The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

1867-50

College of Soil Physics

22 October - 9 November, 2007

Hydrological approach to soil and water conservation 3

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HYDROLOGICAL APPROACH FOR ASSESSING DESERTIFICATION PROCESSES IN THE MEDITERRANEAN REGION

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(Published in: **Pla, I.** 2006. Hydrological approach for assessing desertification processes in the Mediterranean Region. In: "Desertification in the Mediterranean Region: A Security Issue". 579-600. (W. G. Kepner et al. ed.). Springer. Heidelberg (Germany). (ISBN 1-4020-3758-9)

ABSTRACT

Land degradation, which affects the conservation of soil and water in adequate places, amounts and qualities, is the main direct cause of desertification. It is related to climate and soil characteristics, but mainly to deforestation and inappropriate use and management of the natural resources soil and water. The main effects are a decrease in water supply, a non sustainable agricultural and food production, and increased risks of catastrophic flooding, sedimentation, landslides, etc. In the medium or long term, the previewed global climatic changes may contribute to accelerate the processes of desertification in the Mediterranean Region, but at short term, land use practices leading to soil degradation processes would increase the negative influence of those changes.

The processes of soil and water degradation, leading to desertification, are strongly linked to unfavourable changes in the hydrological processes responsible for the soil water balance and for the soil moisture regime. These are affected by the climate conditions and variations, and by the changes in the use and management of soil and water resources.

In the arid and semiarid Mediterranean climates, the rainfall is highly variable among years and during the year, and usually occurs in erratic storms of short duration and high intensities. This factor increases the risks of land degradation leading to desertification processes. In N Mediterranean countries, agricultural production patterns and practices have been drastically changed in the last decades, emphasizing labour-substituting technologies in some cases, with abandon of traditional soil and water conservation practices, and leading to the abandonment of agricultural lands in others. By contrast, in most of the S Mediterranean countries, population growth and lack of resources have obliged to intensify the use of marginal lands without appropriate conservation practices. Both situations frequently lead to accelerated land degradation and desertification processes, although in N Mediterranean countries, if resources are available, these processes and effects are usually masked by technological external inputs of energy, irrigation water, nutrients, and other control measures. Any break in these artificial measures, generally causes a complete loss of productivity and leads to accelerated desertification processes.

Hydrological approaches would be essential to identify and assess the causes and processes of desertification. The evaluation of the hydrological processes, under different scenarios of changing climate, soil properties, and land use and management, with flexible simulation models based on those processes, may help to predict and to identify the biophysical causes of desertification at local, national and regional levels. This is a required previous step for a rational land use planning, and for the selection and development of short and long term strategies and technologies to reduce or to control land degradation processes leading to desertification, and to the related social economic and security problems. There is proposed an integrated framework for the development of this kind of approach, with potential application under Mediterranean conditions.

1. INTRODUCTION

Soil performs a number of key environmental, social and economic functions vital for life. Agriculture and forestry are dependent on soil for the supply of water and nutrients, and for root fixation. Soils perform functions of storage, filtering, buffering and transformations, playing a central role in water protection and regulation, and on the exchange of gases with the atmosphere. Land degradation is a reduction in the soils capacity to produce sustainable, in terms of quantity and quality, goods (plants and food) and services (regulation of water;

environmental filter). The result is a reduction or loss of the biological and economic productivity and complexity of the land.

Desertification is generally viewed as an advanced stage of land degradation, when vegetation cover falls below some level (about 35 %). For many people, desertification is the diminution or destruction of the biological potential of the land, that can lead ultimately to desert-like conditions, usually in dry lands, but sometimes even in humid ones. It is an oversimplified concept with a connotation of emotive image, addressed to decision makers as a way to attract attention, and it is hoped funds (CIESIN, 2003). Frequently there is an insidious misuse of desertification to deflect attention from more sensitive political and social problems, blaming the environment when blame should go to human institutions or individuals. As a consequence, the concept of desertification is still obscure, and therefore there is a lack of consensus on the nature and causes of desertification processes.

Rozanov (1982) proposed the following definition:

> "Desertification is a process of irreversible change, requiring a very long natural process for the restoration of the initial stage, of soil and vegetation of dry lands in the direction of aridisation and diminution of biological productivity, which, in extreme cases may lead to the total destruction of the biological potential and to the conversion of lands into desert"

According to Dregne (1983), desertification processes in arid and semiarid lands are:

- Deterioration of vegetative cover due to overgrazing and deforestation
- Water and wind erosion resulting from improper land management
- Salinisation and sodification due to improper use and management of irrigation water and drainage

These processes reduce productivity rather than create total deserts, except in extreme cases.

Agenda 21 and the UNCCD (UNEP, 1997) consider desertification as the degradation of land in arid, semiarid and sub-humid dry areas, caused by various biophysical and human factors. The areas subject to desertification are defined by the ratio of precipitation (P) to potential evapo-transpiration (PET):

- Arid ($0{,}05 < P/PET \leq 0{,}2$)
- Semiarid ($0{,}2 < P/PET \leq 0{,}5$)
- Sub-humid Dry ($0{,}5 < P/PET \leq 0{,}65$)

Desertification is accompanied not only by a reduction in land and soil potential, but also by a decrease in surface and ground water resources, having negative repercussions on the living conditions and the economic development of the people affected by it. The main direct visible impacts of desertification are damages to crops, livestock, power generation, etc, with indirect effects on non-sufficient food production, poverty and social disruption, causing migration of people from rural areas to urban centres, or to other regions or countries, trying to improve their living conditions (FAO, 1993). Therefore, desertification may be better defined as a phenomenon derived of climatological, hydrological and socio-economic processes, leading to potential threats to the environment, with negative consequences on human welfare and lives.

In the past decades, the degradation of previously naturally vegetated or productive agricultural lands, leading in many cases to barren, desertified, landscapes, has dramatically extended in many regions of the World. The reasons are mainly unfavourable biophysical conditions and negative human impacts. The areas prone to degradation and desertification are often characterized by marginal soils, and low and highly variable rainfall. The negative human impacts are mainly through inadequate land use, including deforestation, overgrazing, and deficient agricultural practices, leading to soil erosion, salinisation and vegetation degradation, as a consequence of drastic changes in the water balance. This might be further aggravated by the ongoing threat of climate change.

Many of the programs to combat desertification have often concentrated up to now on mitigating the effects rather than fighting the causes. Instead, a program to combat desertification would require (Balba, 1982) a survey of the soil and water resources, followed of an identification of the problems and processes of land degradation, as a basis for the formulation of a plan of action to counteract such processes. A sufficiently precise assessment of the desertification processes must be based on the integration of biophysical and social economic factors, for diagnostic purposes and for guiding the implementation of sustainable land use and management strategies and programs (Pla, 1996, 2001)

Although legal measures are necessary for the rational use, management and conservation of the soil and water resources, they alone may not be sufficient for an adequate planning for the rational development of land resources. Soil and water conservation legislation has to be viewed within the larger context of land use planning, which requires site specific data on the physical and hydrological environment under actual or projected conditions. This generally requires improvements in the present research and inventories of soil and water resources, and in the training and formation of manpower at all levels.

2. DESERTIFICATION IN THE MEDITERRANEAN REGION

Desertification in the more vulnerable areas with arid and semiarid climate in the Mediterranean region goes back over millennia (Dupre, 1990). The most important human actions that have triggered or intensified the processes of land degradation have been overgrazing, deforestation and forest fires, and in recent decades new land management practices, associated to agricultural intensification, mechanization, inadequate maintenance or abandonment of vast areas of terraced agriculture, over-drafting of surface and groundwater for irrigated agriculture, tourism, etc. (EC, 2003). These new land use and management practices are a consequence of changes in social economic conditions, market prices and public policy-led subsidies, consumption patterns, etc, associated to technological progress and changing production systems. Desertification has affected more hilly sloping lands, but in valley bottoms where irrigation is being used for increasing productivity, salinisation and sodification have become a widespread form of soil degradation and desertification. There are evidences that land degradation processes leading to desertification in the Mediterranean region are getting worse, because of different or mixed causes varying from one place to the other (EC, 2003).

In N Mediterranean countries, agricultural production patterns and practices have been drastically changed in the last decades, emphasizing labour-substituting technologies in some cases, with abandon of traditional soil and water conservation practices, and leading to the abandonment of agricultural lands in others. By contrast, in most of the S and W Mediterranean countries, population growth and lack of resources have obliged to intensify the use of marginal lands, without appropriate conservation practices. The potential for desertification is still further enhanced through the direct effects of climate change on erosion, salinisation and fire hazard. In general, the most serious impacts on land degradation and desertification have been in the S Mediterranean countries, where lands are more under pressure due to social economic factors, including population growth.

Degradation of local land resources encourages out-migration to urban developed areas in the same country or to other neighbour countries, leaving fewer people to use and maintain local soil and water resources (EC, 2003). This underutilization and abandonment of already severely degraded land usually leads, mainly under arid and semiarid climates, to further degradation. But at times, depending on the soil water regime (soil and climate), population decline and decrease or absence of land use allows recovery and gradual restoration and improvement of soil and water resources. In N Mediterranean European countries, modern technologies, including intensive mechanization, for most of the land use operations, have been spreading fast in most of the dry-lands, for improving productivity and due to the affluence of rural population, with economic considerations often overriding environmental considerations.

Areas under desertification in the Mediterranean region include Central and SE Spain, Central and S Italy, S France, S Portugal, and extensive areas of Greece and N Africa. In poorer countries, especially in N Africa, desertification has more serious social economic consequences, and can ultimately cause the desestabilization of societies, triggering the migration of human populations. In richer European countries in the N of the region, trained human and capital resources are generally available for restoring partially degraded lands, and for masking processes and effects of land degradation and desertification, through technological external inputs of energy, irrigation water, nutrients, and other control measures. Any break in these artificial measures, generally causes a complete loss of productivity and leads to accelerated desertification processes.

Sustainable development in the Mediterranean region requires policies for the development of a long term approach of soil protection, based on an adequate knowledge of the potential direct and indirect impacts of human activities and climate changes, in order to select and apply the best practices and measures for conservation of the soil and water resources.

3. LAND DEGRADATION AND DESERTIFICATION. CAUSES AND EFFECTS

The formulation of a sound soils policy, and the prevention and choice of solutions for the problems of land degradation leading to desertification must depend on the right identification of the processes involved and in the precise analysis, diagnosis and understanding of the causes and potential effects at specific places. Not doing so may lead to catastrophic effects. Despite the modernization of observation facilities by the use of satellite imagery and computer programs to analyse the data, there are still many uncertainties at the regional and national levels in the Mediterranean region, on the causes, the extent and the seriousness of land desertification. These uncertainties prevent those who manage land resources from planning properly, and introduce constraints in operation of early warning systems with regard to agricultural production and disasters such as flooding and landslides.

Land degradation, which affects the conservation of soil and water in adequate places, amounts and qualities, is the main direct cause of desertification. It is related to climate and soil characteristics, but mainly to deforestation and inappropriate use and management of the natural resources soil and water. In degraded lands usually less water can infiltrate, and more rainwater will become surface runoff. The main effects are a decrease in water supply, a non sustainable agricultural and food production, and increased risks of catastrophic flooding, sedimentation, landslides, etc. resulting in destroyed crops, lands, infrastructures and buildings, and in killing people and animals. Sediment will be deposited in reservoirs, lakes and streams, which lead to reduced storage capacity, and reduced power output in power generation plants. Land degradation is together a cause and an effect of food security.

The causes of land degradation and desertification in the Mediterranean region are mainly related to complex interactions of diverse natural biophysical factors (climate, soil, topography, vegetation cover), which mainly determine the land hydrology, and social economic factors (population increase or decrease, migration, socio-cultural and economic changes, institutions), which determine land use changes (deforestation, fires, cropping, grazing, constructions) mainly affecting the hydrology of a territory. The ignorance of land users, and more of land planners and technical advisers about these changes in land hydrology related to changes in land use and management have a strong influence in the desertification processes in many cases.

In the medium or long term, it is previewed that global climate changes may contribute to accelerate the processes of desertification in the Mediterranean region (Imeson and Emmer, 1992), but at short term, land use practices leading to soil degradation processes would increase the negative influence of those changes. There are significant uncertainties in predictions of regional climatic changes, but probably the Mediterranean region will warm significantly, with more precipitation in winter and less in summer, and declining annual precipitation in the southern part (N Africa and SE Spain), increasing the frequency and severity of droughts, and the occurrence of extreme events. This will mainly affect the land hydrology (Wigley, 1992; Palutikof and Wigley, 1996).

Increasing frequency of droughts, based upon reduction in annual rainfall, leads to land desertification, but widespread incidence of drought could be a result of changing land use, without a necessary change in climate, through a reduction in the effectiveness of rainfall by land degradation processes. Climate variability changes in the frequency and magnitude of extreme events could have a greater impact than changes in mean climate alone. In mountainous areas of the Mediterranean region, with already degraded lands, heavy seasonal rainfall and extreme events may result in concentrated runoff, rushing down in great volumes as flash floods, causing extreme damage downstream. Landslides may also be initiated by those intense rainstorms in mountain areas.

Although economic forces, closely linked to political ones, drive people to degrade land, once this is overcome there is required to know how to manage the land to avoid such degradation, or to rehabilitate already degraded land. The basic causes of land degradation and desertification in the Mediterranean region are the same, but the prevention and remedial measures have to be adapted to local biophysical, social economic and political conditions.

4. HYDROLOGY AND DESERTIFICATION

Water, that is often the main limiting factor of plant growth, is also the main factor directly or indirectly responsible for soil and land degradation processes. These processes, leading to desertification, are strongly linked to unfavourable changes in the hydrological processes responsible for the soil water balance and for the soil moisture regime, which are affected by the climate conditions and variations, and by the changes in the use and management of soil and water resources.

The soil moisture regime, determined by the changes in soil water content with time, is the main single factor conditioning moisture availability, plant growth and crop production. It is mainly conditioned by soil properties affecting the capacity and possibilities of infiltration, retention and drainage of rainwater, and the limitations to root growth under the particular rainfall characteristics (Pla, 2002a). These conditions may be modified by soil and plant management practices as tillage, irrigation, drainage, etc. Moisture availability is determined both by water gains from precipitation and water losses through runoff and evapo-transpiration (Tables 1, 2 and 3).

CLIMATE	**LENGTH OF GROWING PERIOD (LGP) (days/year)**
VERY HUMID	365
HUMID	270 - 364
SUB-HUMID	180 - 269
SEMIARID HUMID	120 - 179
SEMIARID DRY	75 - 119
ARID	1 - 74
DRY	0

Table 1. Classification of the climate regime (FAO, 1982) as a function of length of growing period (LGP : days with soil moisture higher than the permanent wilting point)

EFFECTIVE SOIL ROOTING DEPTH (cm)		**FC - PWP (Θ) 0,20**	**FC - PWP (Θ) 0,40**
25	**AWC (mm):**	50	100
50	**AWC (mm):**	100	200
100	**AWC (mm):**	200	400

Table 2. Available water capacity (AWC) of the soil as a function of effective soil depth and of soil water retention capacity (Field Capacity (FC) – Permanent Wilting Point (PWP)) (Θ : Volumetric soil water content)

YEAR	RAINFALL (mm/year)	RUNOFF (% rainfall)		AVAILABLE WATER CAPACITY (mm) 50	100	200	400
DRY	313	0	**LGP** (days/year):	91	95	95	95
		50	**LGP** (days/year):	65	65	65	65
AVERAGE	522	0	**LGP** (days/year):	151	197	205	205
		50	**LGP** (days/year):	122	132	132	132
HUMID*	785	0	**LGP** (days/year):	194	208	228	267
		50	**LGP** (days/year):	183	196	200	200

*Table 3. Length of potential growing period (LGP) during the year, under a semiarid Mediterranean climate as a function of climate variability (total rainfall and distribution), available water capacity of the soil, and % of rainfall losses as surface runoff (*year with rainfall highly concentrated in a few storms at autumn-winter time).*

In the arid and semiarid Mediterranean climate, the rainfall is highly variable among years and during the year, and usually occur in erratic storms of short duration and high intensities. The concentration of rainfall in a relatively cool season (autumn and winter) permits reliable cropping in areas with annual rainfall as low as 330-400 mm (see Table 3). Under non-protected soil surface, associated to some intensive agricultural practices and overgrazing, extra precipitation in winter, occurring in intense episodes, may not be stored in the soil, but lost as runoff (Pla and Nacci, 2001). These factors increase the risks of land degradation leading to desertification processes.

The previewed effects of global climate changes would mainly affect hydrological processes in the land surface, mostly related to the soil water balance. In terms of ecological and social impacts of climate change, changes in moisture availability are more important than changes in precipitation alone. Low levels of moisture availability are associated with droughts and desertification. Reductions in mean annual rainfall leads to drier conditions, but increase in climate variability during the year, or increasing frequency of very dry years, could be equally or more important. Therefore, the term aridity for evaluating desertification, instead of only considering average rainfall conditions, would be more appropriate if it also consider variability through the whole hydrological cycle as well as climatic variations and fluctuations.

Human activities leading to land desertification processes may affect more the soil hydrological processes than the previewed climate changes, or may increase the influence of those changes (Pla, 2001). Forests usually regulate stream flows, protect land from erosion, reduce flooding in adjacent areas, minimize the silting of rivers, canals and dams, and contribute to a stable hydrology essential for providing stable sources of water for human needs and irrigated agriculture. This water balance may be drastically upset by deforestation and forest fires, and especially by the consequent land degradation. Supply of available water may decrease irreversibly under unchanged soil properties and stable hydrological soil parameters due to reduced water income, increasing water consumption, or both. Under unchanged water income by rainfall, the hydrological parameters of soils may change irreversibly as a result of soil degradation (sealing, compaction, erosion, decreased water holding capacity, etc); leading to the same effects of decreasing available water supply (see Table 3).

Irrigation causes drastic changes in the regime and balance of water and solutes in the soil profile, which may result in soil salinisation, one of the processes of soil degradation leading to land desertification. The salinity problems are a consequence of salt accumulation in zones and depths where the soil moisture regime is characterized by strong losses of water by evaporation and transpiration, and by reduced leaching of the remaining salts. The salt accumulation may conduce to a partial or complete loss of soil capacity to provide the required amounts of water to plants, changing fertile lands to deserts (Pla, 1996).

From the previous arguments, it follows that approaches based on water balance models are the more adequate to predict the reliability of the water supply for a plant during its growth. This would be the main basis for determining the suitability of the land for various uses under given conditions of management. There is required research into the basic hydrological processes of land degradation, including climate and soil data. Research is also required on the hydrological changes as a result of various alternative land uses and agricultural systems and practices. The degree of aridization of soil may be quantitatively determined in terms of certain physical properties and water regime of soils (annual supply of available water in the root zone), using soil hydrological parameters. Therefore, basic research in hydrological processes, including climate influences, must precede monitoring of desertification, because we cannot know what to monitor if we do not understand those basic processes and their impact on desertification.

5. ASSESSMENT OF DESERTIFICATION IN THE MEDITERRANEAN REGION

There is required a large scale integrated assessment of land/soil degradation and desertification in the Mediterranean region, in order to formulate the related prevention and mitigation strategies. Assessments should begin at the local levels, rather than begin at the global or regional levels. The assessment must include past trends, current state and prospective development of soil degradation and land desertification, which should be based mainly in soil hydrology related indicators. The most serious constraints are due to the soil data provided by the national soil surveys, which is mainly static information without any indication on changes and trends, very important for environmental protection purposes. There are also required soil monitoring systems, aim to deliver information on changing soil parameters, important for soil functions, based on systematic sampling and measurements.

Rainfall, which is very variable in the arid and semiarid Mediterranean climates, becomes the most fundamental data source for monitoring desertification. Also there is required a systematic tracking of vegetative production and soil conditions. A watershed approach for the biophysical resources would help to effectively integrate the information for estimating degradation processes. For tackling large watersheds, it is recommended to carry out first a reconnaissance level analysis of the problems to identify the areas that need focused attention, and then launch a detailed analysis in the targeted small areas.

Assessment and monitoring of desertification have the primary objective to forewarn about some impending crisis of land degradation and desertification, as well to suggest some preventive and remedial measures. These objectives cannot be met without a proper understanding of the processes responsible for desertification, which is the main limitation with the empirical methods generally used presently for assessing desertification and land degradation. There are required other methods, based on hydrological evaluations, to evaluate the problem.

The most commonly used methods for assessing desertification include:

- Field monitoring
- Productivity changes
- Sample studies based on field criteria and opinion of land users
- Expert opinion
- Remote sensing

- Modelling

None of them could be used alone, some need calibration, and others depend on subjective criteria, or are very expensive to be used extensively and continuously.

In most of the cases a weak knowledge of the hydrological processes involved and of the nature of desertification and the inadequacy of the methods for the assessment and monitoring of such processes hampers the adoption of integrated use of soil and water resources and of management policies and rehabilitation programs (Pla, 1998).

It has been proposed to use a set of indicators for assessment of desertification, taking into consideration the particular natural and socioeconomic aspects (Rubio and Bochet, 1998). Desertification is such a complex process that a single indicator will not be adequate to represent the great number of interrelated components. Indicators of desertification must be able to value the conditions and changes of quality and state of such process, and must provide means to compare trends and progress over time of desertification in different scenarios of climate, soils and land use. This requires a holistic, multidisciplinary approach.

Some desertification indicators that have been used include:

- Rainfall
- Aridity index
- Drought index
- Vegetation cover
- Soil depth
- Slope
- Infiltration capacity
- Population density
- Grazing intensity

Oversimplified indices like drought, using climatic maps; vegetation cover, using satellite imagery, and others, which fluctuate year after year, have limited diagnostic criteria (UNCCD, 2003). When mostly qualitative indicators are used, elements of subjectivity are many times involved in the assessment of desertification, depending on interpreters experience or bias. There is a need for searching more acceptable and easily determinable criteria that are measurable.

So far, Global Assessment of Human-induced Soil Degradation (GLASOD) methodology for identification and mapping of degradation categories (ISRIC-UNEP, 1990), that puts more emphasis on impact of degradation on productivity than on the degree of degradation, has been a methodology widely used. This methodology can not show separately different degradation classes and their severity, due to the poor spatial resolution of the small-scale maps. It would be necessary to use mapping at larger scales, where the areas under different degradation classes and severities could be represented separately, in order to be able to use indicators of desertification for the ultimate objective of understanding the different land degradation processes and for finding area-specific solutions to the problems.

It may be concluded that in order to assess and to predict adequately desertification there are required:

- Collection of sufficient field observations and data, mainly of hydrological nature, to reflect temporal and spatial conditions and variations.
- Identification of the causal processes
- Development, calibration and use of simulation models that can predict future changes

In all cases the used criteria must be clear, relevant, environmentally specific and scale-specific.

6. MODELLING FOR ASSESSING DESERTIFICATION

Most of the existing criteria of desertification, based mainly on climate and vegetation cover, have limited diagnostic criteria. The use of the so called soil quality attributes and indices to assess the vulnerability of soils to degradation and land desertification processes, scored from empirical judgements, do not allow relating the evaluation to the overall sustainability of alternate land use systems for production, control of environmental impacts, etc. There are needed other ways to evaluate the problem.

A hydrological approach to the assessment and prediction of the conservation of soil and water resources against degradation and desertification processes has proved to be essential for an adequate development, selection and application of sustainable and effective land use and management practices (Pla, 1998; 2001). The increased requirements of more quantitative results in probabilities and risks of soil degradation and land desertification, and its influence on crop production and environmental damage may be partially satisfied with the use of modelling, where the large number of important variables involved in the desertification processes, and their interactions, may be integrated.

Analysis and suitable modelling of data and processes helps to find out the trends in desertification and the responsible factors, under different bio-physical and social-economical settings. Modern techniques of digital remote sensing and geographical information systems (GIS) may be very helpful in the analysis and processing of the original and generated information. Modelling desertification requires a previous identification of the main desertification processes. Appropriate models must help in gaining more insight into the processes and on the understanding of the system as a whole. Although models cannot replace deciders, they supply them with valid and quantitative alternatives, required to take successful actions. In any case, simulation modelling has to be used with caution and should be based on sufficient local information. Field-based information is essential, and data obtained through digital remote sensing need to be verified in the field to be useful (Pla, 2002b).

Empirical models, like the so called Universal Soil Loss Equation (USLE) (Ref) and its revised version RUSLE (Renard et al, 1991) have been commonly used in the countries of the Mediterranean region, frequently without verification, for large scale water erosion (one of the more important soil degradation processes leading to desertification) risk mapping. Although the outputs and mapping using GIS may be impressive, they can hardly be used with a guaranty of success for development or prevention of desertification purposes (Pla, 2002b). There are required other non empirical modelling approaches mainly based on soil hydrological processes, deduced from soil hydrological properties together with historical rainfall records, under different scenarios of changing climate, soil properties, topography, and land and crop management, which may be combined in computer-based programs. The bio-physical data, mainly of hydrological nature, may be taken as surrogates for human impact, but in some models the social economic data are also fed into calculation procedures with variable success.

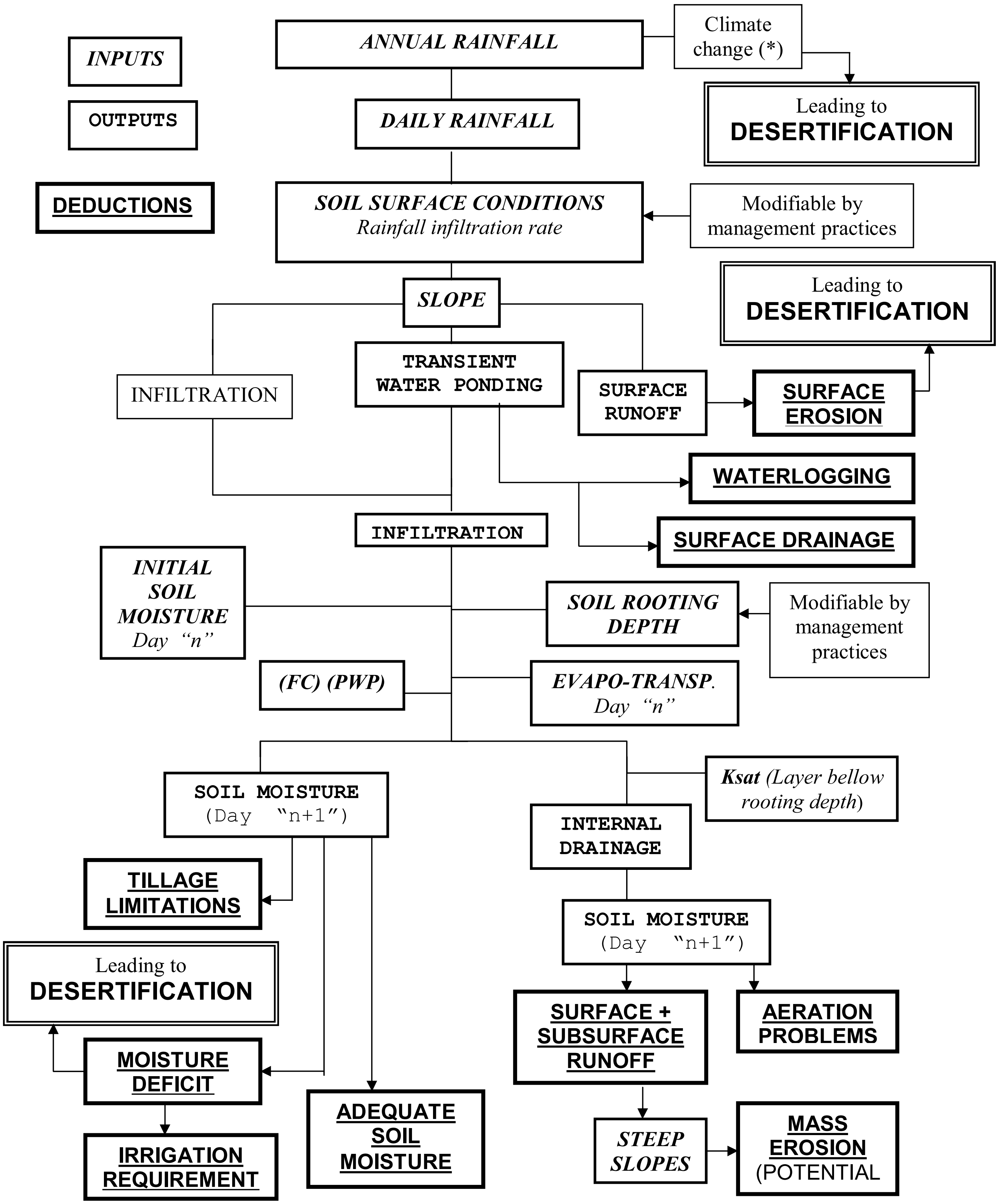
Simulation models based on hydrological processes may be very helpful to integrate and convert the measured or estimated soil, climate, plant and management parameters into predicted soil water balances and soil moisture regimes for each particular combination of them, actual or previewed (Pla, 2002b). These models not only help to understand the complex process of desertification, but they may also serve as decision-making tools to reduce or to avoid negative environmental impacts leading to desertification under different and changing scenarios (Richter and Streck, 1998).

Hydrological approaches allow combining the characteristics of climate with the characteristics of soils and landforms and land-use systems, for interpretation and prediction of land desertification hazards. When applied to a series of scenarios of land use and potential environment and climate change impacts, the results can be used by decision makers for future land use planning and implementation. This approach also makes the extrapolations more soundly based and provides a scientifically solid base which leaves little space for subjective interpretations leading to alternatives for different land use and management for agricultural and non-agricultural purposes. Modelling hydrological processes has proved to be a very reliable tool for evaluation and prediction of land degradation processes for guiding planning strategies for soil and water conservation and management practices, under very different climate, topography, soils, cropping and management conditions (Pla, 1997; 1998; 2001; 2002a).

Figure 1 shows an adaptation of the flow diagram, which was the basis for the development of the simulation model SOMORE (Pla, 1997), based on hydrological processes. This model simulates the evolution of the soil water balance in the soil profile with a time step of one day, using easily obtainable soil and climate data as input. It may be used to predict the soil moisture regime, including water logging, rainfall losses by surface runoff, and surface and internal drainage, under different conditions of soils, topography, climate, vegetation, crops and management. The predictions may be used to identify the more probable land degradation and desertification processes, and for the selection of the best alternatives, with more probabilities of success, and for the assessment of environmental impacts, positive or negative, of soil and water conservation practices (photos 5 y 6) for each combination of soils, climate and topography.

Figure 2 shows the flow diagram which was the basis for the development of the model SALSODIMAR (Pla, 1996), which integrates the influence of climate, crops, soils, groundwater depth and composition, irrigation water quality, and irrigation and drainage management on the desertification by salinisation, sodification and contamination of soils and groundwater. It may be useful, among other things, to preview the best alternatives for the use and management of the available soils and waters, preventing the process of desertification by secondary salinisation. It has proved to be reasonably good to predict salinisation problems and to deduce the best alternative practices for irrigation and drainage to prevent salinisation and sodification and other related environmental problems leading to desertification.

Figure 3 shows how the simulation models based on hydrological processes, used for the evaluation and prediction of potential soil and water degradation processes causing land desertification, may be integrated in the planning strategies leading to sustainable land use, management, and soil and water conservation practices, under different and changing scenarios (Pla,2001; 2002b)



(***Ksat***: Saturated hydraulic conductivity; ***FC***: Field Capacity; ***PWP***: Water retention at 1,5 Mpa)

Figure 1. Flow diagram of a conceptual model based on hydrological processes (SOMORE), to predict the soil moisture regime and to assess the potential soil and land degradation and desertification processes (adapted from: Pla, 1997). (in the Mediterranean region)*

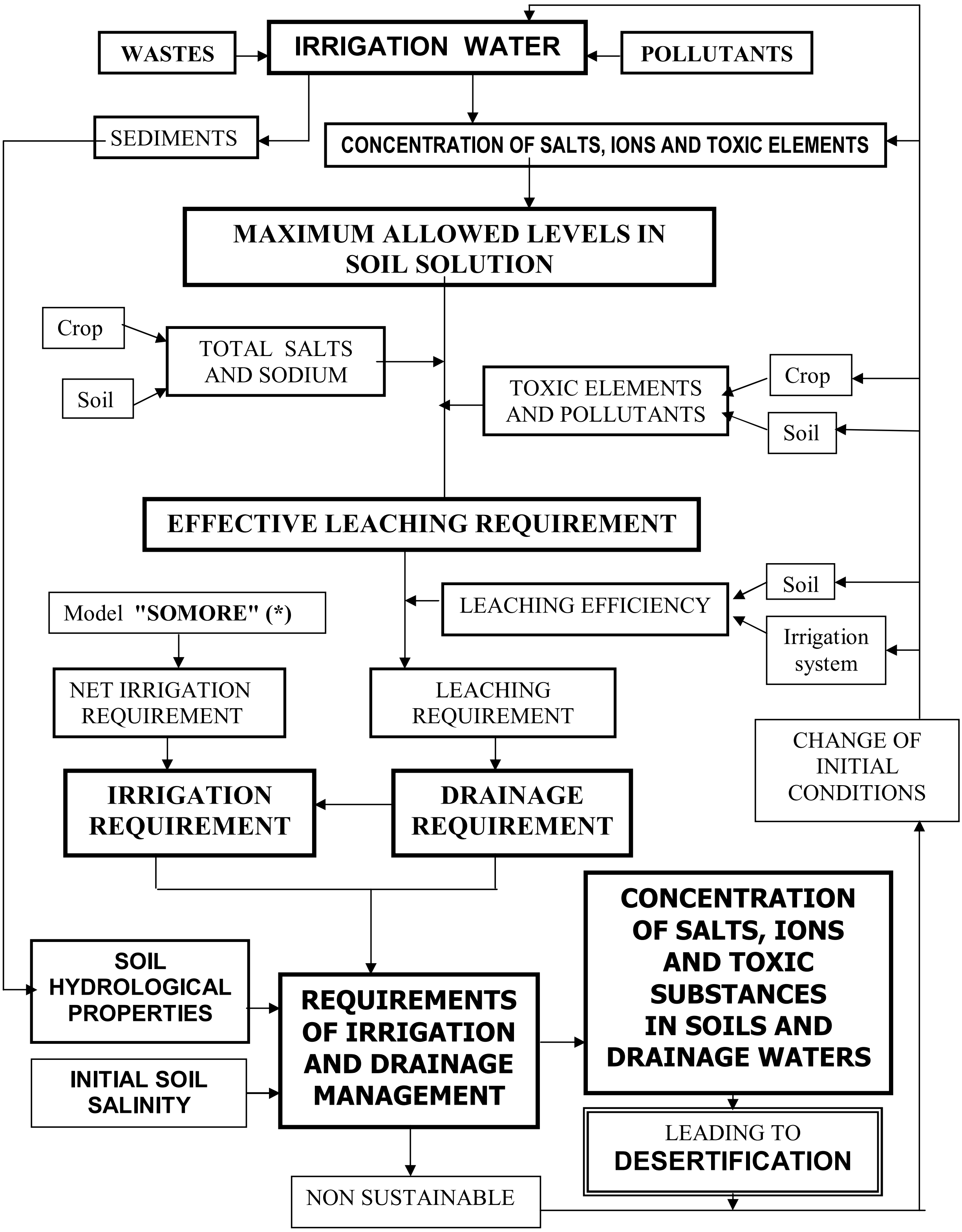


*Figure2. Flow diagram which was the basis for the development of the model SALSODIMAR (Pla, 1996) for evaluating and predicting land degradation and desertification by salinisation, sodification and contamination of soils and water(*see figure 1)*

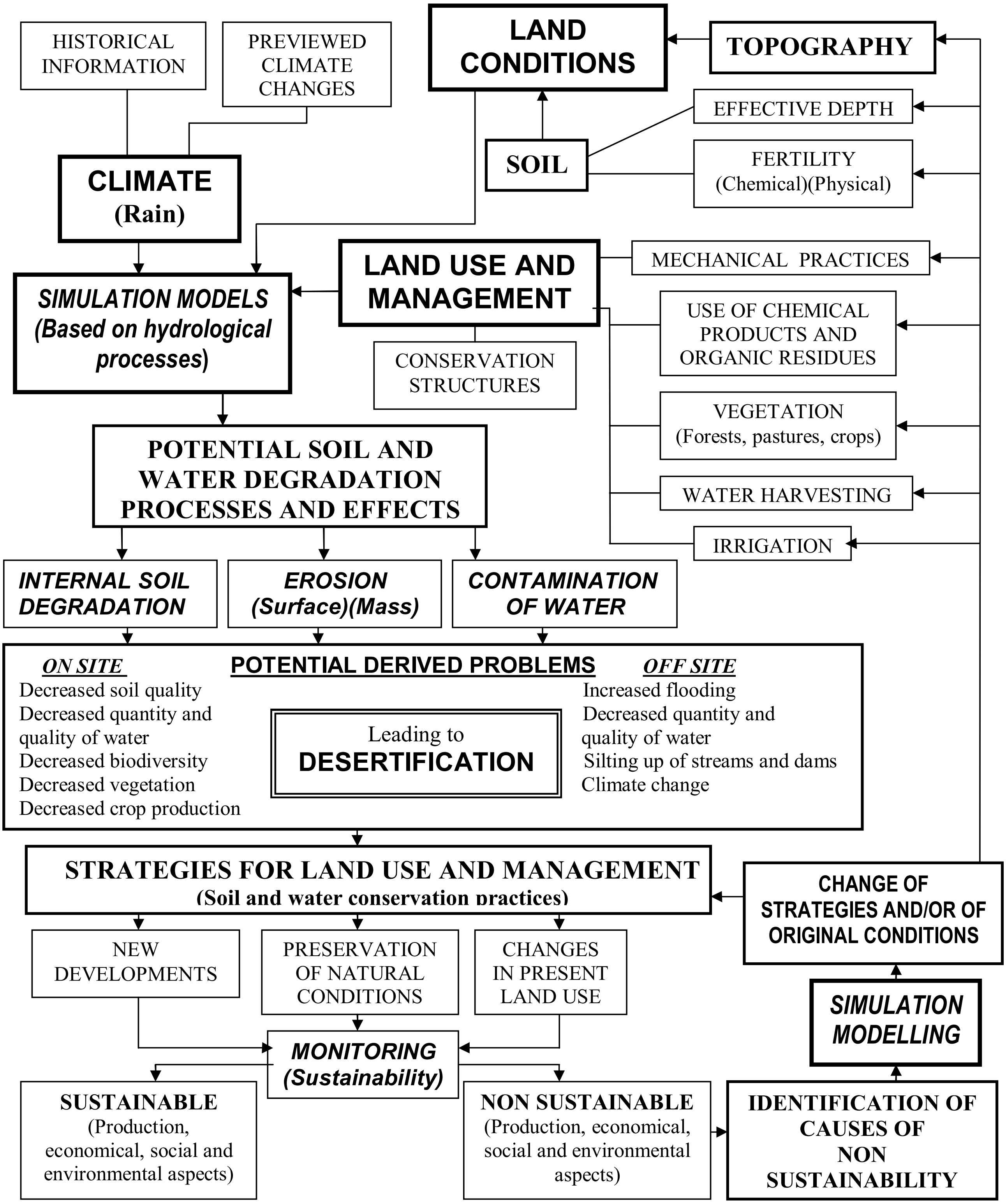


Figure 3. Role of simulation modelling based on hydrological processes(see figures 1&2) for evaluating potential soil and land degradation and desertification, and for planning land use, management and soil and water conservation practices (adapted from: Pla, 1991; 2002b)

7. CONCLUSIONS

Assessment of land desertification processes must be able to value conditions and changes of quality and state of such processes, and provide means to compare trends and progress over time of desertification in different scenarios of climate, soils and land use. To reach such objective, the indicators for land desertification should determine and analyse the cause-effect relationship involved, facilitating comparisons between biophysical and social economic causes and impacts of land desertification, and should be based on qualitative evaluations and quantitative measurements feasible from the technical, economical and institutional points of view.

Relationships between soil characteristics and soil hydrological properties are the beginning point to simulate or to predict dynamic soil desertification processes and their effects. Therefore, a hydrological approach to the assessment and prediction of conservation of soil and water against desertification processes, is essential for an adequate development, selection and application of sustainable and effective land use and management practices. Weak knowledge of the hydrological processes involved, and of the nature of desertification, and the inadequacy of methods for assessing and monitoring of such processes, usually hampers the adoption of integral resources use and management policies and rehabilitation programs in areas subjected to desertification in the Mediterranean region.

Parameters of the available water supply, deficit of soil water and soil water regime, single or together, may serve as reliable measurable criteria of the degree of soil aridization in time and space. Their practical utilization for the assessment of the degree of land desertification will require research on the water regime of soils under desertification, using an adequate methodology. Without such research, other considerations of degree of desertification will be mostly subjective, being based on indirect criteria and not in the direct measurement of hydrological parameters.

Assessment of land desertification processes must be complemented with monitoring, through systematic permanent or periodic observations and measurements of climate parameters, biological productivity and water regime of soils.

The evaluation of the hydrological processes, under different scenarios and changing climate, soil properties and land use and management, with flexible simulation models based on those processes may help to predict and to identify the biophysical causes of desertification at local, national and regional levels in the Mediterranean region. This is a required previous step for a rational land use planning, and for the selection and development of short and long term strategies and technologies to reduce or to control land degradation processes leading to desertification, and to the related social economic and security problems.

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