continuous monitoring systems. The proposed system allows adding or removing information layers according with the need to study in more detail specific aspects of a given area or, for example, to proceed in obtaining a first approximation of ES estimate with a reduced number of information layers, due to the impossibility of quickly and economically obtaining all the desired information⁽²⁾. It is always possible to use other information layers as of lithological, pedological, evapotranspiration, erosive, biodiversity stages of vegetation, the level of environmental sustainability, or political incentive data.

On these basis the methodology under study was developed in different environments with information layers that may change in time and space with the aim to set up a common framework that could be enough independent from the layer number, type and quality.

The proposed methodology to evaluate Environmental Sensitivity in desertification risk areas is carried out proceeding in two phases (figure 2):

- quality evaluation with respect to four different types of information (table 1);
- the evaluation of Environmental Sensitivity

⁽²⁾ It must be noted that the obtained degrees of Environmental Sensitivity have a relative significance (not an absolute value) and only represent a homogeneous base for further evaluations.

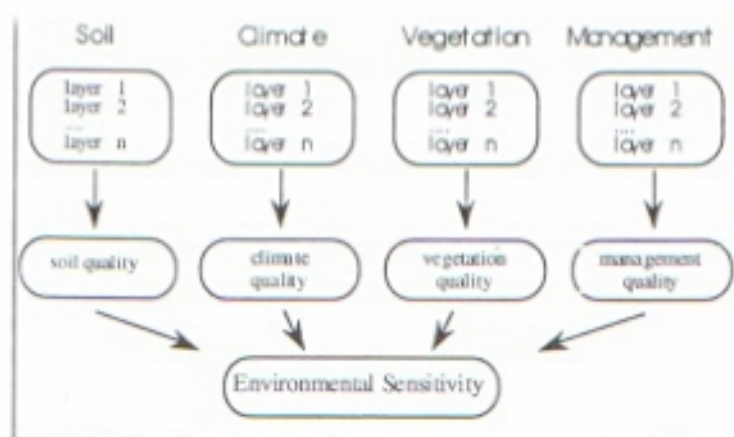


Figure 2 - Methodological approach

Each of the above mentioned qualities is estimated as geometric means between the different scores of each layer:

$$\text{Quality}_{x_{ij}} = (\text{layer}_{1_{ij}} * \text{layer}_{2_{ij}} * \text{layer}_{3_{ij}} * \dots * \text{layer}_{n_{ij}})^{(1/n)} \quad [1]$$

where i, j = rows and columns of a single elementary pixel (30*30 m) of each layer;
 n = number of used layers

The ES is thus estimated as:

$$\text{ES}_{ij} = (\text{Quality}_{1_{ij}} * \text{Quality}_{2_{ij}} * \text{Quality}_{3_{ij}} * \text{Quality}_{4_{ij}})^{(1/4)} \quad [2]$$

where i, j = rows and columns of a single elementary pixel (30*30 m) of each quality;
 $\text{Quality}_{n_{ij}}$ = computed values

The definition of the scores applied to each single layer was carried out in relation to the degree of correlation that the various classes have with the different Environmental Sensitivity levels (FAO, 1976); (Briggs *et al.*, 1992); (Kosmas *et al.*, 1997); (Quaranta, 1997); (Basso *et al.*, 1997). This assignment was done taking into consideration that the system adopted used a simplified layers/scores structure (linear without weights) in order to evaluate their applicability to different territorial contexts^(*). The complete scheme of the used layers and scores is illustrated in table 2.

A further description of the layers, classes and scores can be found in Basso *et al.*, (1997); Kosmas *et al.*, (1997); Kosmas *et al.*, (1998); and Marotta and Quaranta (1996).

The presence of a different number of classes within the single layers and the need of a

system was required by numbers 1 value zero, the score relation to qualities at. Lastly, add different in

(*) All elat

(*) However, the system can be developed to modulate, in a non-linear manner, the layers/scores structure.

system that operates in two phases not bonded to a defined number of layers has required homogenising the assignment of scores. The score values is between the real numbers 1 and 2, with non-classified pixels (urban area and water) represented by the value zero. This methodology makes homogeneous the scores of each layer (assigning the score of 2 to the worst conditions), allowing the division within the classes in relation to the information availability. The resulting scores, relative to the different qualities are between 1 and 2, as are those relative to Environmental Sensitivity. Lastly, adequate instruments Hw and Sw (*) are needed as well as to incorporate the different information sources in a single reference and management system.

(*) All elaborations were carried out on PC's using Idrisi and Cartha for Windows software.

Soil	Parent material	Shale, schist, basic, ultra basic, conglomerates, unconsolidated, clays:	1
		Limestone, marble, granite, rhyolite, ignimbrite, gneiss, siltstone, sandstone, dolomite:	1.5
	Soil texture	Marl, Pyroclastics	2
		I., SCL, SL, LS, CL	1
		SC, SIL, SICL	1.33
		Si, C, SiC	1.66
		S	2
	Rock fragments cover, %	> 60	1
		20 - 60	1.5
		< 20	2
	Soil depth, cm	> 75	1
		30 - 75	1.5
		< 30	2
	Drainage	well drained	1
		imperfectly	1.5
		poor drained	2
	Slope, %	< 6	1
		6 - 18	1.33
		18 - 35	1.66
		35	2
Climate	Rainfall, mm/year	> 650	1
		280 - 650	1.5
		< 280	2
	Aridity index (Bagnouls & Gaussen)	< 50	1
		50 - 75	1.2
		75 - 100	1.4
		100 - 125	1.6
		125 - 150	1.8
		150	2
	Aspect	North	1
		South	2
Vegetation	Plant cover, %	> 40	1
		40 - 10	1.5
		< 10	2

Table 2 - Layers used and relative scores (continues overleaf)

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	Erosion protection	Mixed Mediterranean macchia-Evergreen forests (with <i>Q. ilex</i>). Mediterranean Macchia; Conifer Deciduous (oak, mixed); Permanent grasslands. Evergreen Permanent Agriculture (olive). Deciduous Permanent Agriculture (almonds, orchard). Crops (wheat, maize, rice, oats, barley, annual grasslands, ..), Vines; Barren (soils, exposed rocks, very low vegetated)	1 1.2 1.4 1.6 1.8 2
	Drought resistance	Mixed Mediterranean macchia - Evergreen forests (with <i>Q. ilex</i>). Mediterranean macchia. Conifer, Deciduous, Olives. Permanent Agriculture (vines, almonds, orchard). Permanent grasslands. Crops (wheat, maize, rice, oats, barley, annual grasslands, ..), Barren (soils, exposed rocks, very low vegetated).	1 1.25 1.5 1.75 2
	Fire risk	Barren (soils, exposed rocks, very low vegetated); Permanent Agriculture (olive, vines, almonds, orchard); Crops (maize, tobacco, sunflower, rice). Cereals; Grasslands; Deciduous (oak, mixed); Mixed. Mediterranean macchia-Evergreen forests (with <i>Q. ilex</i>). Mediterranean macchia. Conifer.	1 1.33 1.66 2
Management *	Elderly index	< 200 200 - 400 400 - 500 500	1 1.33 1.66 2
	Illiteracy index	< 6 6 - 7 7 - 10 > 10	1 1.33 1.66 2
	Retirement index	< 10 10 - 20 20 - 30 30	1 1.33 1.66 2
	Employed index	> 40 30 - 40 20 - 30 < 20	1 1.33 1.66 2

*The Elderly index measures the ratio between those above 65 and those that have reached 5; The Illiteracy index measures the ratio between people having at least 1 year school and the ones without; The Retirement index measures the ratio between pensioned people and the residents; The Employed index measures the ratio between employed workers and active population.

Table 2 - Layers used and relative scores

3. Results and discussion

The Environmental Sensitivity of the Agri basin obtained with this methodology is illustrated in figure 3. Similar maps of the intermediate quality layers are produced by the elaboration system. All of this information represents an area of 900 m² (corresponding to a pixel 30 x 30), supplying a detailed framework in reference to the territory. Maps of different territorial ambits (Municipalities, Mountain Communities, climatic zones, etc.) can always be produced.

The sensitivity levels obtained are very close to the real situations encountered in other studies (Del Prete *et al.*, 1995); (Grauso, 1994); (Ippolito *et al.*, 1984) as well as to controls conducted on the applicability of this methodology with indicators at field level, such as C, N and organic soil matter, and soil respiration (Ferrara *et al.*, 1997). This system provides many utilisation purposes that go beyond the simple analysis of the phenomena in progress.

The system makes the weights of each quality class equal and allows the possibility to use an undetermined number of layers within each class, while allowing a high possibility to compare the scores giving investigation capacity with better accuracy of the particular aspects of an area with the simple addition of new layers. A reference framework can be set up to compare areas and different periods (utilising a set of mutual layers), but at the same time capable of deepening the knowledge of the particular aspects of an area through the addition of one or more specific themes or the addition of ulterior information layers (Bellotti *et al.*, op. cit.).

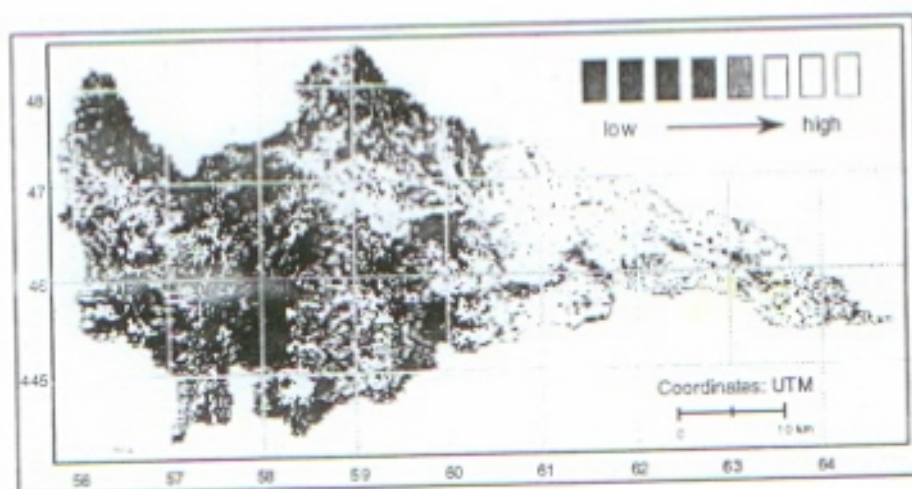


Figure 3: Estimation of Environmental Sensitivity of the Agri basin to desertification. Values between 1 (dark) and 1.8 (light), maximum value.

The evaluation value, since able to define an example of the Municipality.

3.1. An example

The frequency of Sensitivity data was used in the methods.

Figure 4 illustrates five Sensitivity zones. Figure 5 shows the Sensitivity analysis.

As it can be seen, the areas located in the economic field are considered very critical. A geographical economical analysis has worsened. These considerations are efficient to evaluate the techniques *ad hoc* for the degradation. Furthermore, the environmental evolution.

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The evaluation method proposed on Environmental Sensitivity has a *per se* descriptive value, since it allows the application of other and different analysis methods, that are able to define and qualify the obtained sensitivity class contents. The following is an example of an analysis conducted on different degrees of Environmental Sensitivity for the Municipalities in the Agri basin.

3.1. An example of Sensitivity data produced by the system

The frequency of the various classes of all the layers used to evaluate Environmental Sensitivity was considered for each municipality (table 2). The matrix of the obtained data was subjected to *cluster analysis* utilising complete linkage and Euclidean distance methods.

Figure 4 illustrates the dendrogram obtained using the municipality data, which gives five Sensitivity typologies inside the basin that corresponds to five defined territorial zones. Figure 5 illustrates graphs relative to the percentage of different Environmental Sensitivity grades of the four qualities and municipality groups obtained by *cluster analysis*.

As it can be seen municipality groups 1, 2 and 3 have quite the same climate (all three are located in the Upper Val d'Agri). Group 1 differs for its criticality of socio-economic factors and a worse overall quality of soil factors, which need to be closely considered in this ambit; instead group 2, has better vegetation qualities associated to very critical socio-economic factors. Groups 4 e 5 differ, even though are similar from a geographical point of view: group 5 is characterised by a better level of social economical factors and by the worst climatic ones found in the basin, instead group 4 has worse vegetation conditions.

These considerations illustrate the applicability of this flexible method, diversified and efficient that gives broader investigation possibilities and the capacity to precisely evaluate the situations in progress as well as defining the more opportune strategies to reduce the overall environmental sensitivity of a given area. The use of cross analysis techniques in the proposed system, applied to pre-existing information, with other *ad hoc* collected data, can also be used to easily and efficiently point out specific degradation or environmental sensitivity phenomena.

Furthermore, this approach not only allows the identification of different degrees of environmental sensitivity, at the same time allows the analysis of the factors that cause the evolution in progress.

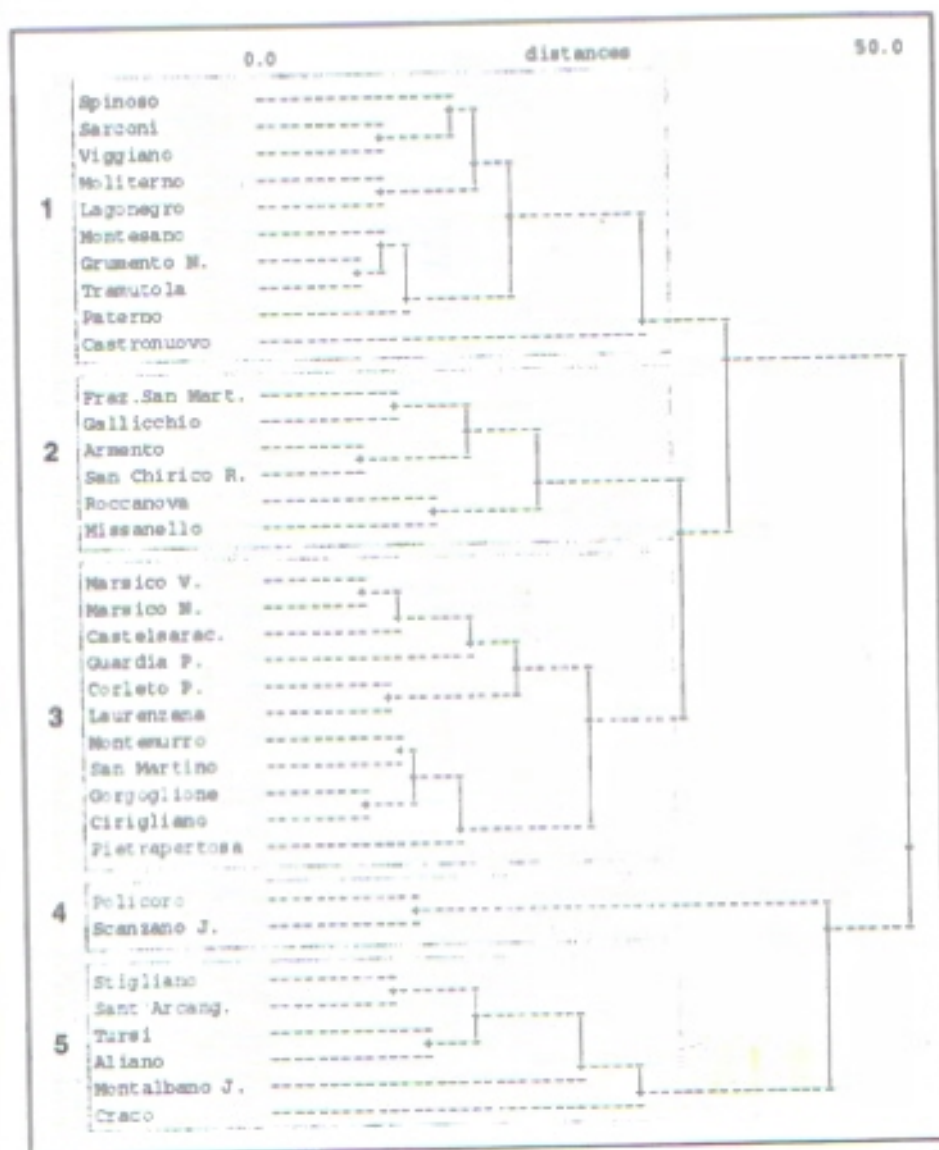


Figure 4: Cluster analysis of the Municipalities located in the Agri basin (complete linkage method, Euclidean distance).

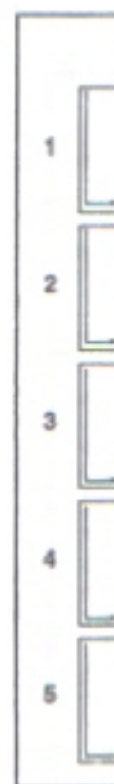


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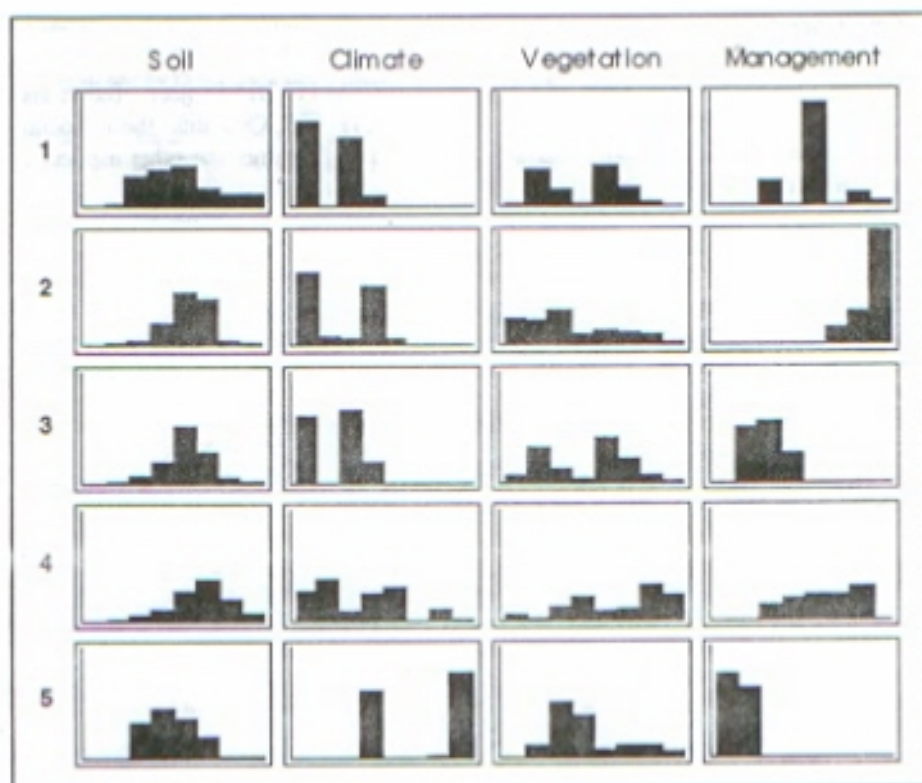


Figure 5: The profiles of Environmental Sensitivity of the municipality groups in the Agri basin. The profiles are expressed in percentages of ES levels in function to the single qualities. (X-axis from 1.1 to 1.8; Y-axis from 0 to 75%).

4. Conclusions

Analytic instruments that allow knowing the factors that concur and accelerate land degradation are needed in order to adequately manage a territory and its resources. Today's territorial managing systems as GIS are able to get and use information from many different sources; field surveys, cartography, aerial photos, remote sensed images, historic archives, databases and development models.

The utilisation of data cross-analysis techniques applied to the information layers, combined with the integration of information derived from pre-existing themes, can be used to easily and efficiently point out the current degradation phenomena or Environmental Sensitivity. This approach not only allows to identify the different degrees of Environmental Sensitivity, but at the same time gives the chance to analyse the factors at the base of the evolution phenomena possible.

Acknowledgements

Research conducted with the aid of UE funds "MEDALUS III" Project. Basso and Pisante had developed the agronomic aspects, Bove and Quaranta those social-economical, and Bellotti, Faretta, Ferrara, Mancino and Taberner the other aspects as well as the actual model.

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