Land and Soil Degradation Assessments in Mediterranean Europe – the GMES-Project LADAMER

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1. Introduction

During the 20th century, purely climate climatic factors were rarely responsible for desertification in the Mediterranean region, because droughts are relatively short-lived. Present land degradation in Northern Mediterranean countries is partially due to dramatic land use changes that occurred during the second half of this century and which in many cases lead to an unstable state of ecosystems. Natural and agricultural ecosystems may be affected, but in most cases they recover easily. Socio-economic disturbances, particularly when they occur combined with climatic fluctuations, become the main drivers of desertification in the area. They affect water balances and land degradation through changes in land-use patterns. In particular, large areas of Mediterranean rangelands are affected from transitional processes that cause conflicts between past and present land uses or economic and ecological priorities, i.e. between optimised productivity and ecosystem conservation. Desertification, as a specific expression of land degradation processes, is a concept applied by scientists and policy makers after droughts threatened the Sahel in the last quarter of the 20th century, defined by the United Nations Convention to Combat Desertification (UNCCD) as "the degradation of the land in arid, semi-arid and dry-sub-humid areas, as a result of several factors, including climatic change and human activities". The dominant symptomatic character of this definition does not account for the underlying processes of the phenomenon. The consequence is that the popular meaning of desertification is often associated with a catalogue of environmental calamities rather than specific distress in the human population-renewable resources system. In such conditions both prospects and mitigation become extremely uncertain.

2. Land Degradation Assessments

A major difficulty of assessing land degradation is inherently related to the very concept, as 'the loss of the land's capacity to produce goods and services'. This is a rather unspecific symptom which may involve a large array of processes, each with its own boundary conditions for its detection or monitoring. Land degradation assessment methods have evolved from classic field survey methods for soil and vegetation mapping and land suitability evaluations to the more recent ecological approaches. These ground-based methods score low for most of the practical requirements, but when based on broad field experience, they may yield very accurate results in relatively small areas.

Initially, although it was already recognized in principle that land degradation involved complex interactions between physical and socio-economic process domains (e.g., Perez-Trejo, 1994), a large part of research activities focussed on soil erosion assessments as a core indicator for degradation processes. The European Commission, for example, launched a first attempt to produce exhaustive maps on natural resources and soil erosion risks in Mediterranean Europe (CORINE, 1992; see also figure 1). These initial mapping experiments on one hand suffered from methodological shortcomings but also revealed major deficits due to the limited availability of base data layers on European scale. The data availability has meanwhile largely improved (i.e. European Soil Map at 1:1 million scale, CORINE Land Cover, etc.) such that recent research activities like the "Pan-European Soil Erosion Risk Assessment"-Project (PESERA) can build on more solid grounds and achieve substantially improved results (Grimm et al., 2001).

Besides, the insight that land degradation assessments must go far beyond the soil erosion issue has grown considerably. Human population and natural renewable resources may be considered two linked elements in a single system, which is affected by climatic or socio-economic disturbances. The former include droughts, rain spells, etc. The latter involve demographic, political, market and technological changes that enable or disenable access to those resources. Under steady-state conditions, intensity and duration of disturbances remain within the range of those that have appeared throughout the history of the system. They have been incorporated in its own evolution, in such a way that it recovers quickly after they have ceased. However, a new or very extreme disturbance or combination of disturbances may happen that takes the system beyond its threshold of sustainability (Puigdefabregas & Mendizabal, 2003). This may occur as an increased availability of resources (i.e. a humid period, the introduction of a new technology) an increased demand for products (i.e., higher prices, local increase in agricultural population) or the contrary, as a reduction of available resources (i.e., extreme drought).

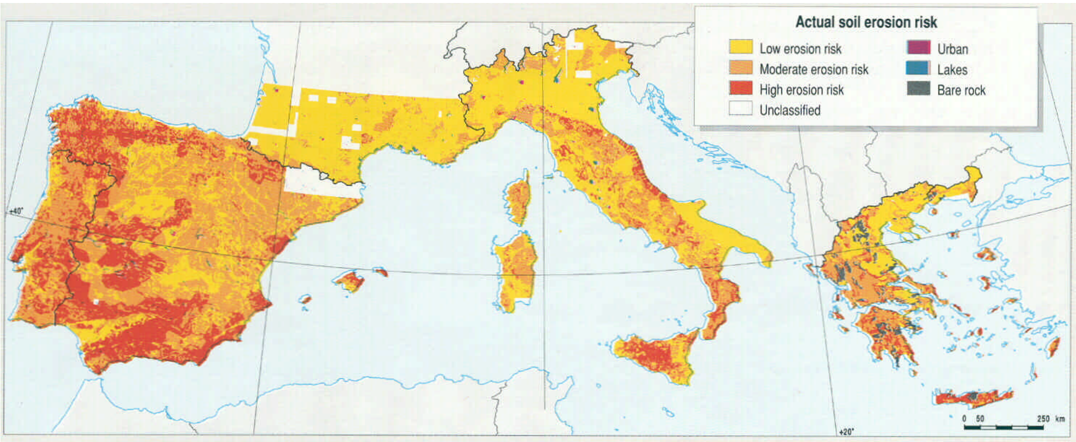

Figure 1. Actual Soil Erosion Risk Map of the European Mediterranean Countries (CORINE, 1992)

In both cases, resources become over-exploited. If the system is endowed with feedback mechanisms to reverse this condition, it can recover and return to the steady state. Otherwise it falls into an over-exploitation loop that leads to its own extinction. This process, when it happens in drylands, may be considered the core of desertification (Puigdefabregas, 1998). Such disturbances or desertification drivers may continue working to date or not. In the first case we are dealing with 'current' desertification. In the second, the forces that drove desertification in the past are no longer at work today. If resilience thresholds of natural resources have not been exceeded, natural recovery is possible, if they have (i.e., extreme soil erosion), we are dealing with 'relict' desertification. In the latter case, the imprints of past desertification are observable today, even after disappearance of the underlying factors. Distinguishing between current and relict desertification is crucial for designing treatment programs (Puigdefabregas & Menizabal, 1998). The former require either relieving driving forces or providing the affected systems with capacity for adaptation. The latter need only ecological and economically sound restoration.

3. The LADAMER Approach

During the past 10 years, the European Commission has funded numerous dedicated research projects in the field of land degradation and desertification which focussed on data collection in specific field sites, detailed methodological studies, assessment and monitoring experiments, and the development of specific modelling concepts. Although substantial scientific progress has been achieved and some projects succeeded to link a considerable number of field sites and case studies across the Mediterranean basin (e.g., Brandt & Thornes, 1996; Hill, 1996), the scientific community has, apart from few initiatives not been able to provide unifying concepts for assessing land degradation processes on Mediterranean scale as required by political decision makers.

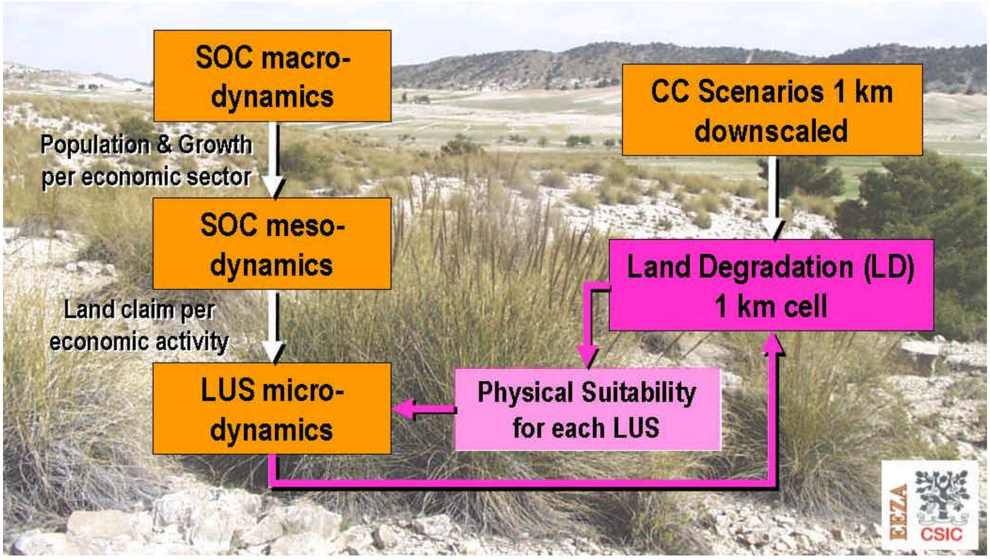

Figure 2. Design of a Dynamic Systems Approach for Land Degradation Assessment.

LADAMER (EVK2-2002-0599) builds on an integrated approach which combines specific fields of expertise in landscape ecology and soil science, remote sensing, spatial analysis and knowledge system management. The major concern of the project is to identify hot spot areas subject to a high desertification/degradation risk, and to provide an assessment of the present degradation status of Mediterranean lands on small scales. With regard to the substantial progress in data availability and methodological concepts achieved during the past decade it is a major objective of this proposal to provide such an exhaustive assessment. Following this rationale, it is believed that the LADAMER approach might supply products relevant to institutional end-users on national and international level, by integrating different models and techniques that have already proven their validity on local to regional scale. The major challenge for this integration is that the resulting methodological packages, in order to ensuring their applicability, are required to be objective, reproducible and transferable; include error estimates of the category assignation; be applicable at the regional scale over large areas; and have low data requirements, be cost-effective and easy to apply (Ludwig & Tongway, 1992; Mouat et al., 1992). LADAMER involves three components which will be streamlined to assess, monitor and forecast land degradation at a European Mediterranean scale.

3.1 The Land Degradation Assessment Component

A major difficulty of assessing land degradation is inherently related to the very concept, as ‘the loss of the land’s capacity to produce goods and services’. This is a rather unspecific symptom which may involve a large array of processes, each with its own boundary conditions for its detection or monitoring. Land degradation assessment methods have evolved from classic field survey methods for soil and vegetation mapping and land suitability evaluationto the more recent ecological approaches. These ground-based methods score low for most of the practical requirements, but when based on broad field experience, they may yield very accurate results in relatively small areas.

Current knowledge of land degradation processes, particularly concerning runoff and soil erosion, has already been incorporated in a range of distributed physically-based models, such as ANSWERS, SHE, KINEROS, LISEM and MEDRUSH (e.g., de Roo, 1993). These models can provide theoretical insight in complex cause and effect relationships and may be suitable to catchment scale case-studies on land degradation. Besides the fact that they are only addressing a facet of the land degradation problem they are also too demanding, in terms of input data, model implementation and calibration, to be an option for national and trans-national assessment studies. Characterisation of terrain form and topographic position have been an almost intrinsic part of land surveys for a long time. More recently, the use of DEMs and derived terrain attributes for the modelling and prediction of runoff and sediment transport patterns has been advocated. These approaches score better on many of the practical requirements and are especially suitable for the identification of potential hazard zones, but cannot be used for the monitoring of change (e.g., Puigdefabregas & del Barrio, 2000).

The vegetation cover interferes more or less directly with all water loss processes at a site in order to optimise to a certain extent the local water availability for their own benefit, an optimisation process which involves several sub-processes and feedback mechanisms. Recently, in the frame of the MEDALUS project, a theoretical framework for land degradation assessments has been developed (Boer, 1999) which relies on these vegetation functions to estimate the local water balance, in terms of rainfall to evapotranspiration ratios. Experience with the application and qualitative evaluation of this method was obtained in a medium sized area (1000 km^2). The approach is innovative in the sense that it provides a process-oriented, rather than descriptive, procedure for assessing land degradation on the basis of an established ecological theory while meeting most of the mentioned requirements for small scale applications. Its adaptation to LADAMER, requires the method to be upgraded in a number of aspects. The conceptual basis will be adapted to a wider range of climates, vegetation types, and land use settings. The temporal resolution will be increased from mean annual to annual and, possibly, seasonal to better capture the cover changes of deciduous and annual vegetation types or crops. Moreover, the conceptual basis and cartographic modelling procedures will be modified to allow application at a range of spatial resolutions (e.g. 30 m – 1 km). Multivariate regionalisation of the target area, in terms of soil-lithology, terrain and land cover types, are used to reduce uncertainty of the assessment.

3.2 The Remote Sensing Component

It is widely accepted that satellite remote sensing offers considerable advantages for land degradation assessments (e.g. Hill & Peter, 1996). With a comprehensive spatial coverage it is intrinsically synoptic, and provides objective, repetitive data which contribute to resource assessments and monitoring concepts of environmental conditions in drylands. However, only if these observations can be coupled with GIS-based ecological modelling concepts, they may develop their full capacity to be used for modifying and adapting environmental management principles and mitigation strategies.

It has long been known that surface properties (i.e., vegetation cover and composition, specific properties of parent material and soils) control water availability or the spontaneous emergence and development of new plants in drylands. Consequently, one of the objectives of remote sensing approaches is to focus on this particular interface. Particularly the application of the ecological assessment concept sketched before requires spatially distributed estimates of the actual vegetation density (i.e. proportional cover), and preferably a set of georeferenced sample sites were the deviation between actual and potential vegetation density can be assumed to be minimal. So far, the primary remote sensing input into the model has been limited to spatially distributed estimates of actual vegetation density (either as fractional cover or Leaf Area Index derived in relation to a satellite-based vegetation estimate) which can be derived with reasonable accuracy. In order to meet the prerequisites of LADAMER, this interface, which so far has been based on limited data series obtained from earth observation satellites (e.g. Landsat TM/ETM, ASTER) must now be extended to accommodate small scale multi-year observations from global monitoring satellites (SPOT VEGETATION, NOAA-AVHRR, MODIS, MERIS, see figure 3). Therefore, the objective is not to classify each pixel into land cover based on predefined classification schemes but rather to derive continuous fields of vegetation characteristics at a resolution of 1 km where also subpixel heterogeneities of land cover can be considered. A number of techniques have been proposed which also appear suited for a dedicated analysis of multi-year time series of SPOT VEGETATION data that cover the Mediterranean member states of the European Communities. Among these, the most interesting approaches include linear mixture modelling to deconvolve proportional land cover based on spectral or spectro-temporal endmembers, and artificial neural networks which make no assumptions about the linearity of the spectral response to mixtures (e.g., Atkinson et al., 1997). In several Mediterranean ecosystem studies, spectral unmixing techniques have already been successfully used at local scales using high resolution Landsat time series (e.g., Hill et al., 1995; Hill et al., 1998; Hostert, 2001; Pickup et al., 1994) which may facilitate a local validation of the continuous vegetation assessment derived global monitoring satellites.

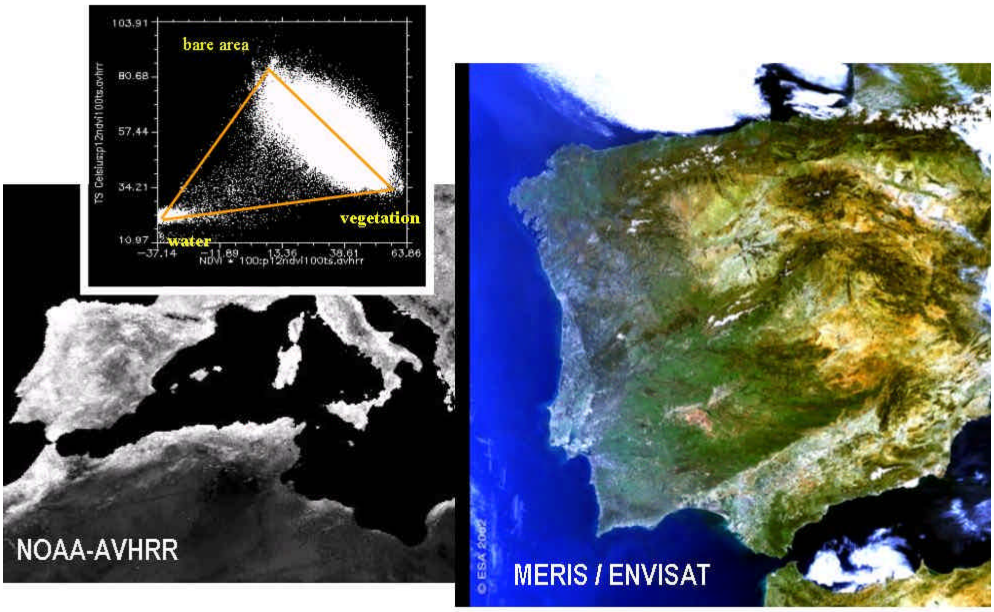

Figure 3. Data products from the NOAA-AVHRR satellites, and the MERIS-System on ENVISAT.

Changes of the vegetation density over time bear important information on land degradation dynamics which are induced by natural or man-made processes. In this respect, the production of suitable small-scale map representations of existing degradation trends, requires the decoupling of long-term trends and cyclic components of vegetation dynamics. Due to the complexity of such approaches, mostly automatic classification or principal-component-related techniques have been employed to global coverage and high temporal resolution imagery for mapping either phenology types or seasonality effects. While this is not yet providing a trend analysis in the classical way, it does constitute information that is of high significance for detecting hot spots of land use changes. The description of regional degradation trends will be further based on a classical trend analysis (parametric and non-parametric) of 20 years of pre-processed 8-km AVHRR Pathfinder data. Major emphasis will be given to novel approaches such as wavelet transforms, singular spectrum analysis, or temporal mixture analysis (e.g., Eastman & Fulk, 1993; De Fries et al., 1995; Piwowar et al., 1998; Marcal et al., 2000; Moody & Johnson, 2001; Shababov et al., 2002). Applied to a regional Mediterranean scale the remote sensing component should additionally provide a regional map on which areas of gradual (i.e. long-term) changes can be identified as well as so-called 'hot spots' of abrupt land use change. By coupling trend analysis of vegetation density with the local water balance approach described in the previous objective, we expect to be able to introduce the time dimension in the land degradation assessment. It is important to state that the methodology will be applied at the regional Mediterranean scale, and its performance for monitoring and early warning purposes will be evaluated.

3.3 The Land Use/Cover Change Modelling Component

The development of integrated assessment models is currently a rapidly expanding activity. This trend is propelled by the growing understanding that policy-making should be based on integrated approaches. Policy makers, responsible for the management of regions, watersheds, or coastal zones are confronted with this reality on a daily basis. They are to manage fragile systems that exhibit an extremely rich behaviour not in the least because of the many intelligent actors, the human inhabitants or users that steer the development in a direction of their own interest. As a result, today's research and development agendas strongly promote the development of tools enabling an integrated approach, which is promoted by the revolution in the computing hardware and software since the beginning of the eighties. Most relevant in the field of spatial planning and policy making has been the rapid growth of high resolution remote sensing and Geographical Information Systems in the past two decades. As a result new dynamic modelling techniques have been added to the toolbox of the spatial scientists. Agent based approaches, and in particular Cellular Automata, are rapidly gaining interest (e.g., Couclelis, 1997; Engelen et al., 1993; 1996).

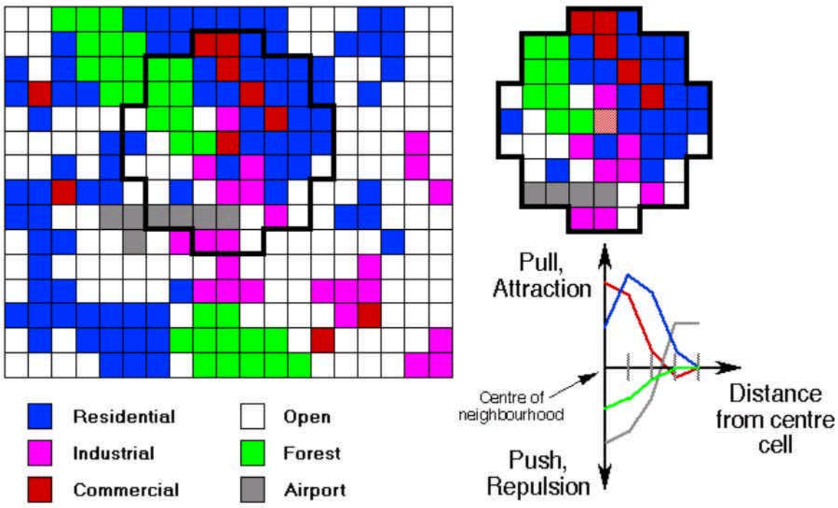

Figure 4. Conceptual aspects of cellular automata

Cellular Automata (CA) models can be thought of as simple dynamic systems in which the state of each cell in an n-dimensional array depends on its previous state and on the state of the cells within its neighbourhood, according to a set of stated transition rules. While the early applications of CA models in the spatial sciences remained rather conceptual and theoretical, most recent applications are developed with an aim to realistically represent geographical systems, both in terms of the processes modelled and the geographical detail represented (figure 4). This trend has come with an increase in the complication of the models developed. One of the very essential relaxations to the standard CA definition is the introduction of the finite non-homogeneous cell space: a bounded cell space consisting of cells having different attribute values representing physical, environmental, social, economic, infrastructural or institutional characteristics of the cell. This has allowed to conceptually and practically link Cellular Automata models with GIS. As a result, most recently, a number of authors have suggested ways to build Cellular Automata functionality into GIS and/or GIS functionality into CA. Just as important in the context of integrated modelling are the possibilities for linking CA models to other cellular models representing changes in the cellular space -in which the CA dynamics unfold- or to dynamic models operating at a more macroscopic scale. In the latter case, the macro-models will constrain the overall dynamics of the CA. The models developed, or under development, as part of EU-projects like MODULUS, Medaction, MURBANDY, and MOLAND have taken full advantage of the possibilities to link CA and other dynamic models. In MODULUS this has resulted in an integrated model representing the non-homogeneous character of the cellular space by means of models calculating among other: the soil quality and water balance, the quality and quantity of the aquifer, the characteristics of the natural vegetation. On top of these physical layers (partially also to be derived from remote sensing data), the human dynamics unfold changing the land use and land cover. These dynamics are governed by CA decision rules, representing human (spatial) behaviour, socio-economic preferences and decision-making, crop choices, etc. This is the basis from which LADAMER will start in its effort to integrate physical, ecological and land use models and apply them to the full Western Mediterranean in an effort to define the 'hot spots' areas prone to desertification.

3.4 Validation and Methodological Refinements

LADAMER is intended to provide a framework for generating at regional scale information on land degradation status and trends, which allows international and national planners and decision makers to identify those areas where efforts and eventually resources should be concentrated to prevent or mitigate desertification and related land degradation processes. To fulfil this function the information must be reliable and unambiguous, respectively the limitations and uncertainty levels of the methodology must be known. Consequently elements of product validation and uncertainty analyses of the various model parameters and remotely sensed variables are needed. An at least partial validation for the western Mediterranean appears feasible with regard to existing case studies produced in former EU-funded projects. Among these we find the southern Alentejo (DesertLinks, MedAction), the Guadalentin region in SE-Spain (MEDALUS, ERMES, DeMon), Languedoc in S-France (DeMon), Sardinia (GeoRange) and Crete (DeMon).

3.5 Specific GMES Aspects

In fact, the project encompasses two separate phases. The first phase will start with the procurement and processing of considerable volumes of geo-scientific, socio-economic and remotely sensed data covering the Mediterranean basin. The establishment of this unified data base will provide the basis for spatio-temporal analyses and the production of a regional land degradation map for the Mediterranean member states of the European Union. Together with the processed geo-data layers and spatialised socio-economic variables, this information will flow into a concept model to produce a land degradation assessment. The second project Phase will be devoted to a more in-depth validation, the integration of additional or improved data layers, and the evaluation of advanced methodological options to upgrade the quality and information content of models and products.

Given the improved availability of homogeneous geo-data layers on European land-use, soils and terrain elevation, the availability of climatic recordings used for agro-climatic modelling on European scale, the recent progress in remote sensing data collection and regionalised socio-economic data it One core element of the approach is to use existing datasets and concentrate on the integration of these, rather than procuring and processing completely new datasets. Although the required base data sets largely exist, it is a major objective of the proposal to assemble these in a unified project data base, where the spatial and thematic consistency of physical and socio-economic information will be ensured. Since much of this information is scattered across various European (e.g. EEA, JRC) and international institutions (e.g. the United States) it is a mandatory prerequisite for using all information in the assessment strategies developed in LADAMER. An additional key element is the provision of an appropriate metadata documentation to support the use of the database by different users. Needless to say that an important aspect in this GMES project is to understand whether “publicly available” data can also in practice be accessed within acceptable delays and transparent licensing procedures.

4. Summary

The combined output of LADAMER should be a comprehensive as well as spatially explicit image of land degradation effects and associated processes for the relevant European Mediterranean countries. It will hence serve as a kind of integrating project between former research approaches and ongoing monitoring and assessment efforts. Consequently, the innovative aspect of the proposed LADAMER Project lies in the novel combination of optical remote sensing methods with advanced physical, ecological and socio-economic modelling components. Combining these in a surveillance system is expected to substantially improve the quality of land degradation assessment and monitoring at the regional Mediterranean scale. The compiled data base is expected to build a basis for further GMES developments in the domain of land degradation research and other closely connected issues.

5. Acknowledgements

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