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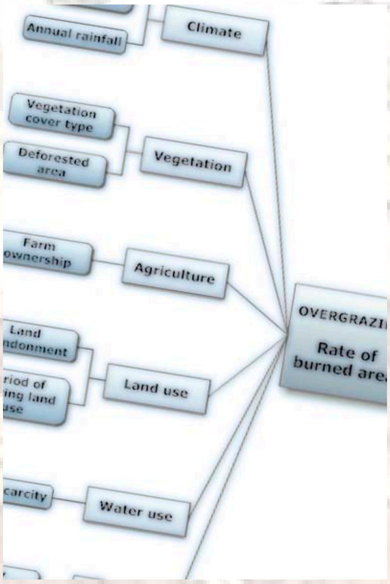

Comparative analysis of indicators existing in the study sites

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WB2: Land degradation indicators
Deliverable: 2.2.1 Comparative analysis of indicators existing in the study sites

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Contents

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1. Introduction

As has been pointed out by UNCCD, indicators can be considered valuable tools for assessing desertification risk and for analyzing the effectiveness of the various land management practices for combating desertification. By using an appropriate number of indicators, complex processes such as soil erosion, soil salinization, and land desertification may be effectively described without using complex mathematical expressions or models that require an excessive amount of data. The European Environmental Agency has considered that an indicator is a measure, generally quantitative, that can be used to illustrate and communicate complex phenomena simply, including trends and progress over time (EEA, 2005). Policy makers need to have as clear as possible a view of such interrelations in the overall complex system. The main means of communicating the pertinent information is through indicators. Indicators can be used to monitor the implementation of systemic policy objectives, as well as to represent trends and developments in the state of a system. Many international or national organizations have recognized that environmental and socio-economic indicators are playing a significant role in supporting developmental policies.

An environmental indicator is a parameter or a value derived from parameters that describe the state of the environment and its impact on human beings, ecosystems and materials, the pressures on the environment, the driving forces and the responses steering that system (ETDS, 2010). In environmental sciences, a single indicator cannot efficiently describe a complex process such as soil erosion or land desertification. Indicators combined in certain ways, creating an Index, permit multiple measurements to be made in various systems, and hence the monitoring of the state of the environment, the comparison of different sub-systems and the maintenance of the Index as well as a policy making instrument.

Many authors have considered that classification of indicators must take into account the linkages between; (a) pressures exerted on the environment by human activities, (b) changes in quality of the environmental components, and (c) societal responses to these changes that can be a useful and valuable tool for land-users and policy makers (O' Connor, 1994; Pieri et al., 1995; SCOPE, 1995; Dumanski and Pieri, 1996). The Organization for Economic Co-operation and Development (OECD) has early on established criteria for selecting environmental indicators. According to OECD , 2003 an environmental indicator should:

- Provide a representative picture of environmental conditions, pressures on the environment or society's responses;
- be simple, easy to interpret and able to show trends over time;
- be responsive to changes in the environment and related human activities;
- provide a basis for international comparisons;
- be either national in scope or applicable to regional environmental issues of national significance;
- have a threshold or reference value against which to compare it, so that users can assess the significance of the values associated with it.
- be theoretically well founded in technical and scientific terms;
- be based on international standards and international consensus about its validity;
- lend itself to being linked to economic models, forecasting and information systems.

The data required to support the indicator should be (a) readily available or made available at a reasonable cost/benefit ratio, (b) adequately documented and of known quality, and (c) updated at regular intervals in accordance with reliable procedures. The objectives of this work package are:

a) Comparison and linking of indicators with land management practices among the various studied study sites.
b) Development of a methodology to simulate and evaluate the various land management practices and techniques in terms of land degradation and economic feasibility for combating desertification using the appropriate indicators.

2. Analysis of data

The data base of indicators created and presented in deliverable 2.1.3 (AUA, 2010b) has been further analyzed in order to identify the most appropriate and effective indicators suited to a range of local physical and socio-economic conditions for assessing the effectiveness of the various land management practices in land uses and landscapes prone to desertification. For the comparative analysis of the study field sites, the indicator data base has been split into six sets with respect to their effects on soil degradation and soil restoration. Particularly, the collected data from all study sites have been organized based on the identified processes and causes of land degradation described in the study field sites as follows:

- Soil erosion
- Soil salinization
- Water stress
- Overgrazing
- Forest fires
- Urbanization.

Data related to soil erosion were further subdivided based on the major land use type namely agriculture, pastures, and forests (Table 1). This division has been made for a more suitable use of certain indicators such as tillage operations, tillage direction, which are very important for agricultural areas, but not for forested-areas, while the indicators grazing intensity, burned area which are more significant for pastures or forested–areas, but not for agricultural areas. The process urbanization has not been analyzed due to the limited number of study field sites in which the corresponding indicators were described.

Table 1. Land degradation processes and causes with the corresponding land uses, and distribution in the study sites

A/A	Degradation process	Major land use	Study sites	Field sites	Number of indicators used
1	Soil erosion	Agriculture	9	477	49
		Pasture	8	244	49
		Forest	6	85	49
2	Soil salinization	Agriculture, natural vegetation	5	258	27
3	Water stress	Agriculture, natural vegetation	5	258	50
4	Overgrazing	Natural vegetation, agriculture	6	265	44
5	Forest fires	Natural vegetation	4	85	29

An empirical approach was adapted to define desertification risk based on the type of environmentally sensitive area (ESA) to desertification and on the main process or cause of degradation identified for each site such as: (a) degree of soil erosion (Table 2a), (b) soil water storage capacity (Table 2b), and (c) electrical conductivity of the soil for the process of soil salinization (Table 2c). The type of ESA has been used to characterize the present stage of land degradation, in combination with the degree of soil erosion or water stress, etc., and thus, the risk of land desertification has been assessed. For example, an area characterized as fragile to desertification will be subjected to high desertification risk under very severe erosion or low risk under slight erosion. The degree of soil erosion has been mainly considered for hilly areas, while soil electrical conductivity has been used mainly in plain areas where the main process of desertification is soil salinization. Soil water storage capacity has been considered for hilly or plain areas where water stress has been defined as the major process of land desertification. Desertification risk in areas where overgrazing or forest fires have been identified as major causes of desertification has been assessed based on the degree of soil erosion since erosion is the most important process of land degradation.

The type of ESA for each study field sites was defined based on the MEDALUS III methodology (Kosmas *et al*., 1999). Five categories of desertification risk were distinguished, namely: very high, high, moderate, low and none. Weighing indices were assigned for each category of desertification risk for statistical analysis (Table 2).

Table 2a. Definition of desertification risk for the degradation processes: (a) water erosion, (b) tillage erosion, (c) wind erosion, (d) forest fires, (e) overgrazing

No	Type of environmentally sensitive area	Degree of soil erosion	Desertification risk	Assigned weighing indices
1	Critical	Very severe, severe	Very high	5
		Moderate, slight	High	4
		no erosion	moderate	3
2	Fragile	Very severe	High	4
		Severe, moderate	Moderate	3
		Slight, no erosion	Low	2
3	Potential	Very severe, severe	Moderate	3
		Moderate,	Low	2
		Slight, no erosion	No risk	1
4	Non-threatened	Very severe, severe, moderate	Low	2
		Slight, no erosion	No risk	1

Table 2b. Definition of desertification risk for the degradation process water stress

No	Type of environmentally sensitive area	Soil water storage capacity (mm)	Desertification risk	Assigned value
1	Critical	<50	Very high	5
		50-100	High	4
		>100	moderate	3
2	Fragile	<50	High	4
		50-100	Moderate	3
		>100	Low	2
3	Potential	<50	Moderate	3
		50-100	Low	2

		>100	No risk	1
	Non-threatened	<50	Low	2
4		>50	No risk	1

Table 2c. Definition of desertification risk for the degradation process salinization risk

No	Type of environmentally sensitive area	Electrical conductivity of soil (dS m^{-1})	Desertification risk	Assigned value
	Critical	>8	Very high	5
		4-8	High	4
		2-4	moderate	3
1		<2	Low	2
	Fragile	>15	Very high	5
		8-15	High	4
		4-8	Moderate	3
		2-4	Low	2
2		<2	No risk	1
	Potential	>15	High	4
		8-15	Moderate	3
		4-8	Low	2
3		<4	No risk	1
	Non-threatened	>15	Moderate	3
		4-15	Low	2
4		<4	No risk	1

The statistical analysis was conducted by using the statistical package STATISTICA-version 8. The harmonized data base provided in deliverable 2.1.3 (AUA, 2010b) has been improved for missing values for some indicators following the appropriate statistical methodology (Steel, *et al.*, 1997). The number of indicators used for the analysis in each process or cause is those given in the data base in deliverable 2.1.3. Using the factorial-principal component analysis, the indicator data base for each process or cause has been split into a number of sets with respect to their effects on soil degradation and soil restoration summarised into developed indicators (principal component analysis) (Table 1). The factor analysis was conducted assigning 4 factors for each process or cause and the final number of factors was decided after running the analysis. The criterion for introducing each indicator in a set was when the factor loading value was greater than 0.70. In addition, a set of indicators was formed only when there were at least two indicators with loading values greater than 0.70. Each set of indicators was named based on the characteristics of the indicators included.

The data were further analyzed in order to define: (a) the interrelationships between various indicators (analysis of covariance), and (b) the effectiveness of each indicator to evaluate the sensitivity to desertification (analysis of variance). For that purpose, a forward stepwise multiple regression analysis was applied for each process or cause with dependent variable the desertification risk and independent variables all the indicators assigned for each process or cause as they appeared in the data base (deliverable 2.1.3) using the following linear model:

$$\mathbf{Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots\cdots + \beta_\kappa X_\kappa}$$ (Steel, *et al.*, 1997).

Where: Y is the dependent variable of desertification risk, β_0 is the Y intercept, β_1, β_2, etc. are slopes of the regression plane, and X1, X2, etc. are the independent variables of the indicators used. A 95 percent confidence interval was used for the multiple regression analysis. The analysis of covariance and variance was a step in the multiple regression analysis. The analysis of covariance was made for every possible pairwise set of indicators. The selection of pair of indicators with significant covariance was made using the matrix of covariance and only for values greater than 0.75. In each pair of indictors which was proved to have high correlation one of them was usually excluded from the analysis of variance.

The selection of indicators highly affecting desertification risk or degree of soil erosion was conducted using the correlation matrix analysis of variance in which the desertification risk or the degree of soil erosion was compared with the independent variables of indicators. Important indicators considered for the comparative analysis of the study field sites were those with correlation coefficients values greater than 0.40. Then the selected indicators mostly affecting desertification risk and related to land management for each process or cause were further analyzed using the correlation matrix of variance and extracting indicators with correlation coefficients greater than 0.40. Important indicators affecting desertification risk and related to the physical environment were not used here for the comparative analysis of the study field sites. The purpose of this analysis was to select and analyze important indicators affected by man actions such as tillage operations, grazing control, soil erosion control, etc., and be used for combating desertification. State indicators such as rain seasonality, slope gradient drainage density, soil depth, etc. were not further discussed here but they were used in the development of empirical relations for assessing desertification risk in deliverable 2.2.2. Then the indicators affecting each land management indictor were classified according to the system given in deliverable 2.1.3 and they were presented in graphs without any meaning of the length of lines connected with the central subject.

3. The comparative analysis of the study field sites

The analysis of the obtained data on indicators have shown that the proposed system of indicators can be successfully applied in a variety of environmental, social, economic and institutional locales. Some difficulties have been faced for collecting data especially for regional indicators such as the rate of soil surface sealing, drainage density, ground water exploitation. Having the harmonized data base, the comparative analysis of the study field sites has revealed some key indicators from a wide list of indicators affecting desertification risk in a variety of environmental social and economical conditions. The discussion on the comparative analysis of the field sites that follows has been based on: (a) the main processes or causes of desertification identified in the study sites such as soil erosion, soil salinization, water stress, overgrazing, and forest fires, and (b) the most important land management indicators affecting desertification risk.

3.1 Desertification risk

The comparative analysis based on desertification risk has been made independently of the process or cause of desertification. The obtained results have shown that the study field sites were subjected to various degrees of desertification risk depending on the severity of acting process and the state of the physical environment. High and very high desertification risks were the dominant classes identified in the majority of the study field sites. As Table 3 shows, all the study field sites in Rendina Basin Basilicata-Italy have been characterized as subjected to very high desertification risk due to high erosion rates caused by surface water runoff and tillage operations. Also, very high desertification risk due to soil erosion and water stress has been identified in the Santiago Island-Cape Verde, and Zeuss-Koutine-Tunisia study sites, covering 57.3% and 43.3%, respectively, of the corresponding study field sites. Very high desertification risk has been estimated in 40% of the study field sites in the Nestos Basin Maggana-Greece caused exclusively by soil salinization due to poorly drained soil conditions and the low quality of groundwater. Very high desertification risk has been defined in some field sites of the Mação Gois- Portugal, Guadalentin Basin Murcia-Spain, Boteti Area-Botswana, Mamora Sehoul-Morocco, Loess Plateau-China, Secano Interior-Chile, Crete-Greece, and Cointzio Catchment-Mexico study sites, ranging from 3.3% to 23.0% due to soil erosion, soil salinization, and forest fires (Table 3).

High desertification risk has been defined in all field sites of Konya Karapinar and Eskisehir Plain-Turkey study sites caused mainly by surface water runoff. The next important percentage of high desertification risk has been assessed for the study sites of Novij Saratov and Djanybek-Russia, Boteti Area-Botswana, and Mamora Sehoul-Morocco, covering 61.4%, 48.1%, and 47.5% of the total study field sites, respectively, caused mainly by soil erosion, soil salinization, water stress, and overgrazing. High desertification risk has been estimated for some of the study sites of Nestos Basin Maggana-Greece, Crete-Greece, Mação Gois-Portugal, Guadalentin Basin Murcia-Spain, Zeuss Koutine-Tunisia, Boteti Area-Botswana, Loess Plateau-China, Secano Interior-Chile, Cointzio catchment-Mexico, ranging from 16.4% to 35.6% of the study field sites, caused mainly by soil erosion, water stress, soil salinization, overgrazing, and forest fires (Table 3).

Moderate desertification risk has been estimated in all study sites except for Rendina Basin Basilicata-Ital, and Karapinar and Eskisehir Plain-Turkey, in a percentage ranging from 16.0% to 45.5% of the study field sites in each area. The main processes responsible for this class of desertification risk are soil erosion, soil salinization, water stress, and overgrazing.

The highest number of field sites characterized with slight or no desertification risk has been estimated in the study sites of Loess Plateau-China, Gois, Mação-Portugal, and Secano Interior-Chile covering 44.5%, 44.4%, and 50% respectively. About 1/3 of the study field sites of Crete-Greece, Guadalentin Basin Murcia-Spain, and Cointzio catchment-Mexico (Table 3). Low percentages of low to no desertification risk, ranging from 3.3% to 14.6%, have been assessed in the study sites of Nestos Basin Maggana-Greece, Zeuss Koutine-Tunisia, Boteti Area-Botswana, Santiago Island-Cape Verde, and Mamora Sehoul-Morocco.

3.2 Soil erosion

Soil erosion by surface water runoff or tillage operations has been identified as the main process of land degradation in the following 13 study sites: Rendina Basin Basilicata-Italy, Crete-Greece, Guadalentin Basin Murcia-Spain, Konya Karapinar-Turkey, Eskisehir Plain-Turkey, Novij Saratov-Russia, Zeuss Koutine-Tunisia, Boteti Area-Botswana, Santiago Island-Cape Verde, Mamora Sehoul-Morocco, Loess Plateau-China, Secano Interior-Chile, and Cointzio catchment-Mexico. The main causes affecting soil erosion in the study field sites were adverse climatic conditions, low plant cover, steep slopes, shallow soils, unsuited land management practices, and lack of measures for controlling soil erosion. The obtained data have shown that in 1074 field sites, or 65.4% of the total, soil erosion (including water and tillage erosion) was the main process of land degradation and desertification.

Table 3. Distribution of land desertification risk estimated in the study field sites of the various study sites

site no	Study site	Distribution of land desertification risk classes (%)				
		No risk	Slight	Moderate	High	Very high
1	Rendina Basin, Basilicata, Italy	0	0	0	0	100.0
2	Loess Plateau, China	22.8	21.7	16.5	21.3	17.7
3	Nestos Basin, Maggana, Greece	3.3	13.3	23.3	20.1	40.0
4	Gois, Mação, Portugal	13.1	31.1	16.4	16.4	23.0
6	Secano Interior, Chile	17.9	32.1	21.4	25.0	3.6
7	Boteti Area, Botswana	0	9.3	33.3	48.1	9.3
8	Novij, Saratov, Djanybek, Russia	0	1.2	37.4	61.4	0
9	Cointzio watershed, Mexico	0	32.2	27.6	33.3	6.9
11	Eskisehir, Konya, Karapinar plain, Turkey	0	0	0	100.0	0
13	Santiago Island, Cape Verde	14.6	7.8	18.4	1.9	57.3
14	Mamora/Sehoul, Morocco	10.0	10.8	19.2	47.5	12.5
15	Zeuss-Koutine, Tunisia	9.2	8.3	19.2	20.0	43.3
16	Guadalentin Basin, Murcia, Spain	1.7	30.6	45.4	19.0	3.3
17	Crete, Greece	10.0	21.6	19.0	35.6	13.8

As was mentioned in deliverable 2.1.1 (AUA, 2010a), the degree of soil erosion was assessed during the field survey using five classes of erosion (no, slight, moderate, severe, and very severe). Moderate erosion was the most important identified class, covering 33.6% of the study field sites (Fig. 1). The majority of the study field sites with moderate erosion are located in agricultural or forested areas subjected mainly to high or moderate desertification risk. The next important classes of soil erosion identified in the study field sites were severe and very severe erosion, covering 24.0% and 11.9% of the corresponding study field sites (Fig. 1). Severe erosion was associated with the presence of gullies and occurred mainly in agricultural or grazing lands subjected to high desertification risk. No erosion or slight erosion has been identified in the rest of field sites covering 12.6% and 17.9% of the study field sites, respectively. Such classes of soil erosion have been mainly identified in field sites located in agricultural or forested areas with adequate plant cover, or properly managed and protected from desertification by applying soil erosion control measures such as sustainable number of animals, fire protection, storage of water runoff, sustainable farming.

The analysis of the indicators related to degree of soil erosion including all land uses (agriculture, pastures and forests) have shown that the most important indicators affecting soil erosion in the study field sites were related to vegetation, soil, water runoff, and land management (Fig. 2). The most important vegetation indicators were vegetation cover type, and plant cover. On one hand, field sites covered with evergreen forest, pines, olive trees, mixed Mediterranean machia. and evergreen forest have been subjected to low soil erosion rates. On the other hand, field sites covered with cereals, vines, annual grasses, Mediterranean machia, and almonds have been mainly subjected to moderate or severe erosion. Plant cover was negatively related to soil erosion. Field sites with permanently adequate plant cover (greater than 50%) were adequately protected from soil erosion.

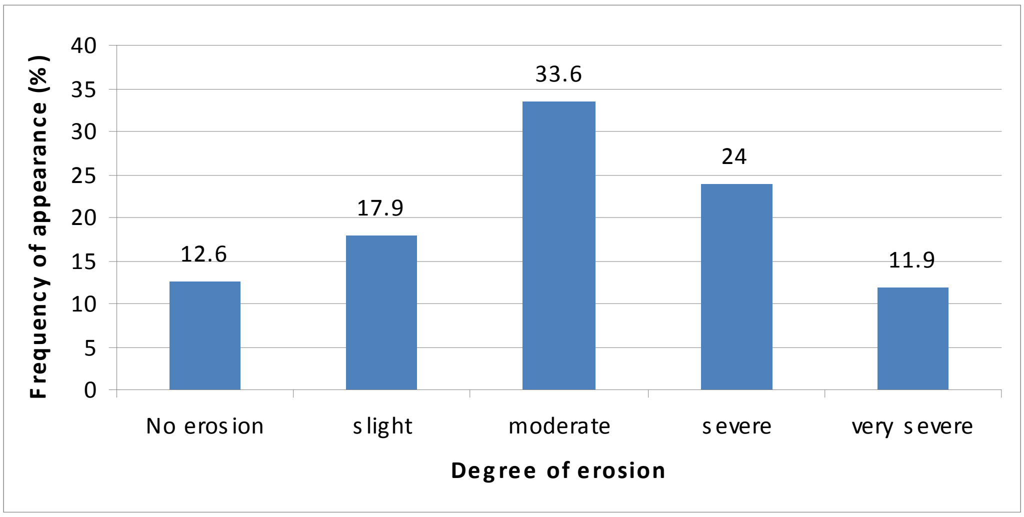

Fig. 1. Distribution of degree of soil erosion classes identified in the study field sites

Among soil indicators, the most important ones identified in the study field sites were slope gradient, soil texture, and exposure of rock outcrops. Soil erosion classes of moderate and severe have been usually identified in slopes greater than 12%. Field sites located in steep slopes with soil textures ranging from coarse to medium were usually more eroded compared to field sites with lower slope gradients and soil textures moderately fine to fine. The presence of high percentage of rock outcrops favored soil erosion since under such conditions rain water is not infiltrating into the soil, but it flows on the soil surface causing severe erosion in spots where soil is present. In the case that the existing bedrock was characterized by cracking or faults, such as in limestone, runoff water generated from the rock outcrops is flowing into the rock through these features, thus significantly reducing soil erosion.

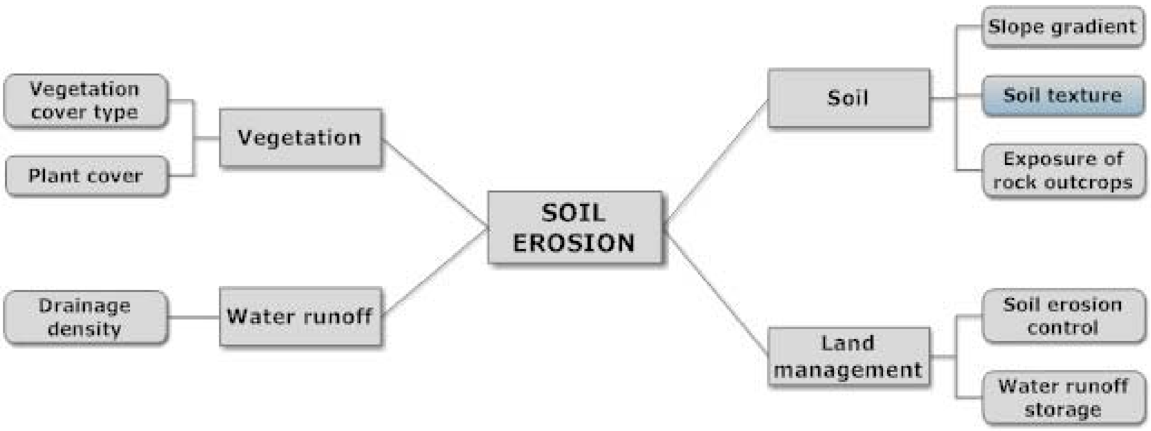

Fig. 2. Important indicators identified in the study field sites affecting degree of soil erosion

The most important water runoff indicator affecting soil erosion was drainage density. Drainage density was positively related to soil erosion. Moderate to severe erosion has been defined in field sites with high drainage density network. This indicator is interrelated to the type of surface geological formations with low infiltration which affects drainage density and soil characteristics.

As it was expected, actions for soil erosion control had a great effect on the degree of erosion identified in the study field sites. Among the most important actions identified by the analysis of the data were soil erosion control, and water runoff storage. Field sites, in which such actions have been undertaken, had usually erosion classes of slight or no erosion. The correlation estimated for other actions such as sustainable farming, grazing control, etc. was relatively low degree of soil erosion.

In the following paragraphs, the most important indicators related to land management, significantly affecting desertification risk due to soil erosion, are selected and discussed. The various field sites have been distinguished in the following tree major land uses: agriculture, pastures, and forests.

3.2.1 Agricultural areas

Soil erosion in agricultural areas has been considered as an important process of land desertification in the following study sites: Rendina Basin Basilicata-Italy, Crete-Greece, Guadalentin Basin Murcia-Spain, Eskisehir Plain-Turkey, Novij Saratov-Russia, Zeuss Koutine-Tunisia, Santiago Island-Cape Verde, Mamora Sehoul-Morocco, Secano Interior-Chile, Loess Plateau-China, and Cointzio catchment-Mexico.

The obtained data of indicators affecting desertification were collected from a variety of climatic and soil conditions, land management practices, social and economical characteristics. The factorial-principal component analysis of the data related to agriculture have shown four important sets of indicators related to land degradation and desertification (Table 4). The sets of indicators have been mainly related to water conservation, cultivation, husbandry, and surface water runoff. The included indicators in these sets are related to: (a) physical environment such as soil water storage capacity, rain seasonality, vegetation cover type, period of existing land use, drainage density, (b) land management such as impervious surface, tillage operations, tillage depth, grazing intensity, (c) land protection such as fire protection, grazing control, (d) social and economic characteristics such as old age index, parallel employment.

Table 4. Sets of indicators related to agricultural crops identified by using factor-principal components analysis

Sets of indicators related to:			
Water conservation (eigenvalue=6.06)	**Cultivation (eigenvalue = 5.54)**	**Husbandry (eigenvalue = 5.47)**	**Water runoff (eigenvalue = 4.66)**
Soil water storage capacity	Tillage operations	Vegetation cover type	Rain seasonality
Impervious surface	Tillage depth	Grazing control	Drainage density
Fire protection	Period of existing land use	Grazing intensity	Parallel employment
Old age index			

Water conservation was positively related with soil water storage capacity since rain water can be stored and adsorbed by the growing plants during the dry period. Impervious surface was negatively related to water conservation because not much water can infiltrate, thus generating surface water runoff and flooding. Protection of the land from forest fires was positively related to water conservation in the study field sites because of the increased surface infiltration. Old age index of the local populations was negatively related to water availability since actions for water conservation by older people were rather limited.

The other set of indicators related to cultivation and effecting soil erosion and land desertification included mainly tillage operations, tillage depth, and the period of existing land use. Tillage operations and tillage depth were positively related to soil erosion and especially tillage erosion. Also, field sites in which the period of existing land use was short, the soil erosion identified was usually high. This is mainly related to the intensity of land use which is often high in such areas.

Field sites located in agricultural areas were in some cases also used for grazing animals during a certain period of the year. Field sites under cereals, olives or vines were usually grazed affecting soil erosion, since part of the vegetation was removed leaving the soil with low plant cover which favors soil erosion especially during early winter. Of course a controlled grazing can be beneficial for the land (fire protection) or detrimental for soil erosion under high grazing intensity.

The last set of indicators was mainly related to surface water runoff. Rain seasonality was negatively related to soil erosion since under dry climatic conditions plant cover is reduced favoring soil erosion. Soil erosion was positively related to drainage density. Finally, field sites in which the farmer has a parallel employment were usually not protected adequately from soil erosion due to limited time devoted to the farming.

The analysis of interrelations among the various indicators (analysis of covariance) has shown that the following pairs of indicators were interrelated:

- Runoff water storage – soil erosion control
- Soil erosion control – sustainable farming
- Grazing control – grazing intensity
- Tillage operations – sustainable farming
- Vegetation cover type – grazing control
- Aridity index – rain erosivity
- Population density – slope gradient.

Soil erosion control was interrelated with runoff water storage and sustainable farming. Also grazing control was related to grazing intensity since sustainable number of animals was the most important action for soil erosion. Grazing control was also related to vegetation cover type since some agricultural land uses were subjected to controlled grazing. Tillage operations were closely related to sustainable farming, since they are considered as an adverse land management practice. Furthermore, some other interrelations were found between indicators which were rather arbitrary than having practical meaning such as parallel employment – drainage density, Such interrelations were not further considered in the analysis.

The analysis of the effectiveness of each indicator to evaluate the sensitivity to desertification (analysis of variance) has shown that the most important indicators (highest correlation coefficients with desertification risk) related to land management in the study field sites were: tillage operations, land use intensity, and policy enforcement. Land use intensity and policy enforcement are not included in the above sets of indicators. But based on their definition, land use intensity was defined on the basis of tillage operations and grazing intensity, while policy enforcement includes actions for protection of the environment such as soil erosion control, runoff water storage, grazing control, etc.

<u>Tillage operations</u>

Tillage operations cause both surface water runoff and tillage erosion, are considered as the most important causes of land degradation and desertification in hilly cultivated areas. Extensive hilly cultivated areas have largely degraded in the last decades due to erosion caused by the use of heavy powerful tillage implements. The analysis of the obtained data showed that tillage operations such as ploughing, disking, harrowing, etc. were affected by various indicators related to the physical environment, land management characteristics, social and economic characteristics (Fig. 3). Tillage operations in the study field sites were negatively affected by climate characteristics such as potential evapotranspiration, rain seasonality, and rain erosivity. Field sites were mainly uncultivated under dry climatic conditions characterized by high evapotranspiration rates and high rain seasonality since soils conditions were not favorable for growing a crop. Also tillage operations were negatively related to rain erosivity.

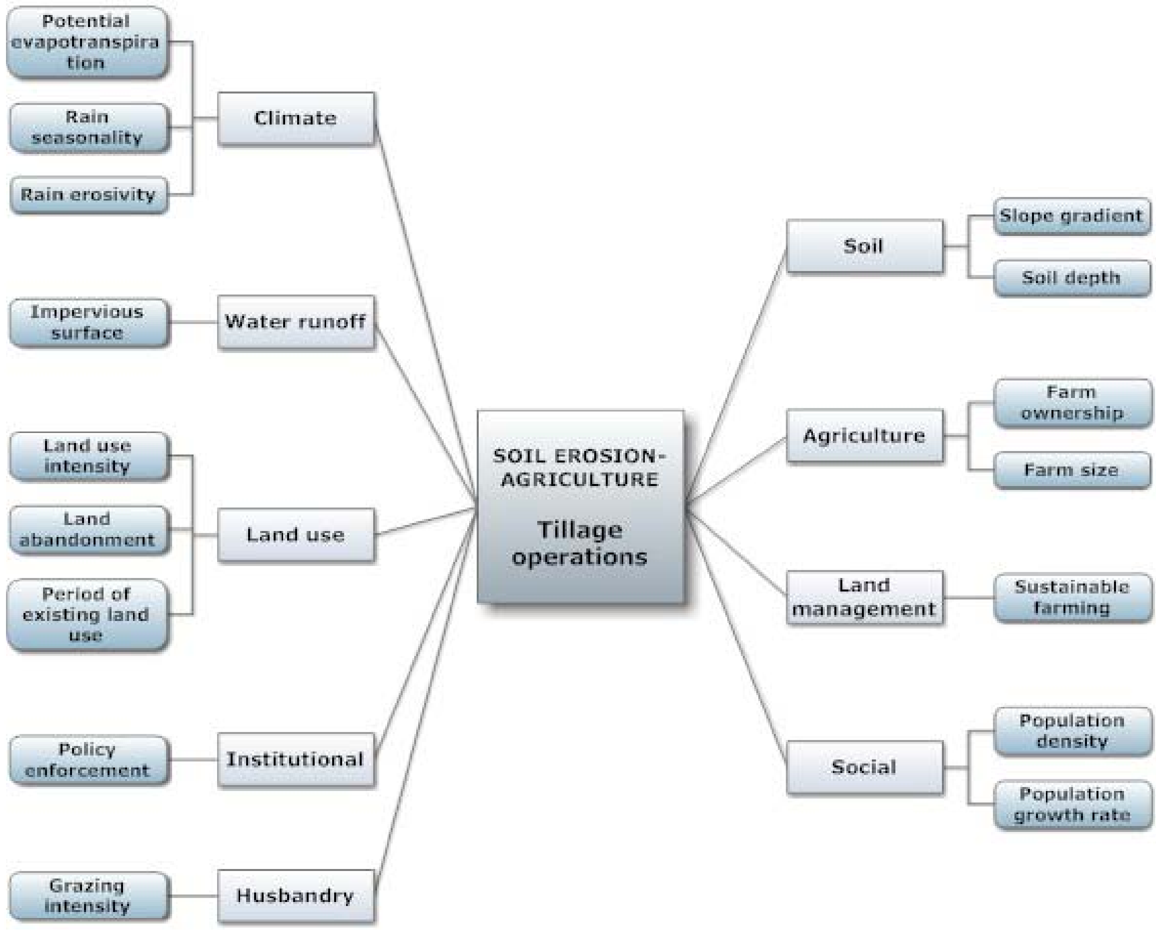

Fig. 3. Important indicators affecting tillage operations in the study field sites under agricultural crops

Among the soil indicators, slope gradient and soil depth were mainly related to tillage operations. As slope gradient increased, or soil depth decreased tillage operations were rather limited in the study field sites. Thus, field sites with shallow soils or steep slopes were rarely cultivated.

The rate of change of impervious soil surface has negatively affected tillage operations. Areas with high rate of change in impervious soil surface were usually related to tourism or industrial activities in which agriculture was rather a secondary branch of economy resulting in less intensive agriculture accompanied by limited number of tillage operations.

Agricultural characteristics significantly affecting tillage operations in the various field sites were land ownership and farm size. As farm ownership changes from owner-farmed to shared-farmed, tenant-farmed tillage operations were reduced. In addition, as farm size decreased tillage operations usually decreased since farmers were not usually organized on a professional basis.

Important indicators related to land use and affecting tillage operations were land use intensity, land abandonment, and the period of existing land use. Land use intensity has affected tillage operations in different ways. In case that the agricultural land was additionally used for grazing animals for a certain period of the year, then tillage operations were reduced. On the contrary, when the land was exclusively used for agriculture, land use intensity increased by applying irrigation, fertilization, etc., accompanied by increased number of tillage operations. Furthermore, as the period of the existing land use increased tillage operations mainly decreased. The rate of land abandonment in the study field sites was positively related to tillage operations. As the rate of agricultural land abandoned increased, the remaining land was more intensively cultivated for compensation of the loss in crop production.

As it is expected sustainable farming was negatively related to tillage operations. Furthermore, policy enforcement of existing regulations for environmental protection was positively related to tillage operations. When measures for protecting the land from degradation were not applied, the land was usually intensively cultivated leading to high erosion and degradation rates.

Among the social characteristics of the study field sites population density and population growth rate were closely related to tillage operations. In field sites with high population densities and high rates of population growth, tillage operations were mainly identified as low. These are opposite trends than were expected. Perhaps people in these circumstances are more likely to have off-farm income. Finally, it seems that some other social and economic conditions prevailing in the study field sites were also influencing the cultivation of the land such as the ratio of rural/urban population, net farm income, etc.

Land use intensity

Land use intensity in the study field sites was related to the degree in which the cultivation of the land was mechanized, the amount of fertilizers and pesticides applied, the extent in which water was used for irrigation. Such practices may cause land degradation or land protection depending on other factors related to the physical environment. The analysis of variance has shown that the most important indicators affecting land use intensity and desertification risk were related to vegetation, water use, land use, cultivation, agriculture, land management, and social characteristics (Fig. 4). High land use intensity has been mainly identified in areas cultivated with cereals, vegetables, and vines. Low land use intensity has been found mainly in olive groves and almond plantations. Furthermore, land use intensity was mainly defined as high when the existing land use was for a period less than 10 years.

Irrigation percentage of arable land has also related to land use intensity. Areas in which the percentage of arable land was low (less than 10%), land use intensity has been characterized as low. The high profitability of irrigated land has resulted in low land use intensity in non-irrigated areas.

Among the most important agricultural indicators affecting land use intensity in the study field sites were farm ownership and farm size. High land use intensity has been mainly identified in field sites characterized as tenant- or state-farmed. Under such conditions, farmers try to gain as much as they can, intensively cultivating the land without applying any protection measures. Also, the obtained data have shown that as net farm income decreased land use intensity has mainly decreased since farmers have not the economic strength for applying fertilizers, cultivating the land, etc.

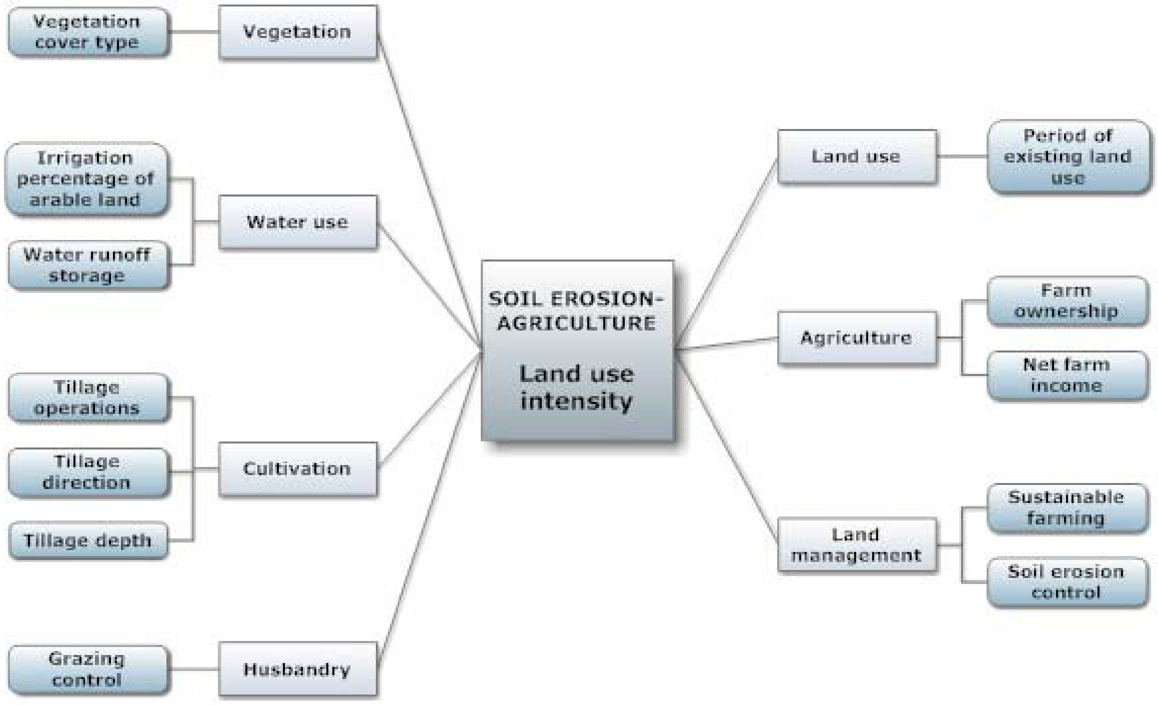

Fig. 4. Important indicators affecting land use intensity in the study field sites under agricultural crops

As was mentioned previously land use intensity was related to cultivation of the land. Field sites with soils ploughed by a moldboard in directions perpendicular to the contour lines in depths greater than 30 cm have been mainly characterized as subjected to high land use intensity. On the contrary, field sites in which actions for the protection of the land have been undertaken such as sustainable farming, soil erosion control, storage of water runoff, grazing control have been mainly characterized as subjected to low land use intensity.

Policy enforcement

Policy enforcement or policy followed is related to the implementation of measures for the sustainability of the environment. The analysis of variance has shown that the most important indicators affecting policy enforcement in the study field sites were related to: climate, soils, vegetation, land management, social and economical characteristics (Fig. 5). Among the climate characteristics, potential evapotranspiration had a great contribution to policy enforcement. Policy enforcement has been characterized mainly as low in field sites with high annual evapotranspiration rates. Areas under high evapotranspiration rates are usually less developed and more remote in which policy enforcement is usually low.

The most important vegetation indicators identified by the analysis affecting policy enforcement were vegetation cover type, and plant cover. Field sites cultivated with cereals, vegetables, vines, policy enforcement of existing regulations for environmental protection was mainly low, while in field sites cultivated with olives, and almonds policy enforcement was mainly moderate or high. In addition, plant cover was positively related to policy enforcement.

Important soil characteristics related to policy enforcement were soil texture, and soil water storage capacity. In filed sites with soils characterized as medium-, moderately fine-, and fine-textured with high water storage capacity, police enforcement has mainly been characterized as high. Such soils usually support an adequate crop production providing an adequate farm income with a higher possibility for investment by the farmer on land protection. Furthermore, increasing rates of impervious surface were accompanied with low policy enforcement in the study field sites.

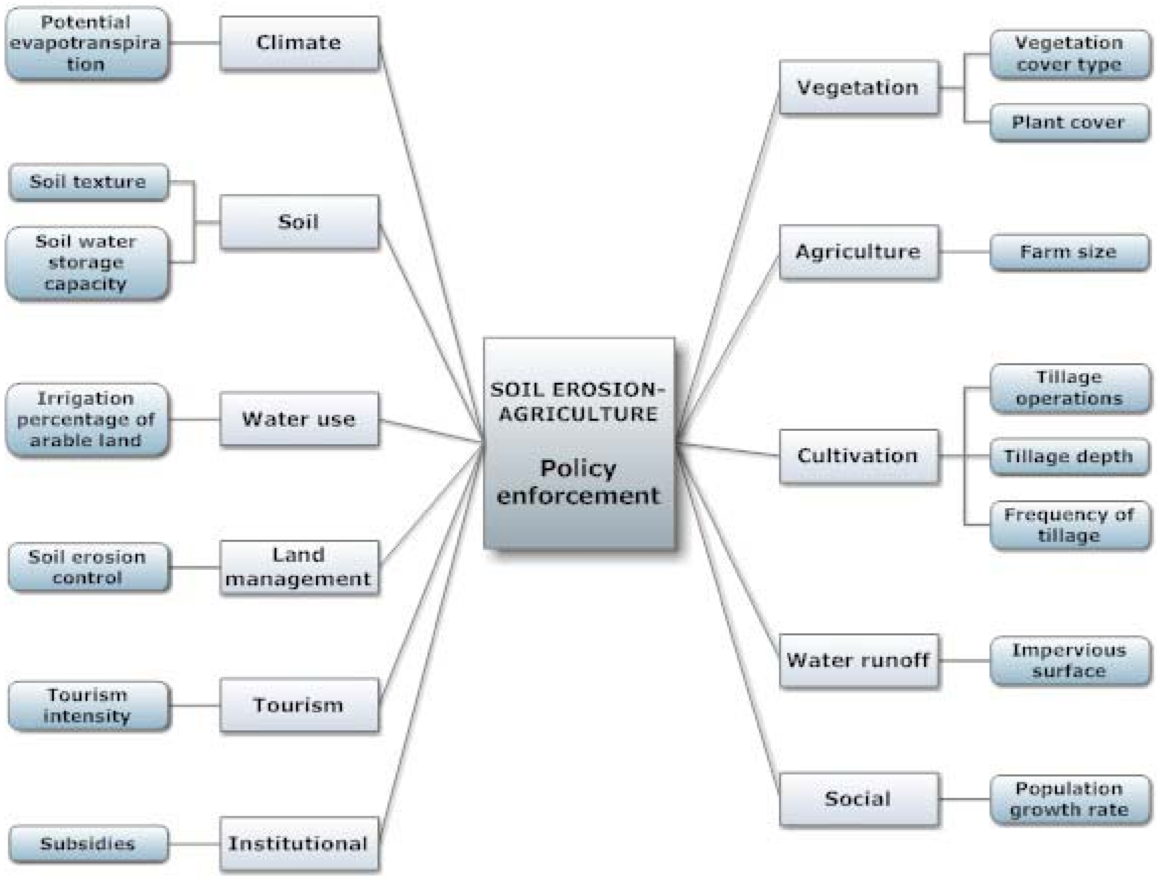

Fig. 5. Important indicators related to policy enforcement in the study field sites under agricultural crops

Policy enforcement has been related to farm size. In large farm sizes (greater than 30 ha), the policy enforcement has been usually defined as low. Farmers occupying large farm sizes used to organize crop production on more professional basis, systematically cultivating the land for maximum production without applying measures for land protection. Furthermore, irrigation percentage of arable land has negatively affected policy enforcement. In areas with high percentage of arable land, policy enforcement has been mainly characterized as low.

Important indicators related to cultivation practices and affecting policy enforcement in the study field sites were tillage operations, frequency of tillage, and tillage depth. Cultivation practices in which the soil was ploughed mainly with a mouldboard or a disk, in depths greater than 30 cm in more than two tillage operations per year, policy enforcement has been mainly characterized as low. On the contrary, field sites in which tillage operations were limited combined with actions for soil erosion control, policy enforcement has been characterized as moderate or high.

Policy enforcement has been also significantly affected by tourism intensity and population growth rate. Field sites in areas with high population growth rates have been mainly subjected to low policy enforcement, independently of population density. Furthermore, field sites in areas with high tourism intensity have been characterized with moderate or high policy enforcement. Under such conditions, local people consider agriculture as a secondary branch of their economy usually accompanied by under-exploitation of natural resources.

3.2.2 Pastures

Soil erosion in pastures has been considered as an important process of land desertification in the following study sites: Crete-Greece, Guadalentin Basin Murcia-Spain, Eskisehir Plain-Turkey, Zeuss Koutine-Tunisia, Santiago Island-Cape Verde, Mamora Sehoul-Morocco, and Cointzio Catchment-Mexico.

The factorial-principal component analysis of the indicators affecting soil erosion in pastures has grouped two main sets of indicators (Table 5). Set one of indicators was mainly related to land management, while the other set of indicators was affecting soil erosion. Old age index in relation with population growth rate has affected land use intensity and fire protection in pastures in the study field sites. Furthermore, major land use under high rain seasonality characteristics associated with high land fragmentation affected grazing control and land abandonment, therefore, soil erosion.

Table 5. Sets of indicators related to pastures identified by using factor-principal component analysis

Sets of indicators related to:	
Land management (eigenvalue = 6,22	**Soil erosion (eigenvalue = 5.81)**
Fire protection	Major land use
Land use intensity	Rain seasonality
Old age index	Land fragmentation
Population growth rate	Grazing control
	Land abandonment

The statistical analysis has also shown many interrelations among the study indicators. The most important interrelated pairs of indicators are summarized as follows:

- Rain seasonality – major land use
- Grazing control – major land use
- Land abandonment – major land use
- Grazing control – grazing intensity
- Annual rainfall – aridity index
- Annual rainfall – rain erosivity
- Rain erosivity – aridity index
- Land abandonment – rain seasonality
- Soil depth - exposure of rock outcrops
- Soil water storage capacity – soil texture
- Surface soil organic matter content – fire protection
- Surface soil organic matter content – plant cover
- Burned area – plant cover.

Major land use has been related to climate (rain seasonality) and land management characteristics. Also, strong interrelations were found among indicators related to climate such as annual rainfall, rain seasonality, rain erosivity, and aridity index. Such interrelations among climate characteristics were expected since rainfall was used to calculate aridity index and rain seasonality. Furthermore, soil characteristics such as soil depth and soil texture were related to percentage of exposure of rock outcrops, and soil water storage capacity, respectively. Soil organic matter content was greatly related to fire protection and plant cover. Such interrelations show the coherence of data collected for the various indicators related to soil erosion in pastures.

The analysis of the effectiveness of each indicator to assess the sensitivity to desertification risk has shown that the most important indicators related to land management in pastures were: grazing control, soil erosion control, and plant cover. The last two indicators are not included in the sets of indicators given in Table 5 since the loading values in those sets were low but the correlation coefficients with desertification risk were high.

Grazing control

Grazing control was considered one of the most important indicator affecting land degradation and desertification in grazing lands. The analysis of collected data have shown that grazing control in the study field sites was related to the physical environment, land management practices and socio-economic conditions (Fig. 6). Annual evapotranspiration and rain seasonality were among the most important climatic indicators. As annual evapotranspiration increased, grazing control was diminished since land productivity was reduced accompanied with lack of measures for soil erosion control. Furthermore, rain seasonality was positively related to grazing control. Under long periods of drought, grazing control was not easily achieved since the produced palatable biomass was not adequate to feed even a medium number of grazing animals.

Grazing control was also affected by the major land use and vegetation cover type in the study field sites. The obtained data showed that pastures were intensively grazing in relation to other types of major land uses such as agriculture, forests and shrublands. Grazing animals in agricultural and forested lands used to remain for a shorter period since these are areas of secondary use for animal grazing. Furthermore, in areas under natural vegetation, grazing control was more limited in annual and perennial grasslands, Mediterranean machia, and deciduous forests than in evergreen forests, mixed Mediterranean machia/evergreen forests. Furthermore, the obtained data have shown that plant cover was high in field sites where grazing control was more effective.

Among the most important soil indicators affecting grazing control were soil depth and soil texture. Grazing control in areas with shallow soils was almost absent since biomass production was highly limited to satisfy the basic needs of the grazing animals. Highly degraded areas with shallow soils were usually considered as badlands by the farmers avoiding any actions against soil erosion through grazing control. As was mentioned above, soil texture was related to soil water storage capacity. Field sites with soils of low water storage capacity or coarse-textured have low productivity and grazing control has usually been defined as absent.

Grazing control was positively related to land protection actions such as soil erosion control and fire protection. Such land protection actions were usually associated with grazing control. No actions for controlling soil erosion were defined in the majority of the study field sites, when the land was intensively grazed. Furthermore, the rate of land abandonment was negatively related to grazing control. Field sites in which the rate of abandonment was high, grazing intensity has been mainly characterized as high, further deteriorating the already degraded lands.

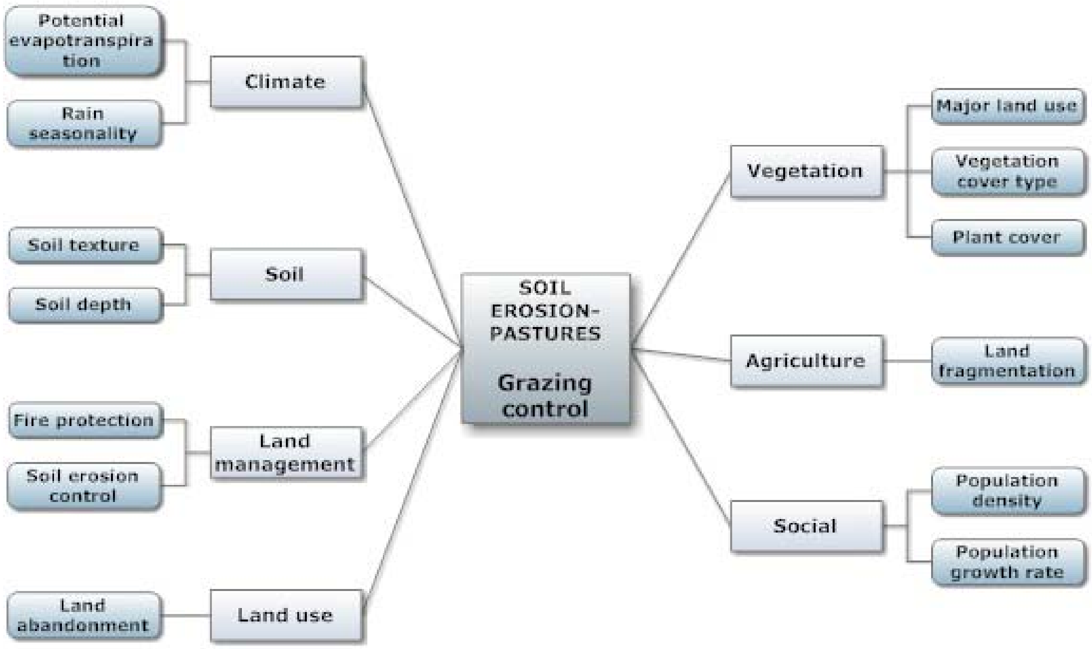

Fig. 6. Main indicators related to grazing control in pastures where the main process of land degradation was soil erosion

Concerning to agricultural indicators, grazing control was mainly related to land fragmentation. Grazing control has mainly decreased as land fragmentation increased. Farmers used to keep the animals for longer period in highly fragmented land or the available biomass for even medium number of animals was rather limited overgrazing it.

Among the social characteristics the most important indictors for the study field sites were population density and population growth rate. Grazing control was more effective in areas with low population density. On the contrary, areas with high population growth rate grazing control was mainly characterized with the actions such as sustainable number of animals or fencing grazing land and alternative grazing.

Soil erosion control

Soil erosion control measures in the study sites were mainly achieved by the following actions: increasing plant cover, grazing control, fire protection, sustainable farming, runoff water storage. Among these actions storage of surface water runoff had the highest correlation with soil erosion control (Fig. 7). The applied soil erosion control measures have better performed in evergreen forests followed with decreasing effectiveness in mixed Mediterranean machia and evergreen forests, Mediterranean machia and pine forests, permanent grassland, annual grasslands, and deciduous forests.

Among the climate indicators, the effectiveness of soil erosion control was mainly related to rain erosivity. As rain erosivity increases, soil erosion control measures have been mainly assessed as low to moderate.

Important soil indicators related to soil erosion control measures in the study field sites were soil depth, soil water storage capacity, exposure of rock outcrops, and organic matter content in the soil surface. As soil depth and soil water storage capacity increased soil erosion control measures were more widely applied in the study field sites because these areas are economically interesting for growing crops. These soil indicators are closely related to land productivity affecting soil erosion control measures. If husbandry is profitable due to high land productivity, then farmers used to invest money for land protection against soil erosion. Furthermore, as exposure of rock outcrops increased soil erosion control measures were more effective. This mainly corresponds to field sites where limestone was the soil parent material.

Limestone usually is associated with deep cracks or faults favouring deep water percolation, thus reducing surface water runoff and soil erosion rates. Finally, high amounts of organic matter content in the soil surface favours soil aggregate stability reducing soil erosion rates. Soil organic matter content was positively related to the effectiveness of soil erosion control measures in the study field sites.

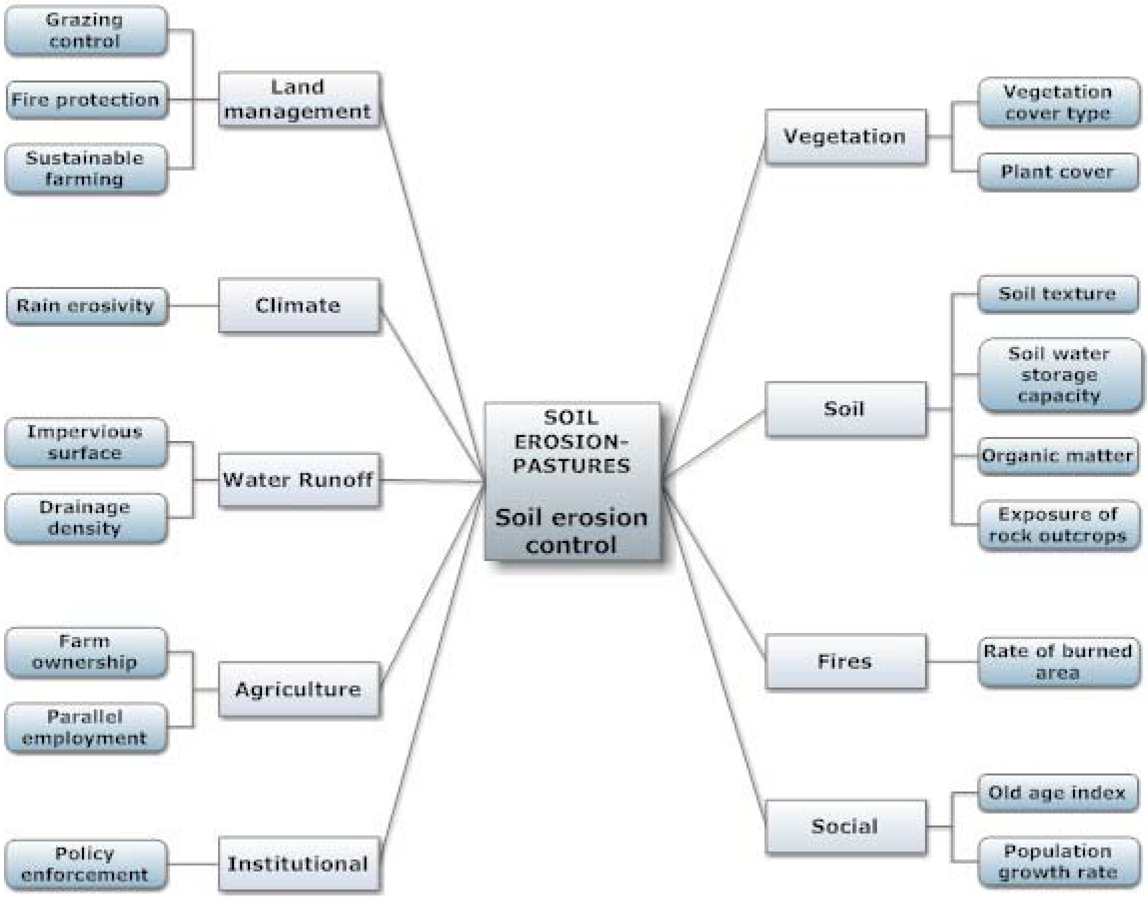

Fig. 7. Main indicators related to soil erosion control in pastures where the main process of land degradation was soil erosion

Soil erosion control was related to drainage density and impervious surface area. The obtained data showed that as drainage density and impervious surface area increased, soil erosion control measures were highly limited. This correlation is mainly attributed to the fact that such land is usually highly degraded with low productivity negatively affecting farmers for investing money in soil erosion control measures.

As it was mentioned above, fires in pastures greatly contribute to soil erosion and land degradation. The obtained data in the study field sites have shown that as rate of burned area increased, soil erosion control measures were mainly characterized as low or non existing. Generally speaking, when farmers applied measures for land protection, the occurrence of fires was rather limited.

Important indicators related to agriculture significantly affecting soil erosion control in the study field sites were farm ownership, and parallel employment. As farm ownership changed from owner- farmed to shared-farmed, state-farmed, tenant-farmed, measures for soil erosion control were diminished. Farmers keeping a grazing land under tenant-farmed conditions usually do not care about measures for land protection. Additionally, if farmers had a parallel employment in industry or in the local municipality, then no erosion or low erosion control measures have been applied in the study field sites.

The most important social indicators related to soil erosion control measures in the study field sites were old age index, and population growth rate. Soil erosion control measures were negatively related to both. These were two opposite trends related to the social characteristics of the study field sites. In one case, old aged people do not care so much for applying measures for soil erosion control, in the other case, high population growth rates lead to over-exploitation of the land. It seems that the optimal social conditions related to these indicators are somewhere in the middle, that means moderate population growth rate and old age indices.

Finally, the degree of policy enforcement of existing regulations for environmental sustainability was directly related to land protection from soil erosion.

Rate of burned area

Fires in grazing land are usually deliberately ignited by farmers to promote the growth of palatable biomass. Of course there are some factors related to the physical environment and to the socio-economic conditions favouring fires. The analysis of the collected data of the study field sites has shown that the rate of burned area (ha/10 years/10 km^2 of territorial surface) was mainly related to climate, soils, vegetation, water runoff, land management, and social characteristics (Fig. 8). Indicators related to climate such as annual rainfall, and rain seasonality greatly affected the rate of burned area in the study sites. As rainfall decreased rate of burned area increased. Low amounts of rainfall combined with high rainfall seasonality favours extensive fires in the study field sites. The study field sites which were mainly located in semi-arid climatic conditions had adequate annual biomass production derived during spring period which was getting dry during the summer period favouring fires.

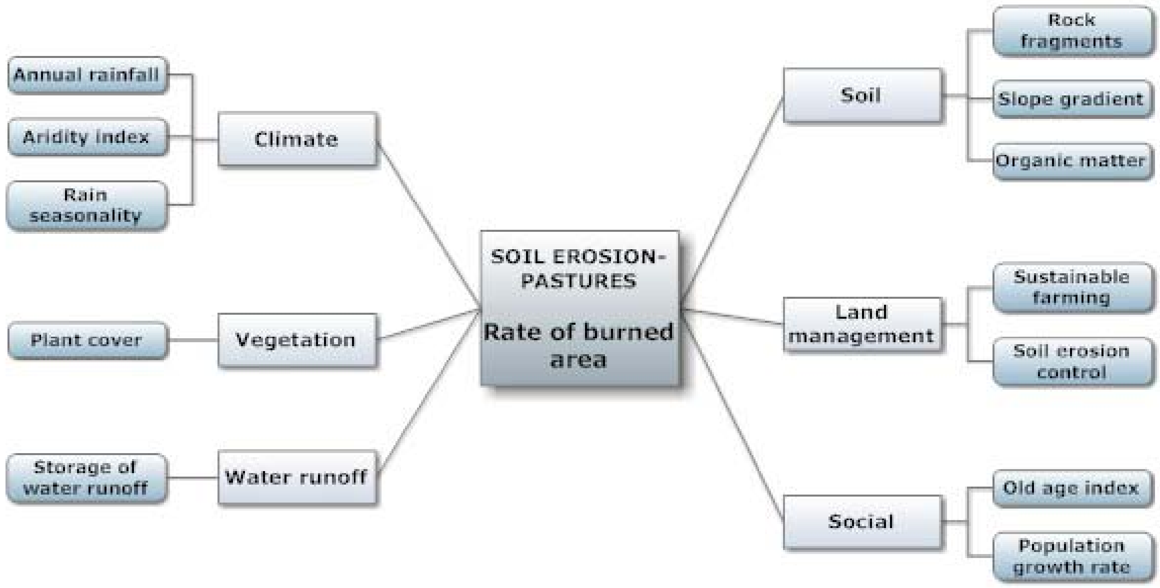

Fig. 8. Important indicators related to rate of burned area in pastures where the main process of land degradation was soil erosion

Important soil indicators related to the rate of burned area were the percentage of rock fragments on the soil surface, slope gradient, and organic matter content on the soil surface. A large amount of rock fragments on the soil surface reduces annual biomass production since soil surface is covered by stones, reducing fire risk and therefore rate of burned area. The rate of burned area increased as slope gradient increased since steep slopes favours fast expansion of a fire but only in the upslope direction. Also as organic matter content in the soil surface decreased the rate of burned area was also decreased since the amount of organic matter was usually low under limited amounts of biomass production, which favours ignition and propagation of a fire.

Plant cover was related to the biomass available for ignition and propagation of a fire. The obtained data showed that as plant cover decreased rate of burned area decreased. Plant cover was affected by various factors including climate, soil, grazing intensity, etc. Adverse soil and climatic conditions combined with high grazing intensity greatly reduced plant cover causing low rates of burned area.

Actions related to the protection of pastures from soil erosion such as sustainable farming, fire protection, soil erosion control, runoff water storage were negatively related to rate of burned area. When actions for land protection were applied in the study field sites, the local population was usually aware of the impacts of fires on soil erosion and measures were applied to protect the existing vegetation from burning. These actions of land protection were related to policy enforcement on existing regulations in the various study field sites. The obtained data showed that as policy enforcement decreased, the rate of the burned area increased.

Finally, the main social indicators affecting the rate of burned area in the study field sites were old age index and population growth rate. Areas with population of high old age index usually do not keep large numbers of animals, therefore, land was extensively grazed leaving high amounts of dry biomass in the land favouring ignition of fires. On the contrary, in areas with high population growth rate, farmers intensively grazed the land with large number of animals. In such cases farmers use to put fires for promotion of palatable grass growth for feeding the high number of animals.

3.2.3 Forests

Soil erosion in forested areas has been considered as an important process of land desertification in the following study sites: Guadalentin Basin Murcia-Spain, Eskisehir Plain-Turkey, Santiago Island-Cape Verde, Mamora Sehoul-Morocco, and Cointzio catchment-Mexico.

The principal component analysis of the indicators corresponding to forested areas in which the main process of land degradation was soil erosion have grouped into two sets of important indicators (Table 6). Set one of indicators is mainly related to soil erosion, and set two of indicators is affecting land protection with total eigenvalues of 12.5 and 8.4, respectively. Soil erosion in the study field sites was a function of the climatic conditions such as annual potential evapotranspiration and rain seasonality. These indicators were greatly affected by plant growth and plant cover in the forested areas. Drainage density was related to the type of parent materials and annual rainfall affecting soil erosion. In the case of private forested areas, soil erosion was related to land fragmentation and farm ownership. The study sites that have been characterized as forests but in parallel they were used as pastures had a great impact on soil erosion.

The other set of indicators shows that land protection is related to the vegetation cover type and soil characteristics such as soil depth and soil water storage capacity. Social and economic characteristics such as parallel employment and population density are introduced in this set of indicators as highly related to soil erosion. Important indicators related to actions for soil erosion protection are soil erosion control and soil water conservation.

The analysis of interrelations among the various indicators (covariance) has shown several pair of related indicators as follows:

- Vegetation cover type - soil erosion control
- Rain erosivity – annual rainfall

- Aridity index – annual rainfall
- Aridity index – rain erosivity
- Annual potential evapotranspiration – runoff water storage
- Land abandonment – rain seasonality
- Soil depth – percentage of rock outcrops
- Drainage density – plant cover
- Land use intensity – farm ownership
- Land fragmentation – grazing intensity
- Farm size – net farm income
- Aridity index – net farm income
- Parallel employment – soil water conservation measures
- Grazing control – rain seasonality
- Grazing control – land abandonment
- Grazing intensity – old age index.

Table 6. Sets of indicators related to soil erosion in forested areas identified by using factor-principal component analysis

No	Sets of indicators related to:	
	Soil erosion (eigenvalue = 12.5)	**Land protection (eigenvalue = 8.4)**
1	Degree of soil erosion	Vegetation cover type
2	Annual potential evapotranspiration	Soil depth
3	Rain seasonality	Soil water storage capacity
4	Drainage density	Parallel employment
5	Farm ownership	Soil erosion control
6	Land fragmentation	Soil water conservation
7	Grazing control	Population density
8	Grazing intensity	
9	Land abandonment	
10	Old age index	

Based on the methodology used to estimate some of the indicators, such interrelations are expected, but this also can be considered as a confirmation of the accuracy of the collected data in the various study field sites in forested areas. Such interrelations have been considered in the analysis of assessing desertification risk. There were interrelations among climatic indicators such as rainfall, aridity index, rain erosivity, potential evapotranspiration and net farm income, grazing control, rate of land abandonment, runoff water storage. Furthermore, grazing control or grazing intensity with land abandonment, old age index, and land fragmentation. Also, interrelations were found between land use intensity and farm ownership. Finally, a percentage of rock outcrops was clearly related to soil depth.

The analysis of the effectiveness of each indicator for assessing desertification risk has shown that the most important indicators related to land management and affecting soil erosion and desertification risk in forested areas are: grazing intensity, runoff water storage, and policy enforcement.

Grazing intensity

Grazing intensity is a very important factor affecting soil erosion and desertification in forested areas. The analysis of variance have shown that important indicators affecting grazing intensity in the study field sites are related to climate, soil, forest fires, land use, land management, agriculture, water runoff, institutional and social characteristics (Fig. 9). As annual rainfall decreased grazing intensity mainly decreased in forested areas since the understory vegetation grazed by the animals was highly restricted. This is further explained by the annual potential evapotranspiration. Grazing intensity has been mainly characterized as low in areas with high annual potential evapotranspiration. Furthermore, under high rainfall seasonality index, grazing intensity has been also defined as high.

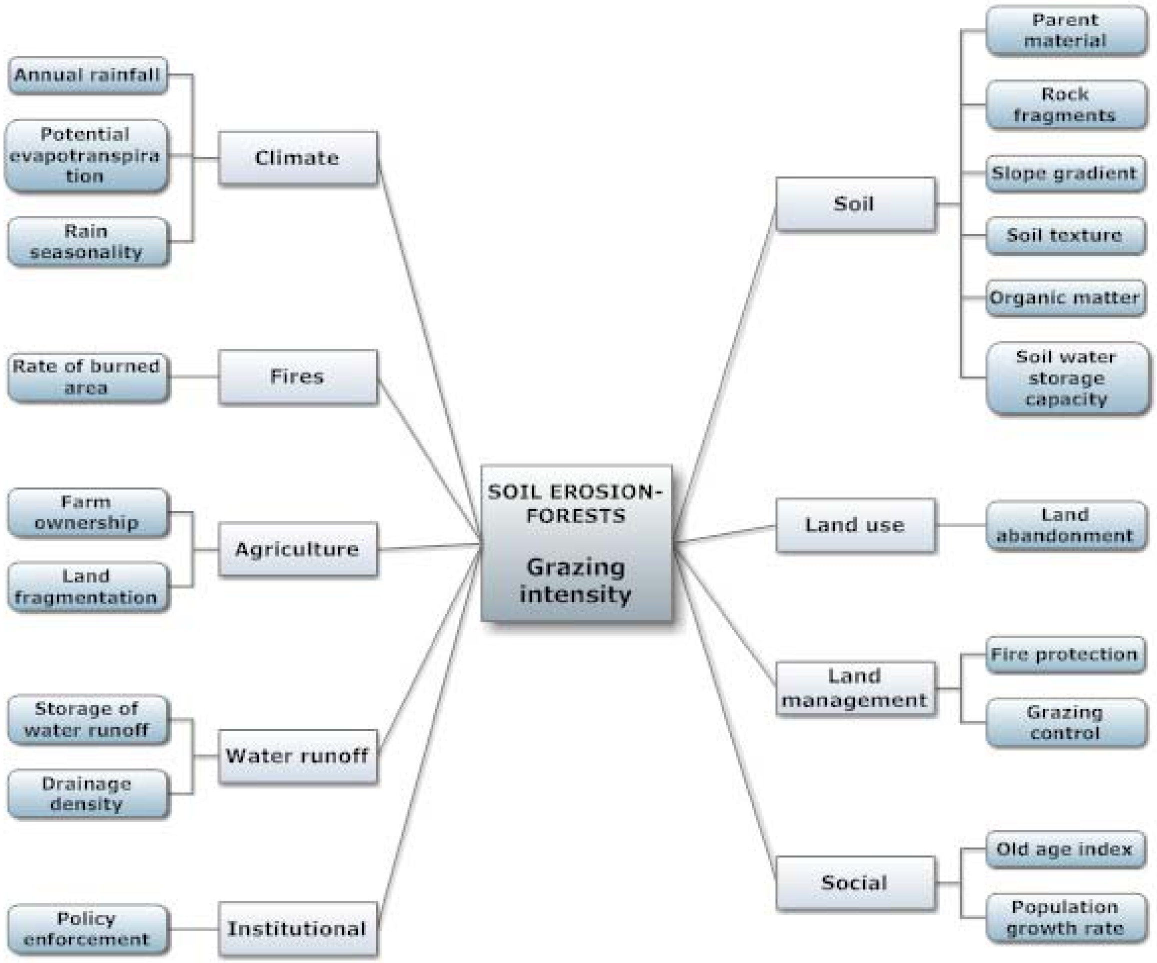

Fig 9. Important indicators related to grazing intensity in the study field sites of forested areas where the main process of land degradation was soil erosion

Important soil indicators related to grazing intensity were parent material, percentage of rock fragments in the soil surface, slope gradient, soil texture, organic matter in the surface horizon, and soil water storage capacity. Grazing intensity has been characterized as moderate to high in soils formed in conglomerates, shale, and basic igneous rocks. Soils formed in such soil parent materials were usually more productive than soils formed in limestone and acid igneous rocks. Soils formed on limestone and acid igneous rocks were usually dry for long period or highly degraded with low biomass production resulting in low grazing intensity. Also, high grazing intensity has been identified in field sites in which soils had low amount of rock fragments in the soil surface. Rock fragments in the soil reduce effective soil depth and probably biomass production. Both indicators of parent material and rock fragments under conditions of low biomass production have been accompanied with low grazing intensity in the study field sites. Furthermore, grazing intensity has been mainly defined as low in field sites with steep slope gradients. Soil indicators affecting water availability to growing plants such as soil textures and soil water storage capacity were related to grazing intensity. Field sites with coarse-textured soils of low water storage capacity have been subjected to high grazing intensity since the produced palatable biomass was rather limited. Finally, high grazing intensities have been defined in areas with soils of low organic matter content since high soil erosion rates are expected in such cases. Of course, soil organic matter content can been affected by other factors such as climate, type of vegetation, other soil characteristics, etc.

Field sites located in areas with high drainage density have been subjected to low grazing intensity. Such land management can be attributed to various factors such as type of parent material (biomass production), degree of soil erosion, accessibility by animals, etc.

Field sites located in areas of high burned rates have been subjected to low grazing intensity. This can be attributed to the existing regulations of land management of forested areas after fire or to the willingness of local people to protect fire affected areas for recovering.

Agriculture indicators such as farm ownership and land fragmentation have affected grazing intensity in forested areas. Field sites characterized as state- and tenant-farms have been subjected to high grazing intensity. On the contrary, field sites characterized as owner- or shared-farms have been better managed subjected to medium or low grazing intensity. Land fragmentation has negatively affected grazing intensity. Field sites in areas with high land fragmentation have been mainly characterized as subjected to medium or low grazing intensity.

An important indicator related to land use characteristics was land abandonment. Field sites located in areas with low rate of land abandonment have been mainly subjected to high grazing intensity since animals have to remain for longer periods in certain regions including abandoned land.

Social characteristics such as old age index, and population growth rate have identified as important indicators affecting grazing intensity. Field sites in areas with low age indices and population growth rates have been mainly characterized as subjected to high grazing intensity. Such social conditions favour the establishment of professional farms with large numbers of animals overgrazing the land. Population density can be a better indicator affecting grazing intensity, but the analysis of the existing data did not show good relationship.

Policy enforcement of existing regulations for environmental sustainability of forested areas were associated with actions such as fire protection, grazing control, storage of water runoff. Areas with field sites where actions for natural resources protection sustainability have been applied such as grazing control, or storage of water runoff, grazing intensity has been mainly characterized as low or medium.

Runoff water storage

Runoff water storage has been mainly related to actions such as adequate shrubby or annual vegetation cover, construction of terraces, concentrating the runoff water in small ponds and retarding runoff, keeping plant residues on the soil surface. Runoff water storage has been related to various indicators related to climate, soil, vegetation, land use, runoff water, land management, social and institutional characteristics of study field sites located in forested areas (Fig. 10). Adequate actions of runoff water storage have been mainly described in areas covered with evergreen forests, mixed Mediterranean machia and evergreen forest, Mediterranean machia, and pine forests.

Among the indicators related to climate, annual potential evapotranspiration and rain seasonality have mainly related to runoff water storage. Field sites located in areas with low or moderate rates of evapotranspiration with moderate to high rain seasonality have been characterized as subjected to moderate or adequate runoff water storage actions.

Soil indicators such as parent material, slope aspect and gradient, soil texture, and organic matter in the soil surface have been significantly related to runoff water storage actions. Storage of water runoff has been mainly identified in field sites in which soils have been formed on marl, basic igneous, shale, and alluvial deposits. Soils formed in such parent material are usually more productive compared to the soils formed on limestone, acid igneous rocks, and sandstone. Runoff water storage actions have been mainly described in field sites located in north-facing slightly to moderately sloping areas. Steep south-facing slopes have been mainly characterized by the absence of runoff water storage actions. Furthermore, runoff water storage actions have been more often described in coarse- to medium-textured soils than in fine- to very fine-textured soils. Finally, field sites located in soils with low organic matter content have been characterized as subjected to low runoff water storage actions.

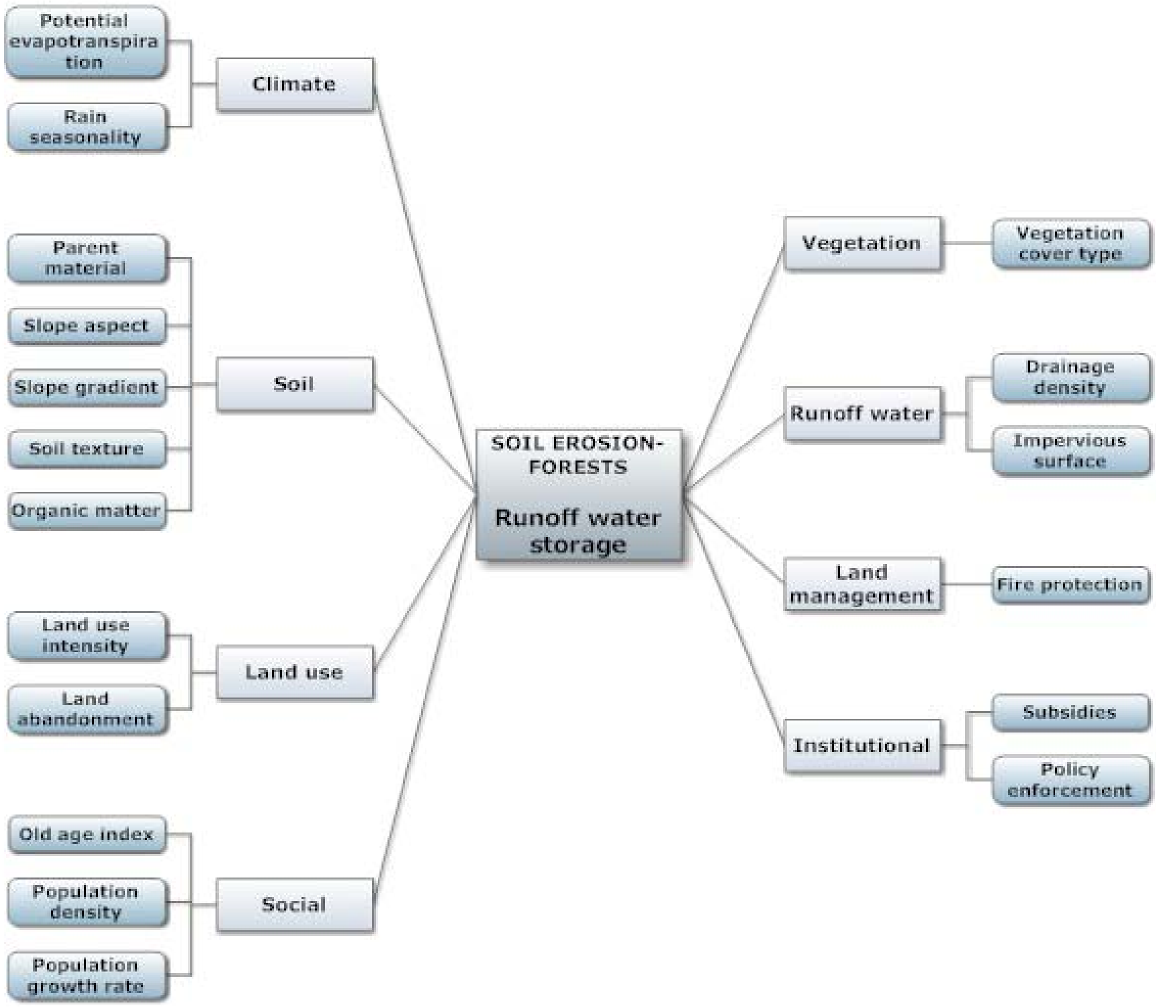

Fig 10. Important indicators related to runoff water storage in the study field sites of forested areas where soil erosion was the main process of desertification

Drainage density and impervious surface have been related to runoff water storage actions. In filed sites located in areas with fine or very fine drainage density, runoff water storage actions were rather limited. Field sites with coarse to medium drainage density have been usually characterized by moderate to adequate runoff water storage actions. Furthermore, runoff water storage actions were more identified in field sites located in areas with low rates of impervious surfaces expansion.

Runoff water storage actions have been usually identified in areas under adequate forest fire protection measures. Also, such actions have been defined in field sites subjected to low land use intensity. Furthermore, runoff water storage actions have been found in areas with low rates of land abandonment. Of course storage of water runoff was considered as an action for environmental sustainability included in corresponding regulations. Policy enforcement and runoff water storage were positively related. In case that subsidies have been allocated on the basis of number of animals, runoff water storage actions were mainly absent in the study field sites.

Important indicators related to social characteristics and affecting runoff water storage were old age index, population density, and population growth rate. Field sites located in areas with high old age indices, low population densities, or high population growth rates have been mainly characterized by the absence of runoff water storage actions.

Policy enforcement

Policy enforcement or following existing policies for environmental protection has been affected in the study field sites in forested areas by various indicators related to physical environment, land management, and social characteristics (Fig. 11). The most important indicators related to climate and affecting policy enforcement were annual potential evapotranspiration, rain seasonality, and rain erosivity. Policy enforcement has been mainly characterized as moderate to low in field sites located in areas of high annual evapotranspiration, accompanied with low rain seasonality. Furthermore, policy enforcement was mainly assessed as low in field sites located in areas of low rain erosivity.

Vegetation cover type has also affected policy enforcement. Field sites with vegetation cover type evergreen forests, mixed Mediterranean machia and evergreen forests or Mediterranean machia have been better protected in relation to field sites with annual grasses and deciduous forests.

Indicators related to soil characteristics such as parent material, slope aspect and gradient, and soil texture have affected policy enforcement. Filed sites in which the soils have been formed in limestone, acid igneous rocks, and sandstone have been less protected than areas with soils formed in marl, basic igneous, shale, schist, and alluvial deposits. This can be attributed to the land productivity which is generally higher in the last types of parent materials. Furthermore, policy enforcement has been mainly characterized as low to moderate in field sites located in steep south-facing slopes. Such field sites have generally low land productivity, discouraging farmers to invest for environmental protection. In addition, policy enforcement has been characterized as medium to low in field sites with fine to moderately fine-textured soils.

Important indicators related to water runoff and affecting policy enforcement were drainage density and impervious surface area. As drainage density and impervious surface area increased, policy enforcement has been mainly characterized as low to moderate in the study field sites.

Policy enforcement has been mainly performed in forested areas by the actions of grazing control, fire protection, and storage of water runoff. Areas in which land use intensity has been characterized as high, policy enforcement was mainly assessed al low to moderate.

Important social indicators affecting police enforcement in the study field sites were old age index, population density, and population growth rate. In areas with high old age index, low population density, and high population growth rate, policy enforcement was mainly characterized as low. Since the social characteristics used here cover broad areas and the urban/rural distribution of the local population is not clear, the conclusions on how such indicators are affecting policy enforcement for environmental sustainability are not satisfactory. Finally, where subsidies have been allocated, policy enforcement was negatively affected.

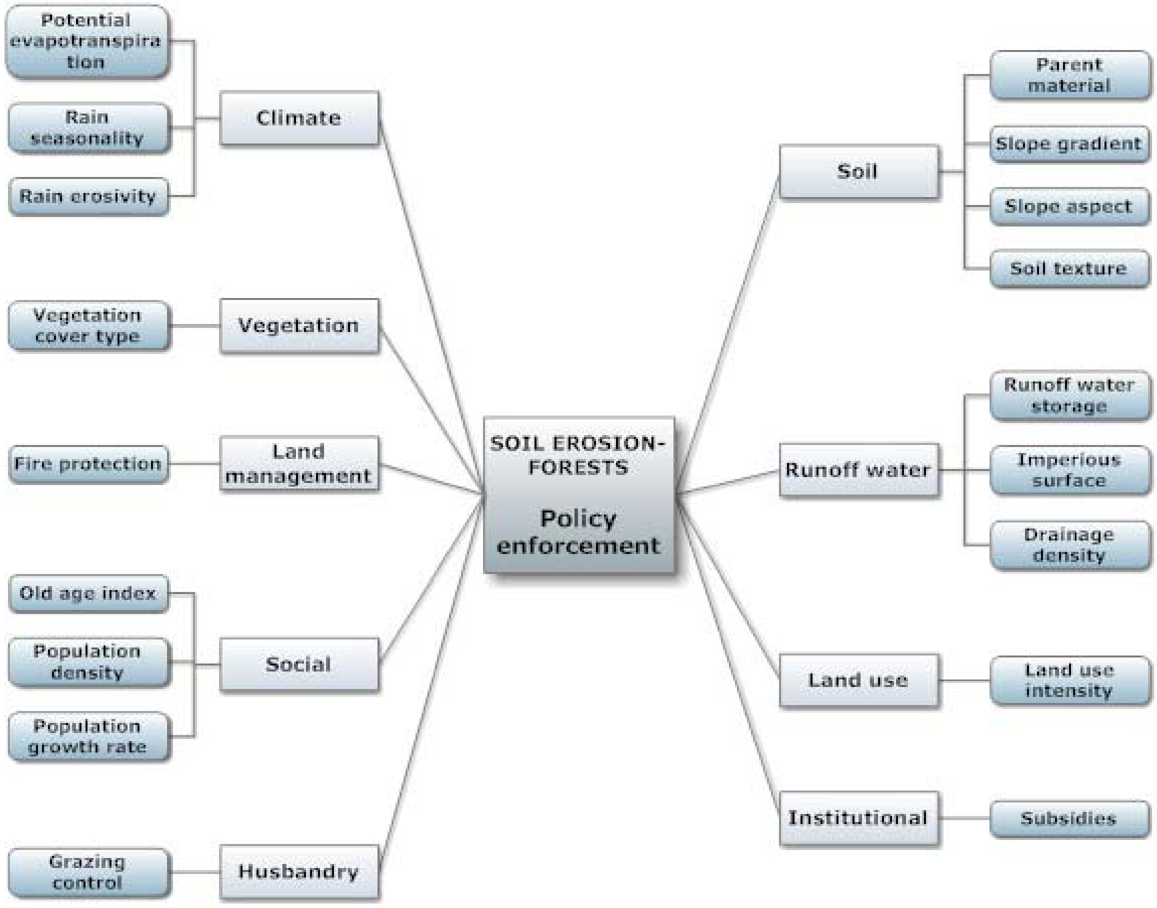

Fig 11. Important indicators related to policy enforcement in the study field sites of forested areas where the main process of land degradation was soil erosion

3.2 Soil salinization

Soil salinization has been considered as an important process of land desertification in the following six study sites: Nestos Basin Maggana-Greece, Crete-Greece, Novij Saratov-Russia, Djanybek-Russia, Zeuss Koutine-Tunisia, and Boteti Area-Botswana. Soil salinization has mainly affected plain areas intensively cultivated mainly with annual crops.

The factorial-principal component analysis of the indicators described in previous study sites has shown two important sets of indicators affecting soil salinization (Table 7). Set 1 of indicators includes indicators mainly related to land characteristics affecting soil salinization. High air temperature combined with high annual potential evapotranspiration rates induces capillary movement of the soil water with obvious effects concentration of salts on the soil surface. The degree of groundwater exploitation was related to the agricultural irrigation needs and urban water demands in the study site. Groundwater overexploitation contributed to extended soil salinization processes by generating brackish water intrusion in the aquifers in coastal areas with negative effects to the groundwater quality. The process of soil salinization was mainly identified in soils formed on alluvial deposits since they are associated with the presence of groundwater in shallow depths. Farm ownership has been considered crucial as far as water exploitation is concerned, while irrigation percentage of arable land has defined the extent in which water resources were used. The distance from the seashore has been identified as a crucial indicator affecting soil salinization. Areas in proximity to the coastline with poorly drained soils were subjected to high salinization and desertification risk. Finally, plain areas with high flooding frequency were more vulnerable to soil salinization.

The other set of indicators is mainly related to the water availability. The indicators water quality and population density were clearly affected by water availability in the study field sites. Obviously under high population density, water demands are high in a specific area leading to overexploitation of natural resources and affecting water quality.

Table 7. Sets of indicators related to soil salinization in the study field sites identified by using factor-principal component analysis

No	Sets of indicators related to:	
	Natural environment (eigenvalue = 10.63)	**Water availability (eigenvalue = 3.70)**
1	Potential evapotranspiration	Population density
2	Air temperature	Water quality
3	Parent material	
4	Farm ownership	
5	Irrigation percentage of arable land	
6	Distance from seashore	
7	Groundwater exploitation	
8	Flooding frequency	

The analysis of covariance among the indicators affecting soil salinization has shown some interrelations. The most important interrelated pairs of indicators based on multiple linear regression analysis are the following:

- Groundwater exploitation – annual air temperature
- Annual air temperature – irrigation percentage of arable land
- Distance from the seashore – flooding frequency
- Irrigation percentage of arable land – Farm ownership
- Irrigation percentage of arable land – Ground water exploitation

The above analysis showed that annual air temperature was an important climate indicator interrelated with groundwater exploitation and irrigation percentage of arable land. Also, irrigation percentage of arable land was interrelated with ground water exploitation and farm ownership. As it is expected flooding frequency has been related to the distance from the seashore. There were some other interrelated pairs of indicators such as aridity index – policy enforcement, farm ownership – irrigation percentage of arable land which were rather arbitrary not considered.

The analysis of the effectiveness of the various indicators for assessing desertification risk has shown water scarcity and water quality had the highest contribution. Of course both indicators are regional in which site specific indicators have minor importance in the description of these two indicators.

Water scarcity

Water scarcity has been defined in this study as the ratio of the available water supply per capita /water consumption per capita during the last 10 years. Water scarcity has been related to climate, water, water runoff, and tourism characteristics of the study sites (Fig. 12). Among the most important climate indicators affecting water scarcity were annual rainfall, aridity index, annual potential evapotranspiration and rain seasonality. Areas with high amounts of annual rainfall have been mainly characterized as subjected to low water scarcity, low salinization and desertification risk. On the contrary, in field sites located in areas with high aridity indices accompanied with high evapotranspiration rates and long rain seasonality, water scarcity has been mainly characterized as high with subsequent high effects on soil salinization risk.

Important water indicators affecting water scarcity in the study field sites were water quality, water quantity, water consumption/water demands. Field sites located in areas characterized by low quantities of available water, accompanied by low water quality, have been subjected to high water scarcity and high soil salinization risk. Water scarcity has been aggravated in areas where the ratio of water consumption/water demands was high. Finally, field sites located in areas associated with high drainage density have been mainly characterized by high water scarcity.

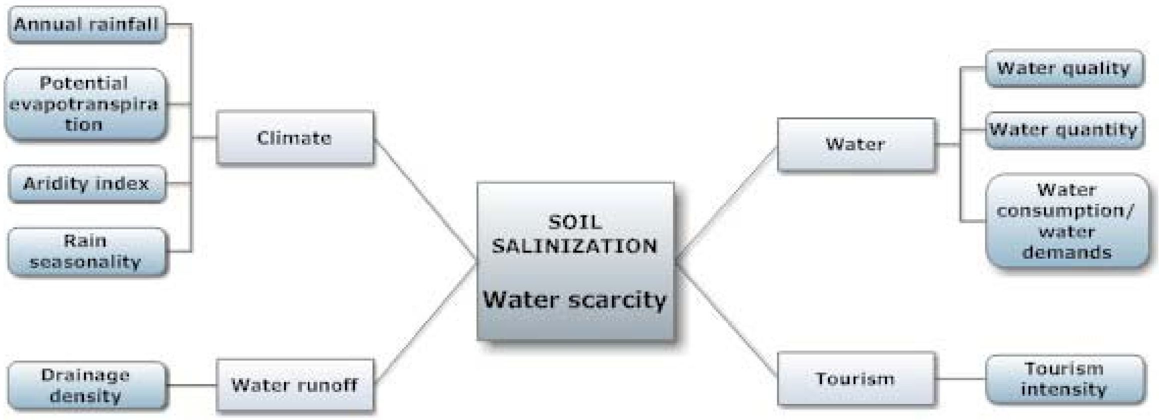

Fig 12. Important indicators related to water scarcity in the study field sites where important process of land desertification was soil salinization

The analysis of the data has shown that tourism intensity has positively affected water scarcity in the study field sites. Areas with high tourism intensities require high quantities of water per capita inducing water scarcity in the broad area. Under such conditions, water is allocated for consumption accompanied with low priority for the amount and the quality of water allocated for irrigation, enhancing problems of soil salinization in irrigated land.

<u>Water quality</u>

Water quality and water scarcity are usually two co-existing indicators highly affecting soil salinization. The analysis of the data collected in the study field sites have shown that water quality has been affected by indicators related to climate, soil, vegetation, water, water use, tourism, institutional, and social characteristics (Fig 13). The most important climate indicators affecting water quality were annual rainfall, aridity index, and rain seasonality. Water quality was positively related to annual rainfall. Areas with high annual rainfall had good quality of ground water. Water quality was negatively related with aridity index. This was something exceptional, but it can be probably explained if other social and land management characteristics of the study sites are considered. Water quality was negatively related to rain seasonality. Field sites located in areas with high rain seasonality had mainly poor quality of water.

Important indicators related to water and water use affecting water quality in the study field sites were water quantity, water consumption/water demands, and water scarcity. Field sites located in areas with low quantities of available water resources had generally poor quality of water. In addition, areas with high ratio of water consumption/water demands had low quality of water. Furthermore, field sites located in areas of high water scarcity had generally moderate to poor water quality. Of course, under the conditions of policy enforcement of existing regulations on water resources protection, water quality was mainly characterized as moderate to high.

Even though soil indicators are of local importance, as they characterize mainly the study field sites, the analysis of the data have shown that areas with medium to moderately fine-textured soils of high water storage capacity had high water quality.

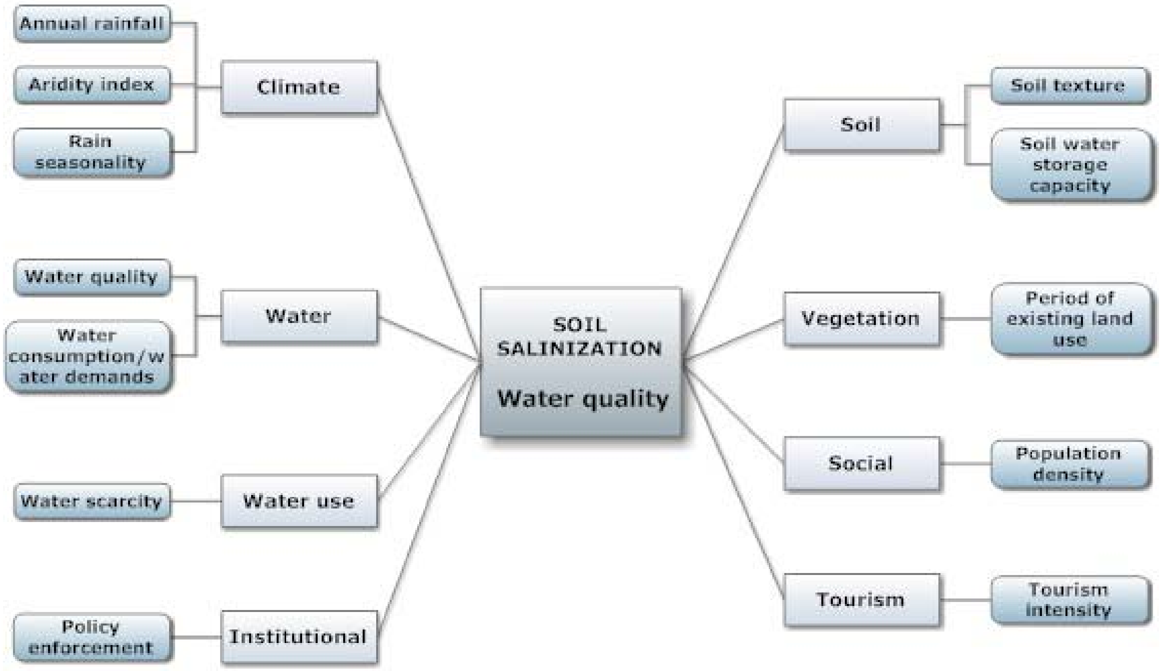

Fig 13. Important indicators related to water quality in field sites where soil salinization was a dominant process of land desertification

Concerning vegetation characteristics, only the period of existing land use was related to water quality. Areas in which land use has changed frequently were mainly characterized by poor quality of water. This can be explained in relation to land use intensity. Land use change occurs frequently in areas intensively cultivated which means high amounts of water are used for irrigation aggravating water quality.

Water quality was significantly related to tourism intensity and population density of the broader areas in which the study field sites are located. Areas with high population density or high tourism intensity had good to moderate quality of water. This can be explained for the study field sites by various factors such as: (a) presence of rivers carrying high quantities of good quality water accompanied with adequate enrichment of ground water, (b) expansion of necessary infrastructure for providing adequate quantities of good quality of remote water to satisfy the needs of local population including tourists during the summer period.

3.3 Water stress

Water stress has been identified as an important process of land degradation and desertification in the following four study sites: Crete-Greece, Novij Saratov-Russia, Djanybek-Russia, and Boteti Area-Botswana.

The factorial-principal component analysis has shown two important sets of indicators affecting water stress (Table 8). Set 1 of indicators was mainly related to water availability in the study sites. These indicators are related to the physical environment, land management, and social and economic characteristics. Aridity index and rain seasonality clearly affects the water availability for plant growth. The degree of groundwater exploitation was related to the water resources available in the study sites. Also, slope gradient and drainage density are considered as important factors affecting surface water runoff and therefore rain water storage into the soil. Sealing of soil surface greatly contributed to decrease in ground water recharge and flooding in the low land. Fire frequency and soil erosion control measures greatly contributed to soil water storage. Extended forest fires have caused severe degradation of natural resources in the last decades. On the contrary, soil erosion control measures have greatly contributed to soil water storage. Land abandonment can have positive or negative impacts on conservation of natural resources depending on the physical environmental conditions at the time of abandonment and the land management characteristics after abandonment. Policy enforcement of existing regulations were closely related to measures for combating lack of water and desertification. Finally, social and economical characteristics such as tourism change, population growth rate, and subsidies can indirectly affect water stress in the growing plants. The expansion of tourism accompanied by high population growth rate especially in areas along the costal areas has aggravated the rate of water availability for the growing plants. Also, subsidies have contributed to the expansion of agriculture in marginal areas causing severe problems of soil erosion and water availability.

Table 8. Sets of indicators related to water stress in the study field sites identified by using factor-principal component analysis

No	Sets of indicators related to:	
	Water availability (eigenvalue =16.35)	**water consumption (eigenvalue = 7.67)**
1	Aridity index	Water quality
2	Rain seasonality	Water consumption per sector
3	Groundwater exploitation	Water scarcity
4	Slope gradient	Human poverty index
5	Deforested area	Population density
6	Drainage density	
7	Impervious surface	
8	Fire frequency	
9	Soil erosion control	
10	Land abandonment	
11	Tourism change	
12	Population growth rate	
13	Subsidies	
14	Policy enforcement	

The other set of indicators was mainly related to water consumption. The indicators water quality, water consumption per sector, and water scarcity are clearly related to water availability in the study field sites. Poor quality of water accompanied by high water consumption in other sectors except agriculture were responsible for high water scarcity in the study areas characterized mainly by arid or semi-arid climatic conditions. Lack of sufficient water supply accompanied by high population density were characterized as the basic determinants for high human poverty indices.

The analysis of covariance of the indicators described for water stress has shown several interrelations among them. The most important interrelated pairs of indicators based on multiple linear regression analysis were the following:

- Annual air temperature – land abandonment
- Annual air temperature – water consumption per sector

- Annual air temperature – human poverty index
- Rain seasonality – aridity index
- Rain seasonality – drainage density
- Rain seasonality – water consumption per sector
- Rain seasonality – deforested area
- Rain seasonality – fire frequency
- Rain seasonality – fire protection
- Rain seasonality – land abandonment
- Water quality – water scarcity
- Ground water exploitation – rain seasonality
- Ground water exploitation – fire protection
- Ground water exploitation – tourism change
- Slope gradient – human poverty index
- Deforested area – human poverty index
- Deforested area – subsidies
- Fire frequency – population growth rate
- Fire frequency – tourism change.

The analysis shows that annual air temperature and rain seasonality are important climate indicators interrelated with many others affecting water stress such as water consumption, human poverty index, rate of deforested area, fire frequency and fire protection, groundwater exploitation. Also, ground water exploitation is interrelated with tourism change and rain seasonality. Fire frequency has been related to the tourism change and population growth rate in the study field sites. As it is expected deforested area was related to human poverty index and to the allocated subsidies.

The analysis of the effectiveness of each indicator for assessing desertification risk have shown that the most important indicators related to land management and affecting desertification due to water stress were plant cover, and land use intensity.

Plant cover

Plant cover greatly affects surface water runoff and soil temperature and, therefore, the extent of water stress and desertification risk. The analysis of the obtained data have shown that plant cover was greatly affected by various indicators related to climate, soil, vegetation, land management, husbandry, water use, institutional, and social characteristics (Fig. 14). The most important indicators related to climate were annual air temperature, annual rainfall, and rain seasonality. High annual air temperatures had promoted low plant cover in the study field sites due to high evapotranspiration demands. Furthermore, high amounts of annual rainfall have positively affected plant cover. On the contrary, high rain seasonality indices have mainly caused low plant cover percentages in the study field sites.

The most important soil indicators identified in the study field sites affecting plant cover and desertification risk were soil depth, soil texture and exposure of rock outcrops. Soil depth and soil texture greatly affects soil water storage capacity and therefore plant growth and plant cover under semi-arid or arid climatic conditions as those prevailing in the study field sites. Shallow soils combined with coarse-textural classes have low water storage capacity and plant cover was usually lower than 60% in the study field sites. On the contrary, deep medium to moderately fine-textured soils were characterized with high water storage capacity favouring high plant cover and lower water stress and desertification risk. Also, the percentage of rock outcrops affected soil water storage capacity, resulting in low plant cover, high water stress and land desertification risk. Deforestation rates in the broader area of the study field sites have affected water cycle and plant cover. Areas with high rates of deforestation have been accompanied by moderate to low plant cover.

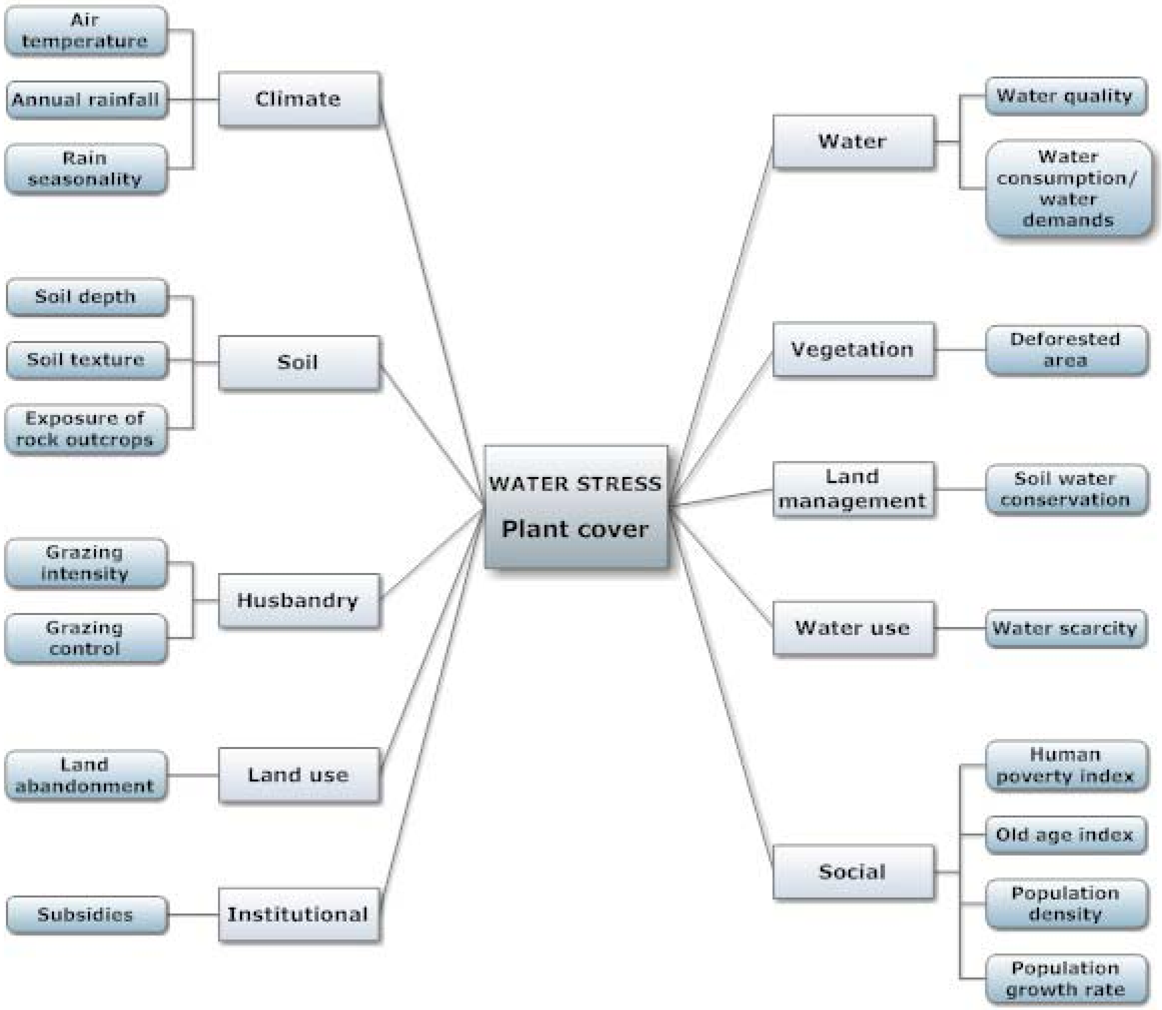

Fig 14. Important indicators related to plant cover in field sites where water stress was the dominant process of land desertification

Field sites which were subjected to high water stress were usually used as pastures, therefore, the indicators grazing control or grazing intensity have greatly affected plant cover and desertification risk due to water stress. Field sites in which grazing intensity was moderate or low accompanied with grazing control such as fencing or sustainable number of animals has been characterized by relatively adequate plant cover, low rates of water runoff, low water stress and desertification risk. High grazing intensities accompanied without any grazing control measures have resulted in low plant cover, high rates of water runoff, and high desertification risk due to water stress.

Soil water conservation measures can greatly affect plant cover. Actions such as temporary storage of water runoff, weed control, mulching have contributed in percentage plant cover, reducing of desertification risk in the study field sites. Land abandonment positively influenced plant cover in the study field sites. Areas in which land has been abandoned with moderate or high rates had mainly adequate plant cover due to partial recovery of natural vegetation.

Important indicators related to water stress affecting plant cover in the study field sites were water quality, water consumption, and water scarcity. Water resources in the study sites of good quality have contributed to more effective use in supporting vegetation growth and promoting higher plant cover percentages. Water consumption per sector with higher amounts distributed with absolute priority for tourism or domestic consumption removing water used for irrigation has been identified as an important cause for plant growth and plant cover decrease in the study field sites. Of course field sites located in areas characterized by high water scarcity had negatively affected plant cover due to high water stress.

Important indicators related to social and institutional characteristics of the study field sites affecting water stress and desertification were human poverty index, old age index, population density, population growth rate, and subsidies. Field sites in areas with low plant cover have been characterized mainly with moderate or high poverty index. Plant cover was related to vegetation growth and generally to land productivity and farmer's income. Furthermore, old age index was negatively related to plant cover. Field sites in areas with high old age indices have been mainly identified as supporting adequate plant cover subjected to lower desertification risk. On the contrary, field sites located in areas with high population density have supported low plant cover due to overexploitation of natural resources promoting high desertification risk. Similarly, field sites in areas characterized by high population growth rates have been characterized as supporting low vegetation cover. Finally, the presence of subsidies, allocated especially for animals have promoted areas with low plant cover accompanied by high desertification risk.

Land use intensity

Land use intensity affects water stress and desertification risk through a series of actions related to overexploitation of natural resources. Land use intensity was associated with several indicators in the study field sites related to the physical environment, land management, and social and economic characteristics (Fig 15). Among the climate indicators, rain seasonality and aridity index have been identified in the study field sites. In areas with high aridity indices and high rain seasonality, land use intensity was mainly characterized as moderate or low. Under adverse climatic conditions in which water stress was the main limitation factor, land productivity was low discouraging farmers to cultivate intensively the land, partially reducing desertification risk.

Water quantity and water quality are positively related to land use intensity. Filed sites in areas of limited amounts of water resources or poor quality of water have been mainly associated with low or moderate land use intensity. The availability of water in arid or semi-arid climatic conditions greatly affects crop production and therefore land use intensity and desertification risk. Furthermore, irrigation percentage of arable land was related to land use intensity. Field sites located in areas with high irrigation percentage of arable land were mainly associated with high land use intensity.

Among the soil indicators, slope gradient has been highly related to land use. Soils in steep slopes were usually less intensively cultivated due to some limitations in mechanization and higher water stress. Furthermore, land use intensity was related to vegetation cover type. Field sites with cereals, vegetables, or annual grasslands have been mainly characterized by high land use intensity. Also field sites located in areas with high rates of deforestation have been usually subjected to high land use intensity.

Important indicators related to water runoff affecting land use intensity were the drainage density, rate of expansion of impervious surface area, and storage of water runoff. Field sites located in areas with high drainage density have been mainly characterized as intensively used for crop production or for grazing. Drainage density can be considered that indirectly affects land use intensity. Drainage density is related to parent materials in which soils have been formed. For example soils formed in shale parent material have been usually characterized by high drainage density, high productivity stimulating farmers for intensively use. Furthermore, high rates of expansion of impervious surface area in the study areas were associated with low land use intensity. Land use intensity was negatively related to the storage of water runoff.

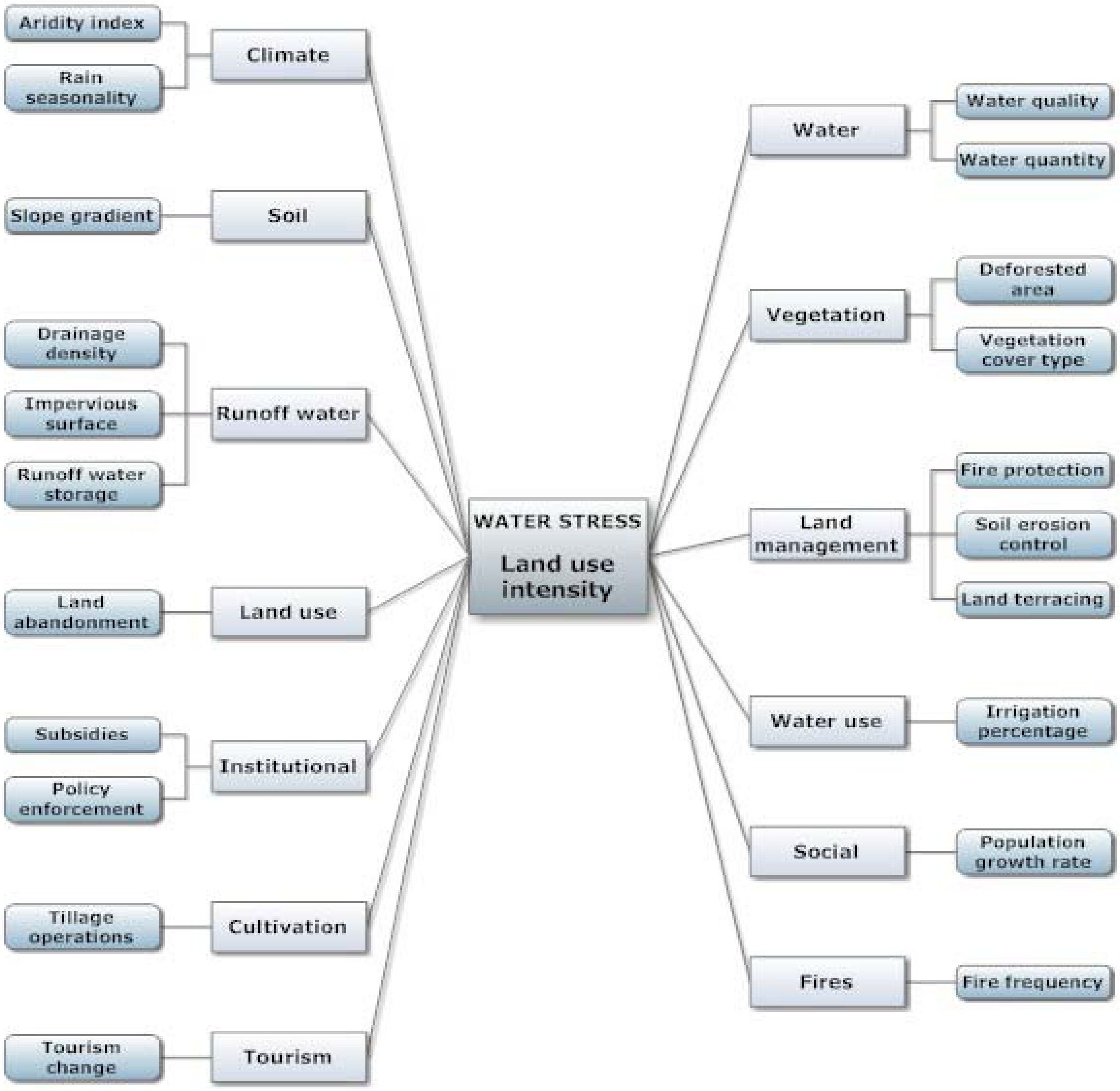

Fig 15. Important indicators related to land use intensity in field sites where water stress was a dominant process of land desertification

Field sites located in areas subjected to high frequency of fires accompanied by low measures of fire protection have been mainly characterized by moderate or high land use intensity. Forest fires are usually associated with an expansion of agriculture in physical areas or elimination of perennial vegetation for allowing palatable grass to be grown for the animals where land is then intensively cultivated or overgrazed.

Tillage operations are clearly related to land use intensity in agricultural areas. Field sites especially in areas cultivated by vines, olives or grass in pastures have been subjected to high land use intensity aggravating soil erosion, water stress and desertification risk.

The most important land management indicators related to land use intensity in the study field sites were soil erosion control, land terracing, runoff water storage, and land abandonment. Field sites located in areas with low measures of soil erosion control, low percentage of terracing, and low actions for storage of runoff water were mainly subjected to high land use intensity. Furthermore, field sites in areas with high rates of land abandonment were mainly characterized by high land use intensity. Such areas are usually used as pastures which are mainly overgrazed, or since the arable land is limited, farmers cultivate it intensively for partial compensation of the missing production due to land abandonment. Policy enforcement which is related with the above actions for environmental protection was negatively related to land use intensity. Field sites in which policy enforcement was characterized as moderate to low have been intensively used as agriculture or pasture land.

Finally, the most important indicators related to social and institutional characteristics of the study field sites were tourism change, population growth rate, and subsidies. Field sites in areas with high rate of tourism change have been characterized by low land use intensity since local population was mainly concerned for tourism which was more profitable than agriculture. Furthermore, field sites in areas with high population growth rates have been characterized by low land use intensity. This trend needs further analysis since other factors may be associated with land use intensity. Also land use intensity has been negatively related to subsidies. This can be true for areas of low productivity in which land is partially cultivated just to meet the requirements for subsidies allocation.

3.4 Overgrazing

Overgrazing has been characterized as an important process of land degradation and desertification in the following three study sites: Konya Karapinar Turkey, Boteti Area-Botswana, and Djanybek-Russia.

The factorial-principal component analysis has shown two sets of important indicators related to overgrazing and land desertification (Table 9). Set 1 of indicators includes mainly indicators related to soil erosion. Overgrazed areas under high potential evapotranspiration rates accompanied by high rain erosivity become vulnerable to soil erosion and desertification. High rates of deforestation were usually accompanied by high fire frequency followed by high grazing intensity. Overgrazed areas usually consisted of machia vegetation characterized by high fire risk. Under low fire protection measures such areas are very sensitive to desertification. Furthermore, if grazing land was rented or shared by the farmer then land protection measures such as soil water conservation, storage of water runoff were usually absent. Finally, areas which has been converted to pastures on a short period were usually undergoing high grazing intensity favouring high soil erosion rates.

Table 9. Sets of indicators related to overgrazing in the study field sites identified by using factor-principal component analysis

No	Sets of indicators related to:	
	soil erosion (eigenvalue = 11.72)	**land management (eigenvalue = 7.05)**
1	Annual potential evapotranspiration	Soil drainage
2	Rain erosivity	Land fragmentation
3	Deforested area	Land abandonment
4	Fire frequency	Policy enforcement
5	Fire risk	
6	Grazing intensity	
7	Farm ownership	
8	Fire protection	
9	Soil water conservation	
10	Period of existing land use	
11	Runoff water storage	
12	Population growth rate	

The other set of indicators was mainly related to land management characteristics in the study field sites. Soil drainage has been introduced in the analysis to include areas characterized as wetlands which were periodically overgrazed. Land fragmentation and land abandonment were two important indicators affecting overgrazing. Highly fragmented land usually can not easily be overgrazed. Land recently abandoned was usually followed by high grazing intensity without applying any measures for protection against desertification.

The analysis of covariance has shown several pairs of interrelated indicators. Several interrelations have been assigned to indicators referring to climate and land management. The following interrelated pairs of indicators have been distinguished for the field sites subjected to overgrazing:

- Rain erosivity – aridity index
- Annual potential evapotranspiration – period of existing land use
- Annual potential evapotranspiration – soil water conservation
- Annual potential evapotranspiration – grazing intensity
- Rain seasonality – parallel employment
- Annual rainfall – rain erosivity
- Annual rainfall – soil drainage
- Deforested area – fire protection
- Land abandonment – fire frequency
- Fire protection – fire frequency
- Fire risk – burned area
- Fire frequency – rate of burned area.

The annual potential evapotranspiration was related to soil water conservation, grazing intensity, and period of existing land use. There was good relation between rain erosivity and aridity index. Annual rainfall was related to rain erosivity, and soil drainage. Rate of deforested area was related to fire frequency. Furthermore, fire frequency was related with rate of land abandonment, fire protection, and rate of burned area. Fire risk had a good relation with burned area. Some other pairs of interrelated indicators have been defined such as rain erosivity – fire protection, potential evapotranspiration - population growth rate which was not considered since this relation was clearly arbitrary.

The analysis of the effectiveness of each indicator in assessing desertification risk in field sites overgrazed have shown that the following indicators had the highest correlation: soil erosion control, water scarcity, and burned area.

Soil erosion control measures

Soil erosion control for assessing desertification risk have been affected by indicators related to climate, soil, topography, land management, water availability, and social characteristics (Fig. 16). Among the indicators related to climate, aridity index and rain seasonality had the highest correlation with desertification risk in the study field sites. Under high aridity indices and high rain seasonality, soil erosion control measures were mainly characterized as moderate to adequate. Under such adverse climatic conditions plant growth was highly restricted and grazing of the land was not profitable discouraging farmers to use it.

Field sites located in areas with poorly drained soils have been mainly characterized as subjected to overgrazing. Such areas are usually wetlands in which during the dry period after water is withdrawn from the surrounding very poorly drained soils, animals are moved to graze them. Also, soil erosion control measures by enhancing plant cover were positively related to slope gradient. The obtained data have shown that field sites with lower slope gradients were subjected to higher grazing intensity without any actions for controlling soil erosion.

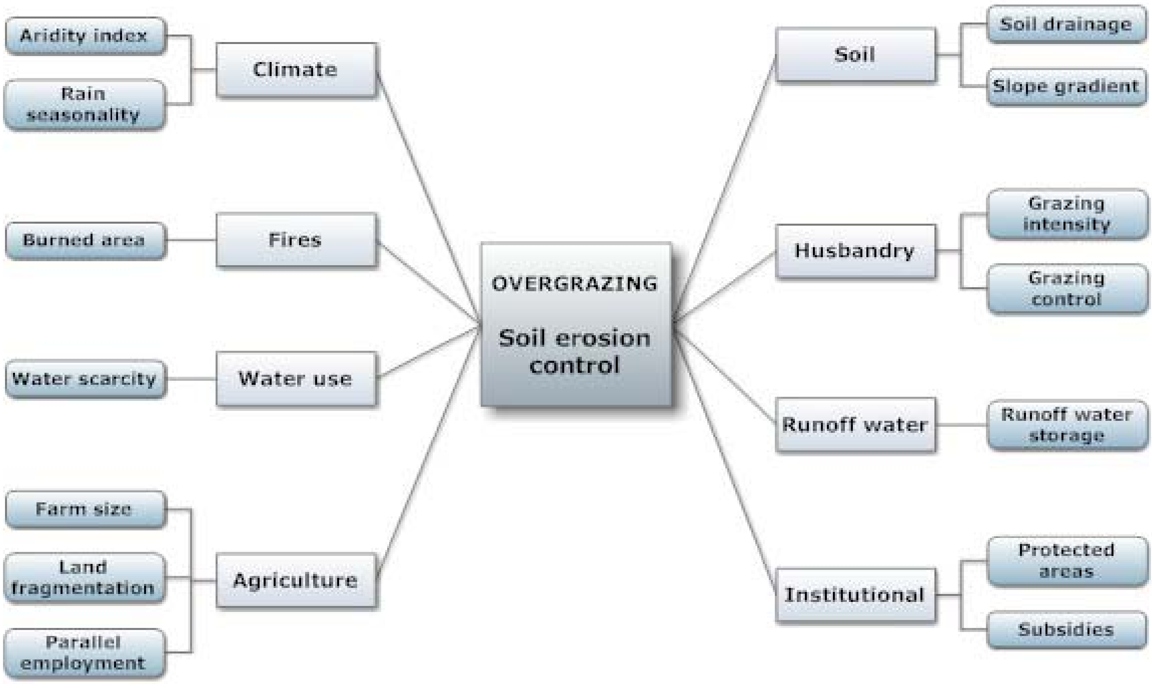

Fig 16. Important indicators related to soil erosion control in field sites where overgrazing was the dominant process of land desertification

The rate of burned area was positively related to soil erosion control measures. It seems that in the study field sites the existing regulations for protection of the land after fire have been effectively applied.

The analysis of the data have shown that water scarcity was negatively related to soil erosion control. Field sites located in areas characterized by high water scarcity were usually overgrazed without any measures for soil erosion control.

The most important indicators related to agriculture affecting soil erosion control in the study field sites were farm size and land fragmentation. Field sites located in farms of small size have been mainly characterized by adequate soil erosion control measures. Such actions are probably related with small numbers of animals kept by the local farmers avoiding overgrazing. Furthermore, land fragmentation was usually positively related to soil erosion control in areas subjected to overgrazing. Field sites belonging to farms with low land fragmentation were subjected to overgrazing since animals use to remain in the same area for a long period. In addition, farmers having some kind of parallel employment in tourism or other economic activities, usually do not apply measures for soil erosion control since they spend most time far from their farm.

Important indicators related to land management practices and associated with actions against overgrazing identified in the study field sites were grazing control, and runoff water storage. Field sites in which such actions have been applied were not overgrazed. Furthermore, protected areas such as national parks or protected landscape included in areas subjected to overgraze were usually moderately protected from soil erosion. The mentioned actions for soil erosion control accompanied with low grazing intensity were associated with the policy enforcement in the study field sites. Police enforcement was positively related with soil erosion control measures and negatively with grazing intensity.

Burned area

Burned area has been highly related to desertification risk in field sites where overgrazing has been considered as a main process of land degradation. The analysis of the obtained data has shown that several indicators have been related to burned area (Fig. 17). Annual potential evapotranspiration and rainfall were the most important indicators related to climate and affecting burned area. The rate of burned area has been mainly defined as moderate to high in field sites located in areas characterized with high evapotranspiration rates and low annual rainfall. The occurrence of forest fires under such climatic conditions is expected to be high in grazing lands.

Among the soil indicators, only the presence of rock fragments in the soil surface appeared to affect the rate of burned area in the study field sites. The rate of burned area was characterized as low in field sites where rock fragments percentage in the soil surface was relatively low. Rock fragments highly affect soil water conservation, soil erosion and therefore biomass production.

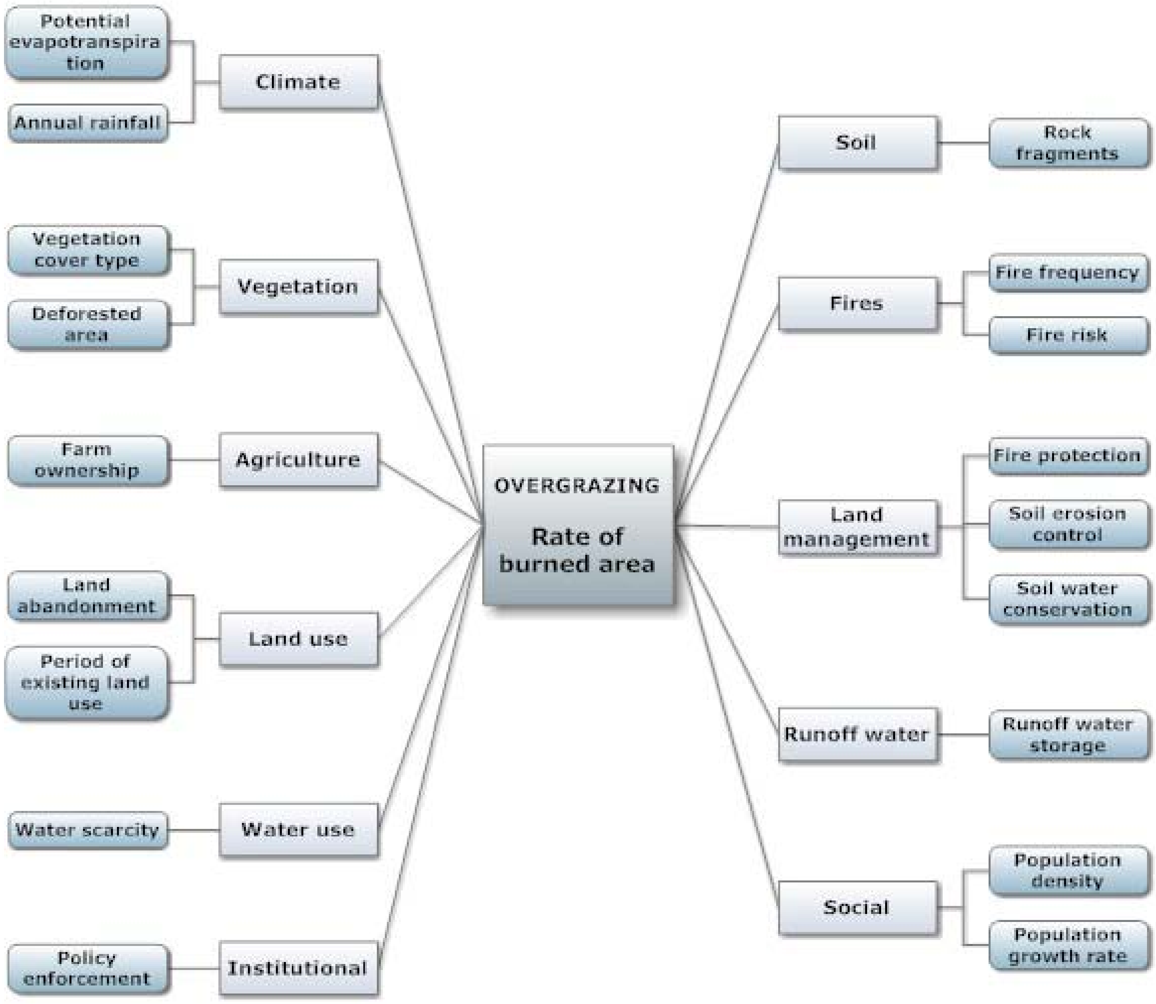

Fig 17. Important indicators related to rate of burned area in field sites where overgrazing was the dominant process of land desertification

Important indicators related to vegetation characteristics were vegetation cover type and rate of deforested area. Rate of burned area has been characterized as high in areas where the vegetation cover type was mixed Mediterranean machia and evergreen forests, Mediterranean machia and pines. The rate of burned area was relatively low in areas covered with permanent grass, annual grass and deciduous forests. In addition, the rate of burned area was positively related to the rate of deforested areas in the study field sites.

The rate of burned area in the study field sites was highly related to fire risk and fire frequency. Areas covered with vegetation of high fire risk were subjected to high fire frequency and therefore the rate of burned was high enhancing desertification risk in the overgrazed study field sites.

Among the indicators related to agriculture only farm ownership was significantly related to rate of burned area. Tenant or state-farmed field sites were usually subjected to higher rates of burned area than owner or shared-farmed field sites. Farmers used to put fire in grazing land to simulate the growth of palatable biomass production for the grazing animals aggravating the problem of desertification in these areas.

Regulations related to actions such as fire protection, soil erosion control, soil water conservation, and runoff water storage were affecting rate of burned area and degree of policy enforcement in the study field sites. The obtained data have shown that the rate of burned area was relatively low in areas where adequate measures for fire protection were undertaken. Also existing actions of soil erosion control, soil water conservation, or runoff water storage were negatively related to the rate of burned area.

The rate of land abandonment was negatively related to the rate of burned area. Areas in which the rate of land abandonment has been characterized as high, the rate of burned area was relatively low. Furthermore, field sites in which the period of existing land use was long, the rate of burned area was relatively low.

An important indicator related to land use and affecting rate of burned area was water scarcity. Field sites located in areas with high water scarcity were subjected to low rates of burned area. Probably people living in such areas are more aware of he importance of environmental protection fighting against forest fires which greatly affects water availability.

Finally, the analysis of the data have shown two important indicators related to social characteristics, population density and population growth rate, affecting the rate of burned area. Field sites located in areas of high population density or high population growth rate were subjected to high rates of burned area. Such actions are very common in many areas with high population density due to imposing high pressure on the natural resources.

3.5 Forest fires

Data for forest fires have been provided from the following four study sites: Mação-Portugal, Boteti Area-Botswana, Gois- Portugal, and Cointzio catchment-Mexico.

The factorial-principal component analysis have shown two important sets of indicators related to forest fires and affecting desertification risk (Table 10). Set 1 of indicators shows that forest fires in the study field sites were positively related to fire frequency, fire risk of the existing vegetation cover type, and rate of burned area. Areas covered of high fire risk vegetation such as Mediterranean machia, pine forests were subjected to high frequency of fires resulting to high rates of burned area. Grazing intensity was negatively related to forest fires. Overgrazed field sites had low amount of biomass for ignition and propagation of a fire. Furthermore, water scarcity was negatively related to forest fires. Areas with high water scarcity were subjected to less frequent fires since vegetation was rather limited in such areas.

The other set of indicators shows that areas under high annual air temperatures and low annual rainfall were subjected to high forest fires due to the presence of high amount of flammable biomass. Also rainfall seasonality affected positively forest fires since under high rain seasonality dry biomass or existence of plant species of high content of resins or essential oils favored forest fires. The rate of land abandonment was negatively related to forest fires.

Areas characterized by low rate of land abandonment were subjected mainly to a high rate of forest fires.

Table 10. Sets of indicators related to forest fires in the study field sites identified by using factor-principal component analysis

No	Sets of indicators related to:	
	Fire characteristics (eigenvalue = 6.81)	**Physical environment (eigenvalue = 5.43)**
1	Fire frequency	Annual air temperature
2	Fire risk	Annual rainfall
3	Burned area	Rainfall seasonality
4	Grazing intensity	Deforested area
5	Water scarcity	Land abandonment

The analysis of covariance of the various indicators has shown the following important sets of interrelated indicators:

- Water scarcity – fire frequency
- Fire frequency – fire risk of the existing vegetation
- Fire frequency – burned area
- Grazing intensity – burned area
- Vegetation cover type – burned area
- Vegetation cover type – water scarcity.

Fire frequency was closely related to fire risk, water scarcity, and rate of burned area. Vegetation cover type was related both to burned area and water scarcity in the study field sites. Also there was high correlation between grazing intensity and rate of burned area.

The analysis of the effectiveness of the various indicators related to forest fires for assessing desertification risk have shown significant influence from the following indicators: rain seasonality, fire protection, and land abandonment. Rain seasonality is a state indicator depending on the climatic characteristics of the study sites not directly affected by the local population, while fire frequency and land abandonment are indicators affected by anthropogenic actions discussed here.

Fire protection

Fire protection or fire resistance has been affected by indicators related to climate, soils, land management, and social characteristics (Fig. 18). Among the most important climate indicators annual air temperature, annual rainfall, and rain seasonality have been found affecting mainly fire protection in the study field sites. Fire protection has been mainly characterized as low in areas characterized by high annual air temperature and low annual rainfall. Such climate conditions favour the production of dry biomass of high flammability and combustion promoting ignition of forest fires. Furthermore, fire protection has positively related to rain seasonality. Forest fire protection has been mainly characterized as low in areas of high rain seasonality. Under such climatic conditions, dry flammable biomass is available for easy ignition and propagation of fires.

The most important soil indicator affecting fire protection identified in the study field sites was soil depth. Fire protection was negatively related to soil depth. Fire protection in areas with deep soils was mainly characterized as moderate to low. Areas with deep soils generally produce high amounts of biomass, and fires that occur there can not easily controlled.

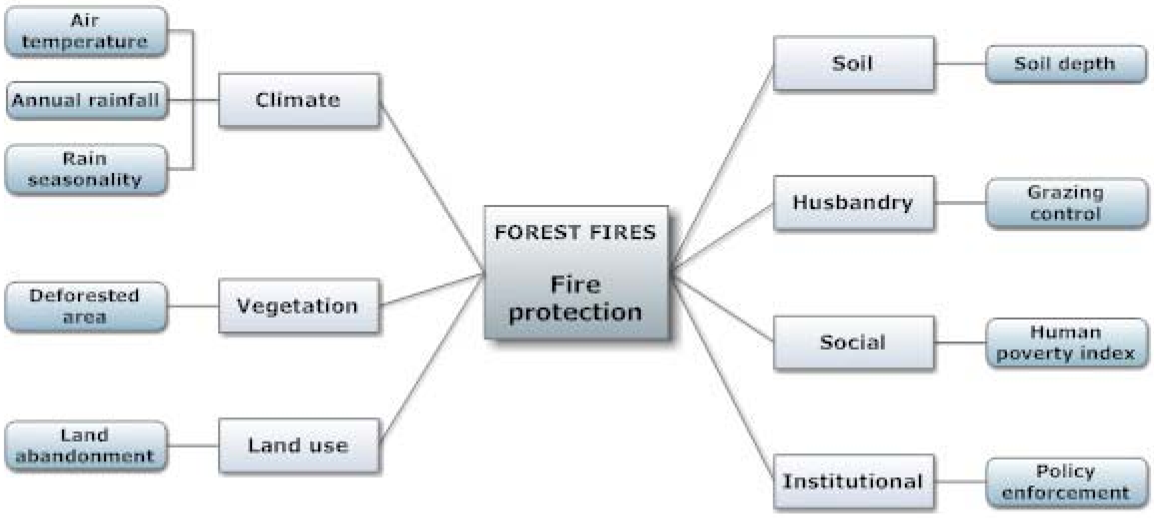

Fig 18. Important indicators related to fire protection in field sites where forest fires was the dominant process of land desertification

Fire protection was significantly related with the following land management indicators: deforested area, grazing control, land abandonment, and policy enforcement. Fire protection was mainly characterized as high in field sites where the rate of deforestation was high. This can be explained by the reduction of forests or available flammable biomass by clearing them for changing land use. Grazing control was positively related to fire protection. Farmers protecting the land from overgrazing use to protect the land from fires too. Furthermore, field sites located in areas with low rate of land abandonment were mainly highly protected against fires. Finally, field sites characterized by high policy enforcement of existing regulations for environmental sustainability were adequate protected from fires too.

Among the social indicators only human poverty index was significantly related to fire protection. Field sites located in areas of high poverty indices were mainly inadequately protected from fires. Under such conditions, funds available for environmental protection are usually limited or absent.

Rate of land abandonment

Land abandonment has been considered as an important factor affecting land desertification in the study field sites. Rate of land abandonment was negatively related to desertification risk due to forest fires. Areas under low rates of land abandonment were subjected to high rates of forest fires and high desertification risk. Land abandonment can affect desertification positively or negatively depending on the physical conditions at the time of abandonment and the management characteristics afterwards. The analysis of the data has shown that land abandonment has been affected by indicators related to climate, vegetation, soil, husbandry, fires, water use, land management, and social characteristics of the study field sites (Fig. 19). Among the indicators related to climate, air temperature, annual rainfall, and rain seasonality have mainly related to rate of land abandonment in the study field sites. The rate of land abandonment was negatively related to annual air temperature. Areas with high annual air temperature have been characterized by low rate of land abandonment. Similarly, areas with moderate annual rainfall have been mainly subjected to high rates of land abandonment. Also, areas with high rain seasonality have been characterized by low rates of land abandonment. These trends of rate of land abandonment may be attributed both to high rates of land abandonment in previous decades resulting in low rates in the last decades in areas with high annual air temperatures and to high rates of land abandonment in the last decade due to low prices of agricultural products in areas with high annual rainfall or low rain seasonality values.

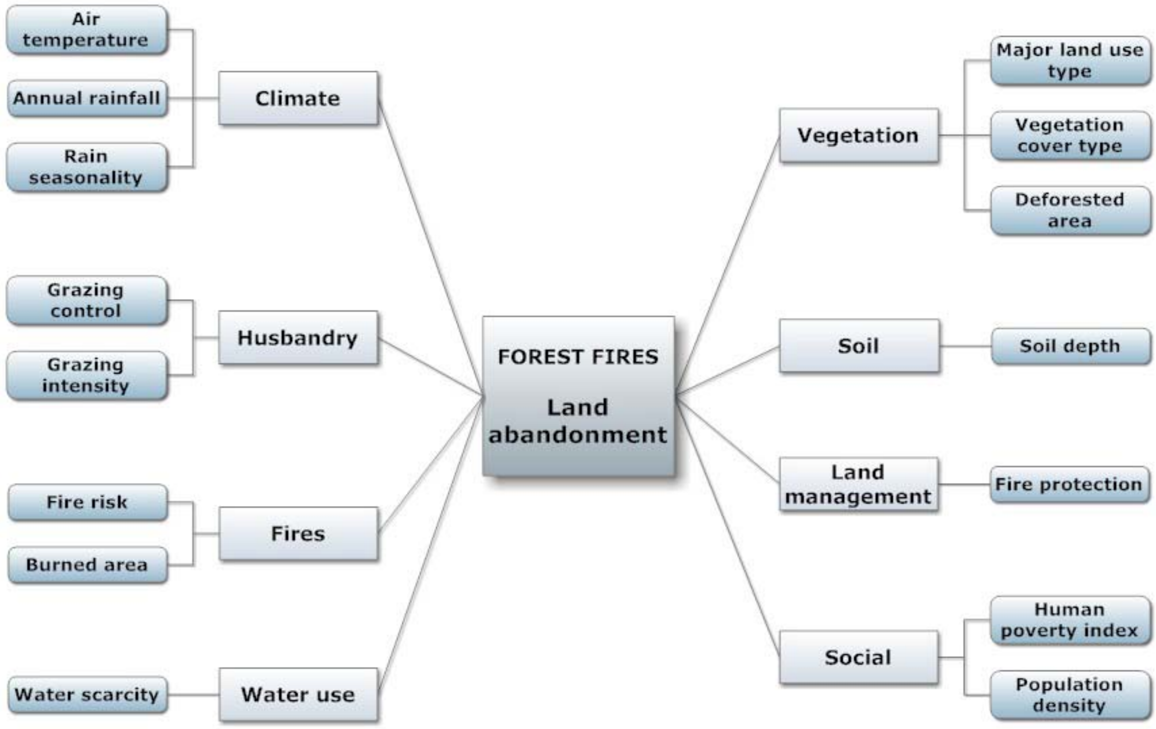

Fig 19. Important indicators related to land abandonment in field sites where forest fires was the dominant process of land desertification

Important vegetation indicators related to rate of land abandonment were major land use, vegetation cover type, and the rate of deforested area. Areas used for agriculture were characterized by a higher rate of land abandonment than those used as pastures. Also areas cultivated with olives, vines and almonds had higher rate of land abandonment than areas with cereals. The rate of deforested areas was positively related to the rate of land abandonment. Areas with moderate or high rate of land abandonment were predominately subjected to high rates of deforestation.

Soil is a major determinant in land abandonment. Soil depth greatly affects water storage capacity and water available for plant growth. Areas with shallow soils are usually abandoned with higher rates than areas with deep soils since crop production becomes unprofitable.

Some important animal husbandry indicators related to the rate of land abandonment in the study field sites were grazing control and grazing intensity. The rate of land abandonment was negatively related to grazing control actions. Areas with adequate grazing control actions had higher rates of land abandonment. This is true for areas that land after abandonment was under low rates of grazing intensity. In addition, areas subjected to high grazing intensities were predominately characterized by low rates of land abandonment since farmers cultivated the land for feeding the animals.

Indicators related to fires and affecting land abandonment were the fire risk and rate of burned area. Fire risk was positively related to rate of land abandonment. Areas covered with vegetation of high fire risk have been subjected to higher rates of land abandonment. Fires in such areas are frequent, causing high soil erosion rates and land degradation followed by abandonment. In addition, the rate of land abandonment was positively related to the rate of burned area. Areas characterized by high rates of burned area were usually combined with high rates of land abandonment.

Among the land management characteristics only fire protection was significantly related to rate of land abandonment. Fire protection negatively affected rate of land abandonment in the study field sites. Areas characterized by low measures of fire protection have been mainly subjected to low rates of land abandonment.

An important water use indicator affecting land abandonment was water scarcity. Areas characterized by low water scarcity were predominately subjected to high rates of land abandonment. This may be attributed to the low prices of agricultural products leading to land abandonment even in areas with adequate water supplies or no agricultural crops were present.

The rate of land abandonment has been related to the social characteristics of the study sites such as human poverty index and population density. Areas with high human poverty indices have been mainly characterized by high rates of land abandonment. Also, areas with low population density were mainly characterized with high rates of land abandonment. This can be explained with the migration or rural population to urban areas or working parallel in other economical sectors such as tourism or industry.

4. Conclusions

The comparative analysis of the study field sites has shown various classes of desertification risk depending on the severity of the acting processes or causes and the state of the physical environment. High and very high desertification risk has been estimated in the majority of the study field sites. Soil erosion has been defined as the main process of land degradation followed by soil salinization, water stress, overgrazing, and forest fires. The main indicators affecting soil erosion were related to: (a) soil such, as slope gradient, soil texture, and exposure of rock outcrops; (b) vegetation, such as vegetation cover type, and plant cover; (c) water runoff, such as drainage density; and (d) land management, such as soil erosion control, and water runoff storage.

The comparative analysis of the study field sites carried out for the following processes: (a) soil erosion, (b) soil salinization, (c) water stress, (d) overgrazing, and (e) forest fires has shown that the most important indicators affecting desertification risk characterized as **critical** were related to land management practices (Fig. 20).

Desertification risk due to soil erosion in agricultural areas was predominately related to tillage operations, land use intensity, and policy enforcement. Tillage operations and land use intensity were positively related to desertification risk, while policy enforcement has negatively affected desertification risk. The indicators grazing control, rate of burned area, and soil erosion control was predominately related to desertification risk in pastures. Grazing control and soil erosion control were negatively related to desertification risk, while the rate of burned area has positively affected desertification risk. In forested areas in which soil erosion was the main process of land degradation, desertification risk was mainly related to the indicators: grazing intensity, runoff water storage, and policy enforcement. Runoff water storage and policy enforcement of existing regulations were negatively related, while grazing intensity has positively affected desertification risk in forested areas.

The main indicators affecting desertification risk in field sites where soil salinization was the main process of land degradation were water scarcity and water quality. Filed sites located in areas with high water quality or low water scarcity have been mainly subjected to low or moderate desertification risk.

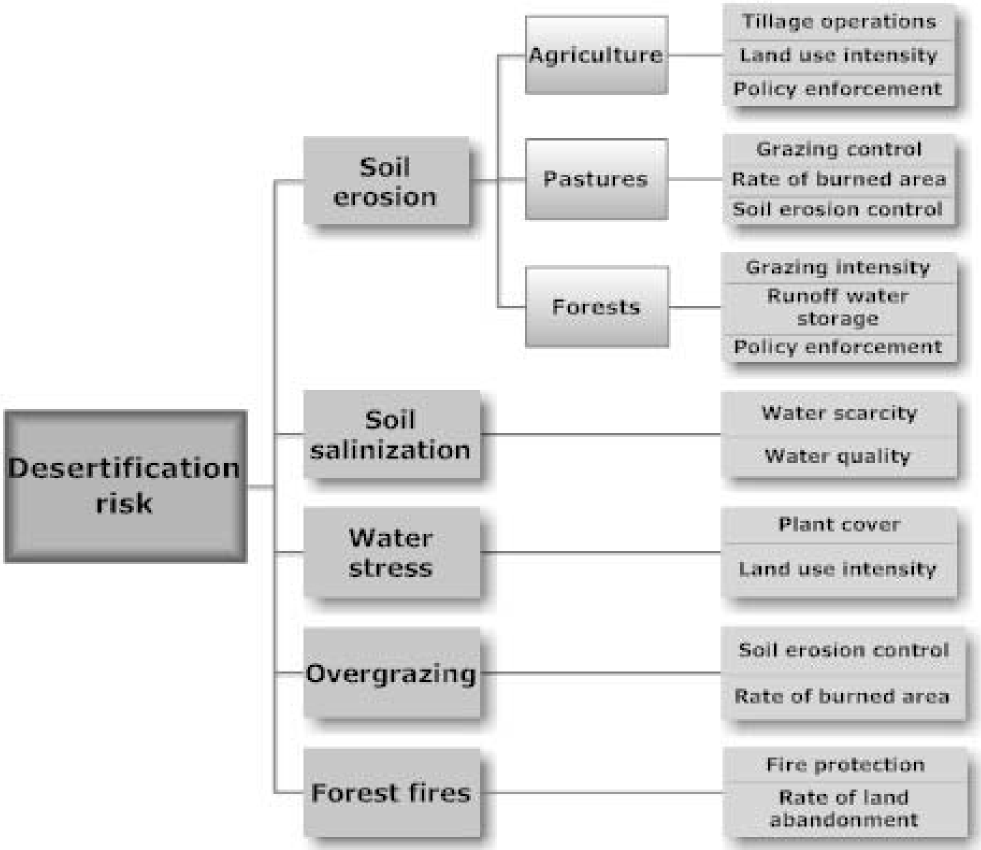

Fig. 20. Critical indicators mainly affecting desertification risk under various processes or causes of land degradation in the study field sites

Desertification risk due to water stress was predominately related to the indicators plant cover and land use intensity. Field sites subjected to high land use intensity or having low permanent plant cover have been mainly characterized by moderate to high desertification risk.

Desertification risk due to overgrazing has predominately related to the indicators soil erosion control, and rate of burned area. Field sites located in areas subjected to high rates of burned area or without any action for soil erosion control have been mainly characterized with moderate or high desertification risk. On the contrary, field sites in which adequate measures of soil erosion control have been applied, desertification risk was mainly characterized as low.

The indicators fire protection and rate of land abandonment have been mainly related to desertification risk in areas where forest fires has been defined as the main cause of land degradation. Field sites located in areas in which adequate measures have been undertaken for fire protection have been subjected to low desertification risk. On the contrary, field sites located in areas with low rates of land abandonment were predominately characterized with low to moderate desertification risk.

Land management indicators mentioned above as the most important affecting desertification risk under the various land degradation processes or causes were further analyzed to define relations among the long list of **effective indicators** described in the study field sites. The indicators were ranked according to their importance and frequency of appearance in the statistical analysis and presented in Fig. 21. The most important indicators with the highest correlation and frequency of appearance affecting land management indicators and desertification risk were: rain seasonality, rate of land abandonment, population growth rate, and potential evapotranspiration rate. Other indicators such as vegetation cover type, drainage density, runoff water storage, annual rainfall, slope gradient, soil erosion control, old age index, population density appeared as the next important group affecting land management actions for combating desertification or deteriorating present condition of land degradation. Indicators such as soil texture, percentage of impervious soil surface, farm ownership, grazing control, grazing intensity, subsidies, aridity index, land fragmentation, period of existing land use, water scarcity, fire frequency, and policy enforcement were included in the analysis of land management practices and desertification risk with lower frequency of appearance.

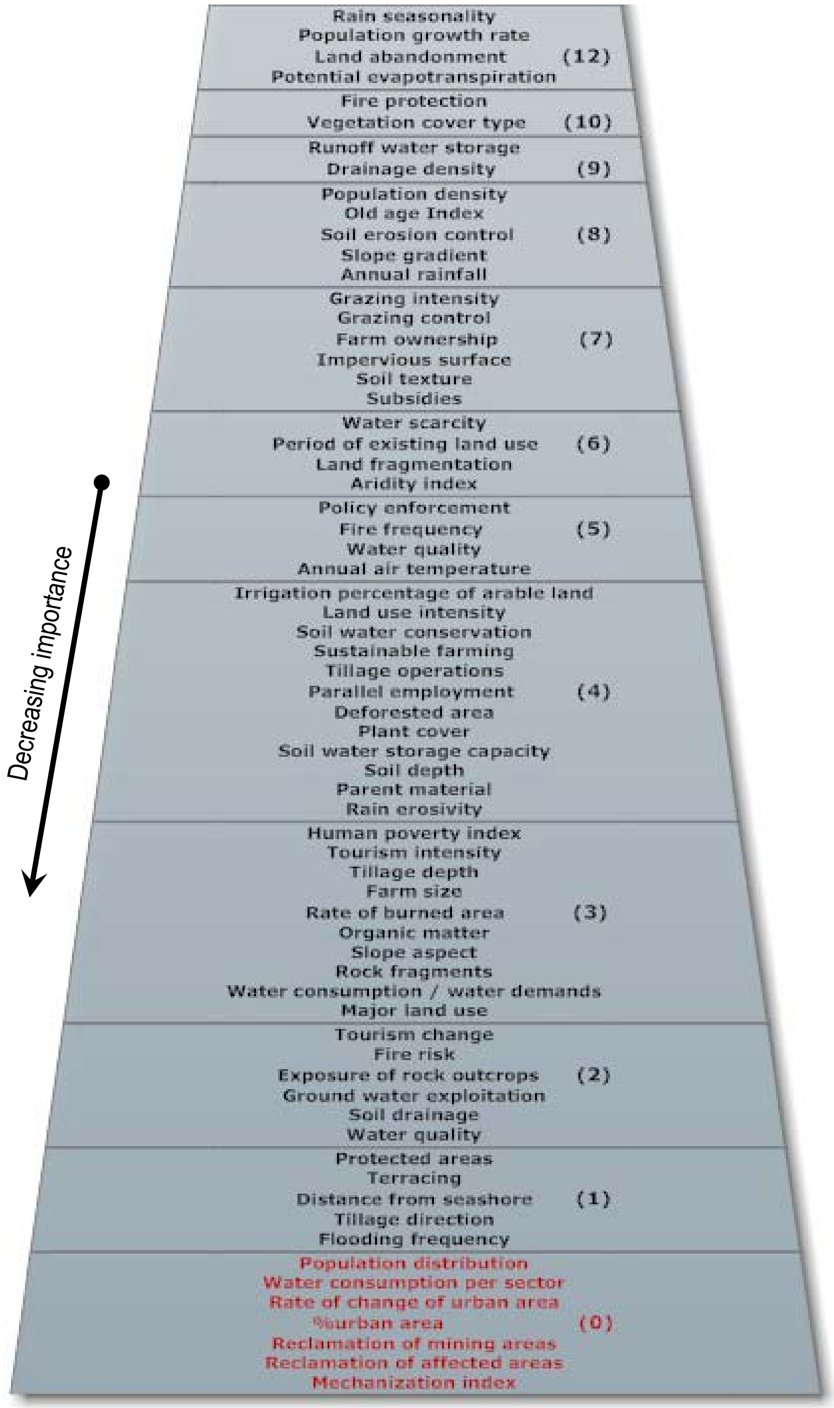

Fig. 21. Ranking importance of effective indicators based on correlation and the frequency of appearance in the comparative analysis of the study field sites (numbers in parenthesis corresponds to frequency of appearance in the analysis)

Some indicators such as rain erosivity, parent material, soil depth, soil water storage capacity, rate of deforested area, parallel employment, sustainable farming, irrigation percentage of arable land, major land use, water consumption/water demands, rock fragments, slope aspect, organic matter on the soil surface, farm size, tillage depth, tourism intensity, soil drainage, water quantity, ground water exploitation, exposure of rock outcrops, fire risk, tourism change, etc., appeared in the analysis less frequently but are very important for some processes or causes of desertification such as soil salinization, water stress, overgrazing, and forest fires. There were also indicators such as mechanization index, reclamation of affected areas, reclamation of mining areas, % urban area, rate of change of urban area, water consumption per sector, and population distribution that were not included in any analysis of desertification risk.

The questionnaire of indicators used in this study did not work appropriate in some field sites for the following indicators: farm ownership (Boteti Area-Botswana, Mação-Portugal), vegetation cover type (Mação-Portugal, Boteti Area-Botswana, Novij Saratov-Russia), land fragmentation (Mamora Sehoul-Morocco), parallel employment (Mamora Sehoul-Morocco), tillage operations (Mamora Sehoul-Morocco, Santiago Island-Cape Verde), major land use (Konya plain-Turkey, Boteti Area-Botswana, Mação-Portrugal), land use type (Boteti Area-Botswana), and grazing intensity (Mação-Portugal). The indicator system used in DESIRE project can be easily improved by including new classes for describing these indicators.

Some indicators such as policy enforcement, population growth rate, old age index there were described as subjected to cause-effect relationships. In some cases cause and effect are reserved, and that in other cases there might be a correlation, but not a cause-effect relationship at all. This is particularly the case for indicators related to policy enforcement. The central meaning of policy enforcement or better policy followed used in this study is related to the implementation of existing regulations on environmental protection and it is related to land user decision. Policy formulation on environmental protection is related to the politicians and can be associated to the living conditions of the people or to the land management characteristics resulting in unfavourable changes in the physical environment. In this report policy enforcement is related to the degree of implementation of a specific policy formulated for the protection of the environment.

The analysis of the existing data collected from the various study sites has shown that indicators may be widely, even globally, used for assessing the various land management practices on land desertification risk at field level. Of course, some indicators related to agriculture, social, and institutional characteristics in some cases show trends that are opposite to what happens in other study sites. These trends can be explained by further investigation including other indicators or processes affecting desertification risk that it was not possible to consider in this effort. Applied to desertification risk, efficiency and performance indicators seem the most promising for further research, particularly combined with economic principles. In this regard policymaking may benefit using the indicators as an aid, a means to achieve more focus responses timely and accurately. However, the great number of indicators may be treated cautiously, since confusion or “noise” may proliferate leading to the same pre-existing obscurity for the selected policy responses.

The list of indicators presented in this analysis is reduced in smaller effective numbers in the development of empirical relations for defining desertification risk (deliverable 2.2.2). It will be very enthusiastic to search for a single desertification indicator with universal applicability but this can not be achieved since causes and processes of desertification and land degradation are manifold, with wide range of local variability.

5. Comparison of results with earlier projects

Over recent years a number of research projects or groups have been worked on the identification of desertification indicators. Indicators have been used in the National Actions Plans for Combating Desertification to identify desertification affected areas. Particular emphasis has been given on identifying and using indicators which are relevant to the concerns of local people or national level, rather than to regional or worldwide scale. The European research project Desertilnks through the Desertification Indicator System for Mediterranean Eropue – DIS4ME has made a great effort to collate and describe a list of about 140 desertification indicators drawn from the following sources:

- Commission on Sustainable Development (CSD)
- Organisation for Economic Cooperation and Development (OECD)
- European Environment Agency (EEA)
- Indicator Report on the Integrated Environmental Concerns into Agricultural policy (IRENA)
- Towards European Pressure Indicators (TEPI)
- Land Degradation Assessment of Drylands (FAO-LADA)
- Agri-environmental indicators for sustainable development in Europe (ELISA)
- Proposal on agri-environmental indicators (PAIS)
- International Institute for Sustainable Development (iisd)
- Recent and contemporary research projects : MEDALUS III, MEDACTION, GEORANGE, INDEX, DISMED, DESERTNET, RIADE, SURMODES
- National Action Programmes for Portugal, Spain, Italy and Greece.
- Suggestions from Focal Point and National Committee representatives, within and beyond Annex IV
- Suggestions from stakeholder workshops and activities.

The identifying indicators in Desertilinks project have been briefly described with respect to the importance on land desertification, the data required to calculate and data sources, benchmarks and limitations in using them, etc., presented in the DIS4ME system. Based on the DIS4ME source of indicators and suggestions made from the various research groups of the DESIRE project, about half of the indicators (72 candidate indicators) were selected in this project for assessing desertification risk and evaluating the various land management practices and techniques in terms of land degradation for combating desertification. Moving forwards previous projects, a manual has been prepared for describing each indicator including classes and weighing indices for each indicator. Questionnaires were prepared for identifying important processes or causes of desertification identifying in 17 study sites located in Europe, Latin America, Africa, and Asia. It is the first time in which data for so many indicators related to land desertification were collected in such a variety of physical environments, social and economical conditions. Data on indicators have been selected in other desertification projects but on a limited number of field sites and environmental conditions. The obtained data of desertification indicators from the various study sites were compared and important relationships were found. Such relations can clear many disputes points on indicators existing in the scientific community up today. Furthermore, the application of indicators on assessing land desertification risk has been generalized in this project and regional indicators have been included. The derived methodologies in other projects such as MEDALUS and DESERTLINKS had limited range of environmental conditions for application.

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