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SOIL DEGRADATION IN SARDINIA (ITALY): MAIN FACTORS AND PROCESSES

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Introduction

Soil degradation, defined as the deterioration of soil quality in relation to its current and future productivity and/or as the reduced potential of soil as a natural resource (Lal et al., 1989), is a serious threat for an increasing number of areas all over the world.

The role of man in the process is well known. Globally, it has been estimated that nearly 2 billion hectares of land are affected by human-induced soil degradation (UN, 2000). In Europe, damage to soils from modern human activities is increasing and leads to irreversible losses due to sealing of soil surfaces, local and wide-spread contamination and soil erosion (EEA, 2000). In this context, the Mediterranean islands have been recognised as “hot spots” for various forms of soil degradation (EEA, 2000).

In Sardinia (Italy), landscape morphology and climate make the island's soils very fragile and sensitive to all uses which do not consider soil suitability and its limitations. Due to these environmental conditions, the soil degradation problem is of great concern on the island and the subject has been widely investigated over the last decades in the frame of national and international projects. The main factors and processes of soil degradation studied in Sardinia in the framework of the MEDALUS (Mediterranean Desertification and Land Use)-EC funded project are presented and discussed in this study.

Materials and Methods

The island of Sardinia is located in the Western Mediterranean Sea, between 38°51'52" and 41°15'42" N and between 8°8'10" and 9°50'8" E (Fig. 1), and has a surface of 24,089 km^2. Sardinia has a population of roughly 1,640,000 inhabitants (ISTAT, 1991), almost a quarter of whom are concentrated in the metropolitan area of Cagliari, in the south of the island. In addition to the resident population, about 1,700,000 tourists visit the island each year.

The climate is Mediterranean, with an average annual rainfall < 500 mm occurring only in some areas located in the south of the island, and an average annual rainfall of 700-900 mm occurring in the inner hilly areas. Rainfall is concentrated in autumn and winter, while the summer is dry. Rainfall variability is the rule in Sardinia, but it is important to note that rainfall often peaks in November-December, just after a long dry season.

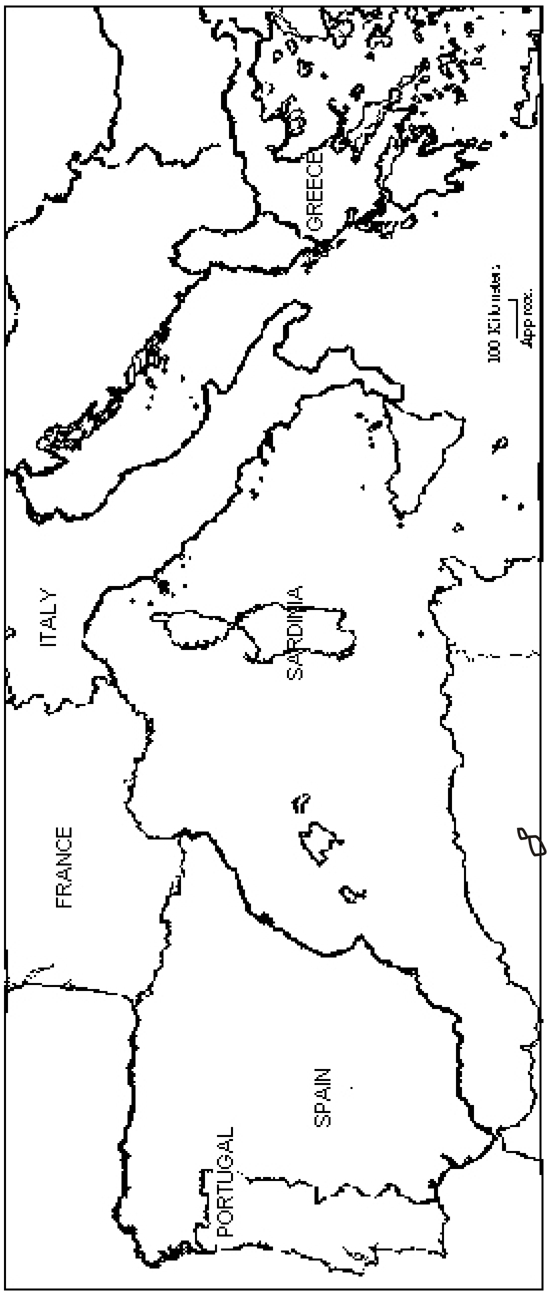

Figure 1. Western Mediterranean.

As far as erosion is concerned, there is a very important fact to notice. Almost all the geological ages are present, with a broad variety of lithologies of widely ranging composition. The soils are strongly influenced by landscape nature and morphology, with mountain (18.5% of the island surface) and hilly areas (67.9% of the island surface) prevailing over the plains (13.6% of the island surface).

In consequence, only 18% of the island's surface has soils with few limitations while 28% of the island has shallow soils, often associated with rock outcrops, presenting high erosion risk (Aru et al., 1991). In the remaining 54% of the island, soils show different degrees of suitability depending on the differences of parent materials, landscape morphologies, and vegetation covers (Aru et al., 1991).

These soils are marginal for intensive agriculture and may show strong limitations. The main land cover types are grassland and grazing land (almost 40% of the island's surface) and Mediterranean “macchia” (more than 20% of the surface). Hardwood forests cover almost 10% of total surface.

Studies carried out in the framework of the MEDALUS-EC project have involved site and area investigations. The main objectives on site investigations were: to assess soil erosion versus land use with measurements in runoff plots; to assess overexploitation of groundwater and salt water intrusion; to ascertain pollution by heavy metals in mining areas; and to assess soil loss on recent alluvium due to quarry activities with sand and gravel excavation. The main area investigations were made to assess soil loss by urbanisation, assessment of the influence of agricultural, forest and pastoral practices on soil degradation, and to evaluate the status of soil degradation in selected catchment areas.

Results and Discussion

The findings of studies carried out in the framework of the MEDALUS-EC project have shown that anthropogenic factors are the leading cause of soil degradation in Sardinia (Table 1). Three main groups can be identified: agriculture, pastoral and forestry activities, industrial activities and urbanisation.

Major soil degradation processes induced by these factors are the physical, chemical and biological actions and interactions as summarised in Table 1. For the sake of clarity the main processes will be presented and discussed separately, but in real terms these processes are intimately linked.

Accelerated erosion

Area investigations carried out in Sardinia from the 1970s have shown that accelerated erosion affects large portions of the hilly and mountain areas subject to irrational agricultural, pastoral and forestry activities, such as deep ploughing, deforestation, exotic tree species plantation, overgrazing, and the use of fire to increase pasture areas (Aru, 1984, 1985).

Table 1. Factors and processes of soil degradation in Sardinia.

soil degradation					
factors			**processes**		
agricultural, pastoral, and forestry activities	*industrial activities*	*urbanisation*	*physical*	*chemical*	*biological*
a plowing in forest areas	a quarries in agricultural areas	a conversion of land to non-agricultural uses	a accelerated erosion	a leaching	a decline in organic matter
b amelioration techniques for pasture improvement	b indiscriminate and excessive exploitation of coastal aquifers	b indiscriminate and excessive exploitation of coastal aquifers	b consumption and sealing of agricultural soils	b decline in fertility	b decrease in population activity and species diversity of soil fauna and flora
c overgrazing	c waste disposal of polluted materials		c compaction	c salinisation	c alterations in biological processes from favourable to unfavourable trends
d indiscriminate and excessive exploitation of coastal aquifers	d conversion of land to non-agricultural uses		d imbalance in water/air ratio	d contamination	
e tree exotic species plantation					
f burning to increase grazing areas					
g deforestation					

Plot erosion measurements made during the last years have quantified the soil erosion process in some of these areas. For instance, soil erosion measurements in three areas under different land use (abandoned grazing land, burned "macchia", and *Eucalyptus* sp. plantation) revealed up to 303.52 g m^{-2}, in the period from March 1992 to February 1998, under the *Eucalyptus* sp. stands (Vacca *et al.,* 2000). In the same period, in the abandoned grazing land and under burned "macchia", maximum soil erosion was 137.62 g m^{-2} and 51.44 g m^{-2}, respectively. Almost 20,000 hectares have been planted in Sardinia with *Eucalyptus* sp.

The amelioration techniques applied in Sardinia for pasture improvement, consisting in bush cutting, ploughing and seeding, have increased the loss of soil in large portions of the island. As these areas are mainly located on moderately steep to steep slopes, it has been observed that in autumn, after the first heavy rains, the shallow soils are eroded to the extent that, in many cases, the bedrock appears as rock outcrops.

The necessity to enlarge the pasture areas is influenced by the number of sheep, which has recently risen to over 3,000,000. This is also the reason why the use of fire to increase pasture areas is still common in Sardinia. The breeding of sheep is an economic mainstay of the region. Despite the Government Anti-Fire Service, which keeps hundreds of men on the alert during the summer months, fires occur at regular intervals every year (Table 2). Each fire leads to erosional transport of solids, in some years in considerable quantities, depending on the intensity and duration of rainfalls.

Table 2. Average annual fires in Sardinia (source: Assessorato Difesa Ambiente, Regione Autonoma della Sardegna).

Period	No. of fires	Forest (ha)	Pasture (ha)	Other (ha)	Total surface (ha)	% of the island surface
1980-89	3,214	6,174	32,312	4,133	42,619	1.8
1990-99	3,197	7,939	19,497	5,795	33,231	1.4

Overgrazing also causes accelerated soil erosion, which is rather common in many areas of the island. Soil compaction due to overgrazing has been evaluated by penetrometer tests revealing doubling of values (from 2.0-2.5 kg cm^{-2} to 4 kg cm^{-2}) (Madrau et al., 1995). This is negatively affecting soil permeability and increasing runoff and consequently erosion.

Consumption and sealing of agricultural soils

Urbanisation and industrial activities mainly cause consumption and sealing of agricultural soils in Sardinia. Urbanisation, both for housing and industrial development, takes mostly place along the coasts and in the coastal plains, in areas which were once used for rainfed or irrigated agriculture. The analysis of urbanisation, carried out by means of aerial photographs and satellite images, has shown that most of the urbanisation has affected prime agricultural land (Aru et al., 1998a).

Sand and gravel extraction is a major problem in regions where fertile soils in recent alluvium are limited. This is true throughout the island, where fertile soils account for only a small percentage of the total land. The uncontrolled extraction of materials by quarry activities in the alluvial plains has strongly modified the landscape leading to the irreversible loss of soils, especially of those with the highest agricultural potential.

For example, studies carried out in the flood plain of the Rio Santa Lucia (southern Sardinia) have shown that almost 96% of the soils affected by quarry activities, (in an area of 248 hectares), belong to the first two classes of Land Capability System (Klingebiel and Montgomery, 1961) (Table 3).

Table 3. Soil consumption due to quarry activity in the alluvial plain of Santa Lucia river (SW Sardinia) (after Puddu and Lai 1995, modified).

Land Capability Classes (Klingebiel & Montgomery, 1961)	**Soil consumption**			
	ha	**relative %**	**m^3**	**$m^3\ ha^{-1}$**
I-II	248.0	95.75	$1.86\ 10^6$	7,500
III-IV	2.6	1.01	$0.19\ 10^6$	7,500
VI-VII	8.4	3.24	$0.25\ 10^6$	3,000

Salinisation

Despite the difficulties in quantifying the salinisation process due to its high variability in space and time, two main types of soil salinisation have been identified: a natural salinisation, occurring in the areas bordering the lagoons, and an anthropical salinisation. In the latter case, the non-appropriate management of groundwater used for irrigation induces the process.

As a matter of fact, the over-pumping of coastal groundwater increases the infiltration of saltwater. The use of this low quality water for irrigation is increasingly affecting several coastal areas in Sardinia. The Cedrino river delta, in the coastal area of Orosei (east-central Sardinia), and the Flumendosa river delta, in the Muravera coastal plain (south-east Sardinia), are emblematic examples.

In these areas, highly productive soils have been degraded by seawater intrusion into the phreatic aquifer, which was used for irrigation purposes. Groundwater salinity has increased sodium content in the soil exchange complex, resulting in the degradation of the main physical and chemical soil parameters and in severe phytotoxicity for cultivated crops.

Consenquently, large tracts of arable land have been abandoned. A water budget evaluation has been made for the phreatic and underlying confined aquifer of the coastal area of Capoterra, in the Bay of Cagliari (southern Sardinia). Infiltration is 1.8 million m^3 higher than groundwater runoff. Only a part of this volume can be considered a usable resource, while the remainder is being contaminated by saltwater intrusion caused by over-pumping. The use of this water for irrigation purposes induces increasing soil salinity in the area.

Contamination

Mining is the oldest industrial activity in Sardinia. The island's ore deposits have been historically exploited for their lead, zinc, iron, silver, barium, fluorite, and antimony. Mining activity continued until the 1980s. Since then it has suffered a serious crisis culminating in the closure of most mines. Almost all the mine sites have been abandoned, along with their spoiled heaps, flotation tailing dumps and tailing impoundment.

It is estimated that a total amount of 14,300,000 m^3 of material is deposited in abandoned mine dumps throughout the island (Aru, 1993). These dumps tend to be unstable and prone to accelerated erosion, resulting in heavy metals contamination of soils and water bodies in neighbouring areas (Aru et al., 1995, 1998a, 1998b).

For instance, in the plain located downslope the mine of Montevecchio (south-west Sardinia) tons of wastes eroded from the mine area have covered fertile soils Vertisols previously used for agriculture. Actually, the heavy metals contained in the topsoil, and sometimes in the deeper soil horizons as well, preclude their continued use for agriculture (Fig. 2).

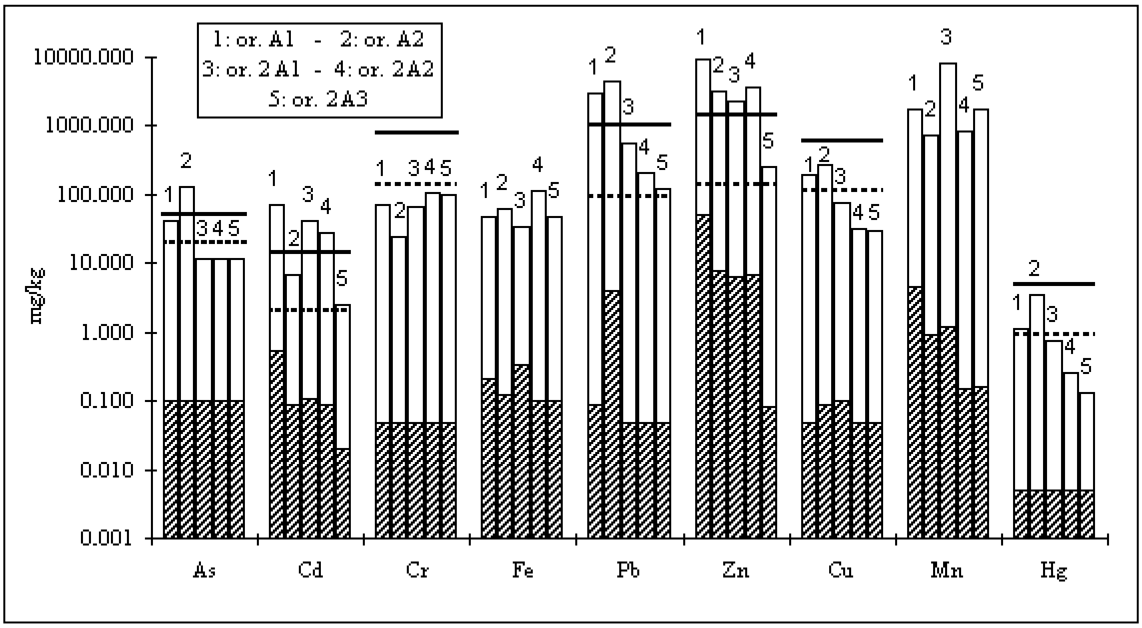

Figure 2. Total (white area) and DTPA extractable (hatched area) heavy metals content of a soil in the plain located downslope the mine of Montevecchio (south-west Sardinia) (after Aru 2001, modified). The limit provided by the Italian legislation (which considers only the total content) for agricultural use is the broken line, the limit for industrial use is the black line in bold type.

Decline in organic matter

Reduction of organic matter content in the forest floor and in the soil has been detected in many areas used for agricultural, pastoral, and forestry activities. For instance, in Gallura (north-eastern Sardinia) ploughing and repeated use of fire for clearing pasture areas in *Quercus suber* forests have caused a significant decline in organic matter content.

In *Quercus suber* forests mainly used for cork production well-developed ectorganic horizons are always present, with a total thickness ranging from 5.2 to 9.5 cm, and the mineral soil is generally 50 cm deep. In these areas the organic matter content in the forest floor ranges from 1.76 to 3.72 kg m^{-2} (Vacca, 2000). In *Quercus suber* forests used mainly for grazing, the ectorganic horizons are very poorly developed, with a total thickness normally ranging from 1 to 3 cm, and the mineral soil is generally 20-25 cm deep.

In these areas, the organic matter content in the forest floor ranges from 0.45 to 1.84 kg m^{-2} (Vacca, 2000). Trastu et al. (1996) have measured 34 g kg^{-1} of organic matter in surface horizons of *Quercus suber* forests not subjected to ploughing, and only 15 g kg^{-1} in surface horizons of ploughed forests.

Similar studies made under a 15 years old *Eucalyptus* sp. stand have shown an average reduction of 4% in organic matter content of the topsoil in respect to adjacent soils kept under natural vegetation cover (Puddu et al., 1998).

Mitigation examples

The only possible way to mitigate soil degradation is the planning of the human activities, which have been recognised as major soil degradation factors. Land planning at different levels, based on an inventory of the natural resources, including soil, on their evaluation and on the definition of alternative, suitable uses, is therefore viewed as the key issue in preventing and mitigating soil degradation in Sardinia (Aru, 1997; Previtali e Madrau, 1997).

From 1989 onwards, methodologies to evaluate the suitability of Sardinian soils for pasture improvement have been suggested (Aru et al., 1989; Zucca et al., 1998). Unfortunately, these methodologies have been applied only for research projects, which confirmed their effectiveness, while they have never been used to plan and to evaluate the government-financed projects for pasture improvement.

From 1991 onwards methodologies to evaluate the suitability of soils for reafforestation have been suggested in Sardinia (Delogu 1991, 1993; Madrau, 1995; Baldaccini and Madrau, 1996). Unfortunately, also in this case they have never been used.

On the other hand, the Regional legislation regulating the quarry extractions provides guidelines for soil protection actions and the Regional GIS Lab was set up to plan the quarry activities. These structures contain soil information that could be used to assess land suitability for the extraction activities (Lai et al., 1990).

Soil is also considered in urban planning. In fact, the Regional legislation provides the soil map as a tool to evaluate and exploit soil productivity, meanwhile assuring soil protection. Nevertheless, the final choice for urban planning is political, and the soil is the only one aspect of the land resources playing a major role in the urban planning process.

Conclusions

The characteristics of the geography of Sardinia and its pronounced Mediterranean climate make the soils particularly fragile and sensitive to any action that do not take into account their qualities and limitations. The results derived in the framework of the MEDALUS-EC project it appears that in Sardinia the main factors of soil degradation are essentially human related and associated with agriculture, forestry, livestock production, industry, and urbanisation. The physical, chemical and biological soil degradation processes consist mainly in accelerated erosion, loss of prime farmland, compaction, salinisation, contamination, decrease of organic matter content, and adverse alteration of biological processes.

Land planning at different levels - based on an accurate inventory of the natural resources, including soil, on their evaluation and on the definition of alternative, suitable uses - is therefore viewed as the key issue in preventing and mitigating the effects of soil degradation. In some cases, such as the quarry activity and urban planning, the soil science has recently assumed a prominent role in the planning process. On the contrary, there are still few applications in agriculture, forestry and grazing.

Land use planning that does not take into account the effective potential and limitations of the soil can only exacerbate degradation, which in turn will affect increasingly larger areas of the island.

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