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SPACE FOR THE UNCCD AND THE DESERTWATCH PROJECT

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ABSTRACT

The ESA DesertWatch project goal was to develop an Information System for assessing and monitoring desertification using EO technologies, for supporting local authorities in reporting to the UNCCD. The project has selected the most robust and reliable methodologies developed during the related research projects, integrating them into a unique environment, which is easy to use, as automatic as possible and cost effective. The system outputs consist in a series of desertification indicators and products, generated at regional, national and sub-national scale. For demonstration purposes these products have been implemented over large areas of Portugal, Italy and Turkey for the years 1984, 1994 and 2004. The validation phase has shown that the results are in line with the user requirements. The system has been much appreciated by the end users and will be physically installed at various national and local authorities. The possibility of expanding the system in extra-European countries is under evaluation.

1. INTRODUCTION

Desertification is defined by the United Nations Convention to Combat Desertification (UNCCD) as “land degradation in the arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities” [1]. In the Northern Mediterranean 99.4 million hectares show signs of desertification, corresponding to about 32% of territory with arid, semi-arid and dry sub-humid climate [2]. As part of the Data User Element (DUE) of the Earth Observation Envelope Programme, the European Space Agency (ESA) launched in the 2004 the DesertWatch (DW) project, whose requirements have been defined in collaboration with North Mediterranean Region National Focal Points of the UNCCD. DW exploits the potential of Earth Observation (EO) technology for desertification monitoring, building an Information System (IS) aimed at supporting the

UNCCD and the parties in the convention implementation.

2. OBJECTIVES

The main project objective is to monitor desertification at various scales and through time, developing an IS which can be operationally adopted by national and local authorities for reporting to the UNCCD and for local rules and policy development. The system shall be easy to use, as automatic as possible and, most importantly, minimise the need of costly input data.

Many past and ongoing national and European research projects, such as MODULUS, MEDALUS, LADAMER, GeoRange, DeSurvey and RIADE combined EO and field data for monitoring land degradation at regional level. The DW IS is based on those research results, in particular on the commonly accepted MEDALUS approach, which integrates into a holistic view biophysical, socio-economic and management parameters to identify Environmental Sensitive Areas to desertification. The DW IS adapted this MEDALUS approach to compose a mainly EO-based system, which shall be a standardised, robust, reporting-oriented, and user-friendly tool.

3. STUDY AREAS

The DW IS shall be able to generate a set of desertification related indicators and products over large areas. For demonstration purposes the project has identified a number of study areas in Italy, Portugal and Turkey. In particular, the following areas have been analysed:

- Portugal: whole continental country
- Italy: Sardinia, Basilicata and Sicily regions
- Turkey: Konia Karapinar and Corouh watershed

Multitemporal mapping for the years 1984, 1994 and 2004 has been conducted over the study areas to demonstrate the system capability of monitoring changes and trends.

4. METHODOLOGY

Monitoring desertification extent requires the evaluation of a complex set of indicators, related to climatic (e.g.: rainfall, evapotranspiration, aridity indexes), biophysical (e.g.: morphology, soil and vegetation properties) socio-economic (e.g.: population density and age, employment) and management (e.g. policies, protected areas, master plans) factors [3]. The mentioned MEDALUS project approach, identifies Environmental Sensitive Areas (ESAs) through the definition of climate, vegetation, soil and management quality indexes [4].

Some of these indexes can be successfully assessed exploiting remote sensing technologies and geomatic applications [5], [6] and [7]. The DW IS uses primarily EO data, in combination with some ancillary data, into a seamless data processing facility.

To assess the needed indexes the following principal approaches/techniques were used:

- land cover mapping
- spectral mixture analysis
- land degradation index assessment
- spatial dynamic modelling

These techniques will be briefly described in the following paragraphs, along with the corresponding indicators/products generated.

4.1. Land cover mapping

Land cover maps are invaluable instruments for environmental monitoring and territorial planning.

In desertification monitoring, a land cover map provides a number of indicators which can be directly extracted from the map, thus providing useful and easily accessible information.

Even if land cover maps are usually available for the EU area (i.e. CORINE 2000 project, [8]), those maps are rarely updated or organized at the needed thematic detail for desertification monitoring purposes.

Hence, the first concern of DW project was to provide users with updated, cost-effective and accurate land cover maps, so that frequent monitoring and trends detection could also take place.

From those maps, the indicators needed to identify the ESAs areas are thus extracted by the DW IS facility. Other indicators, not used in the MEDALUS approach are also identified, as requested by users and UNCCD National Focal Points. All indicators can be aggregated spatially, providing statistics according to administrative boundaries (municipal, district, regional, national level etc.).

Land cover mapping relies on a fully automatic procedure that uses as input:

- 2 pre-processed Landsat satellite images (possibly from spring and fall seasons),

- Digital Elevation Model, Slope and Aspect
- CORINE land cover map (CLC)

All the steps are conducted into the DW IS. Preprocessing includes georeferentiation orthorectification and radiometric correction.

The most significant 5 bands are selected out of the input 2 images, using PCA technique and are merged with altitude, slope and aspect maps to produce a 8-band file ready to be segmented. A segmentation procedure, based on a multi-scale hierarchical weighted aggregation approach ([9]) is applied. Allowing to perform object oriented classification.

The training set can be extracted either manually (e.g. furnished from an external source) or automatically, via a filtering procedure based on the pre-existing CLC map.

The image classification adopts the Maximum Likelihood algorithm and is designed at producing 3 maps: one obtained using the bands for each season and one using the joined bands of both seasons. Burnt areas and internal and marine waters are masked with CLC dataset. A weighted consensus procedure, which uses the 3 classification results plus the original CLC map, is used for creating a unique land cover map. This map is cleaned up with a clump and sieve procedure which creates the final map having a Minimum Mapping Unit (MMU) of 5 hectares.

The adopted legend is an aggregation of the CLC legend into 12 classes (see *Tab. 1*), specifically identified to provide the necessary information for desertification assessment purposes.

Table 1. Land Cover legend used in DW

Coniferous forest
Deciduous forest
Mixed forest and Mediterranean maquis
Grassland
Permanent trees and heterogeneous agriculture
Not irrigated crops
Irrigate land
Artificial areas
Wetlands
Water
Bare land
Forest fires

From the land cover map a number of indicators are assessed by direct land cover class extraction:

- Forested areas (simply aggregating the vegetation classes of interest, i.e. Deciduous Forest, Coniferous Forest)
- Soil sealing (equal to the Artificial areas class)
- Irrigated lands (equal to the Irrigated area class)

Other indicators are assessed through specific spatial analyses:

- Forest Fragmentation (defined as in [10]): estimates forest quality over an area which is usually coincident with an administrative boundary, in terms of forest density (amount of forested area over total area) and continuity (number of patches/adjacent pixels into the forested area).
- Re-naturalized Areas: estimates the land cover change from agriculture to natural vegetation classes and relates it with demographic changes. Where a change from agriculture to natural vegetation occurs in a given area simultaneously with a population reduction (estimated by ancillary data such as census), the area experiments a re-naturalization.
- Burnt Areas: a specific Fire Tool has been developed and integrated into the DW IS to estimate those area. The tool uses the Normalised Burnt Ratio (based on the analysis of Landsat bands 4 and 7) to detect areas interested by fires in the time period comprised by the two seasonal satellite images acquisition dates.

4.2. Spectral mixture analysis

The semi-empirical model, known as *Spectral Mixture Analysis* (SMA), describes spectral reflectance signatures as a mixture of few prototype spectra, also called *endmembers* ([11] and [12]). In natural environments, the principal endmembers are typically represented by vegetation, soil, bedrock and shade, which commonly mix at the sub-pixel scale producing mixed-pixel spectra. SMA attempts to unmix such multispectral reflectance in order to assess, for each pixel, the relative abundance of each component. Using this technique it is possible to retrieve the following useful indicators ([13], [14] and [15]):

- Vegetation Abundance (VEA)
- Normalized Soil/Rock Ratio (NSRR)

The vegetation abundance, which simply corresponds to the proportion of the vegetation endmember, besides being an indicator in itself, can be used in conjunction with other parameters for the assessment of the vegetation quality index, as explained in section 5.5.

In Mediterranean ecosystems, NSRR can be seen as a surrogate of soil erosion, especially if the trend analysis shows a decrease of the ratio as explained in [15]. This technique can be used with both Landsat and MERIS EO data, for obtaining maps at local and national scales.

4.3. Land degradation index

The Land Degradation Index (LDI), whose computational details are described in [6], exploits remote sensing images, in conjunction with climatic and physiographic parameters, for assessing the landscape status with respect to its natural resources potential. It works on the assumption that sites in good condition will show outputs in their local water balance mostly through evapotranspiration rather than through runoff. Vegetation abundance, computed as indicated in the previous section, is used to estimate vegetation status. Input data fall into the following categories:

- remote sensing data: 2-years time series, with at least 6 frames per year, for VEA calculation
- climatic data: rainfall and potential evapotranspiration
- topographic data: obtained from DEM
- daily rainfall series from a single location
- external physiographic layers: lithology, soil types, terrain types, land cover

Based on the external physiographic layers, homogeneous land systems are identified and their status is expressed in terms of number of standard deviations from the population mean. The final values are then converted into 3 broad classes, that indicate, poor, normal and good land conditions. This index can be computed at various resolutions, according to the required mapping scale. For this project both Landsat and MERIS data have been used.

4.4. Spatial dynamic modelling

A spatial modelling tool has been developed for simulating Scenarios of Desertification (named ScenDes). The tool is able to generate possible scenarios for desertification monitoring, starting with a land use map at a certain time and simulating the land use evolution during the years. The complex simulation model uses local, zonal and neighbouring map-based rules for computing the land use transition potential. For each map pixel, the system computes the probability to change (transition potential) into each of the possible land use classes. In addition to this, based on socio-economic data, such as population, growth rate, job availability, etc., the ScenDes evaluates the total demand for each land use. For each simulation step (in these simulations the time step is set to 1 year) the system will try to meet the overall demand for each land use class, starting to change the pixels with highest transition potential, until the total demand is met. The core algorithm, based on the cellular automata paradigm, is described in detail in [16], [17], [18], [19] and [20]. The major input variables are listed hereafter:

- land use maps corresponding to at least 2 time periods, required for setting the initial status and for calibration purposes

- physiographic data (e.g.: soil type, digital terrain model, geological maps, climatic layers), used for defining the transition potentials, based on local suitability
- communication network (e.g.: roads, railways, with location of access points, stations), required for computing the transition potentials based on accessibility
- zoning maps (master plans, protected areas, natural reserves, etc.), required for identifying areas where certain land use types are not allowed in the simulation (e.g. the urban land use is not allowed in a natural reserve)

The simulation is typically carried out on periods of 10-20 years and allows to visualise possible land use scenarios. These land uses are finally translated into desertification indicators, in a way similar to what indicated in section 4.1.

4.5. Validation approach

The collection of validation data has been carried out by local teams identified by the DW end users, under the coordination of the project team. Validation data have been acquired directly on the field and, to a lesser extent, using photointerpretation. Different validation approaches have been used for the various product types described above.

For whole validation purposes, 3 areas have been identified in Italy (*Fig. 1*, left) and 10 areas in Portugal (*Fig. 1*, right), covering a total of about 25000 Km².

To validate the land cover maps and related desertification indicators, sampling points were selected using a stratified random sampling method, according to land cover type abundance.

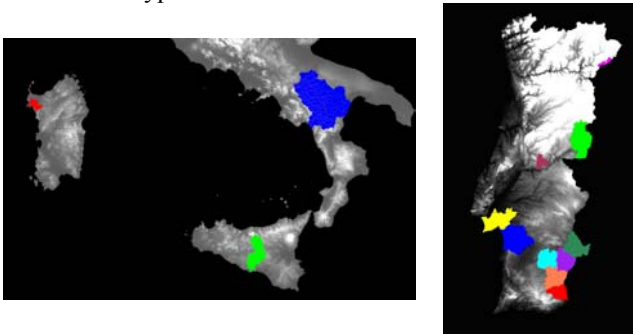


Figure 1. Validation areas in Italy(left) and Portugal(right)

The validation of SMA products have been based on the comparison of the relative abundances of vegetation, soil and exposed rock against the field measurements. For validating the LDI product, a number of qualitative attributes were estimated on the field, corresponding to ground attributes (topography, rock type, landform, etc.)

vegetation attributes (structure, density, condition, vigor, etc.), soil degradation features (signs of erosion, rock fragments, exposed deep horizons, etc.).

The final LDI validation shall be based on expert judgment of the produced maps, versus the field observation.

The ScenDes product, can be validated using at least 3 land cover maps acquired at different times. The 1st and 2nd land cover map are used for the calibration of the system, where the 3rd map shall be computed against the simulated scenarios.

5. RESULTS

5.1. Land cover related products

An example of land cover map generated over the whole Portugal is reported in *Fig. 2*. Land cover maps have been generated and validated against field data over Italy and Portugal, with an accuracy ranging between 75% and 85%. For Turkey the validation has been conducted against land cover maps provided by local partners, obtaining similar values of accuracy.

The indexes derived from the land cover map are not directly validated, considering that the validation of the original land cover map is most appropriate. Anyhow, the accuracy of the indexes, often being aggregation of more than one land cover type, ranges usually over 80%.

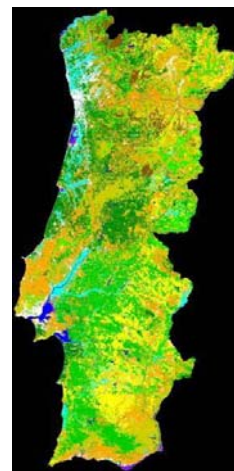


Figure 2. Land Cover map produced over Portugal

5.2. Spectral mixture related products

The VEA and NSRR maps has been generated over all the project demonstration areas. A preliminary validation analysis has been carried out in Sicily, using 45 sampling plots and the Landsat-based VEA map. The scatterogram of the ground based estimates vs. the VEA best pixel within 30 m, reported in *Fig. 3*, shows a good correlation, with $R^2=0.74$. Validation of NSRR is still in progress.

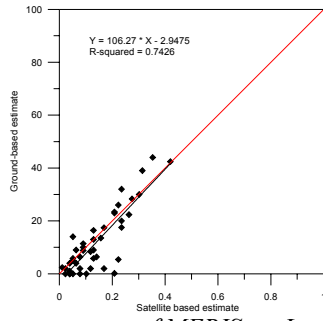


Figure 3. Scatterogram of MERIS vs. Landsat derived vegetation abundances

5.3. Land Degradation Index products

The LDI maps have been generated in most project areas. An example of map generated in the Southern part of Portugal is represented in Fig. 4. The product validation is still in progress.

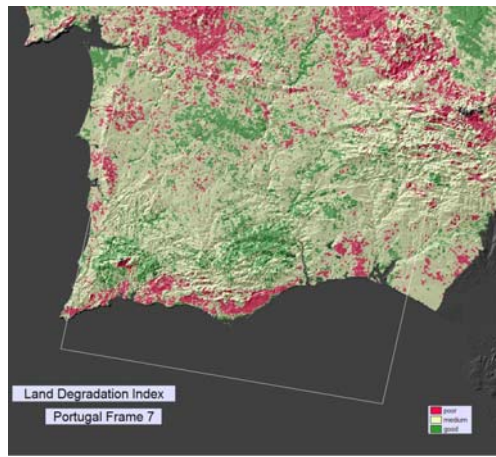


Figure 4. LDI map generated over a South Portugal area.

5.4. Desertification Scenarios

The ScenDes tool for the generation of desertification scenarios has been set-up and calibrated over 4 areas, corresponding to the whole continental Portugal, and the Italian regions of Sicily, Sardinia and Basilicata. The results have been judged and discussed with expert panels during ad-hoc thematic workshops.

5.5. Generation of the Environmental Sensitive Areas (ESA) map

According to the previously mentioned MEDALUS methodology, it is possible to generate the Environmental Sensitive Areas (ESA) map, which gives the susceptibility to desertification. The ESA map is computed according to the following formula:

$$ESA = (CQI * VQI * SQI * MQI)^{1/4} \quad (1)$$

where: CQI is the climate quality index; SQI is the soil quality index; VQI is the vegetation quality index; MQI is the management quality index. CQI and SQI are computed using external GIS data. The VQI is defined as follows in [4]:

$$VQI = (FR * EP * DR * PC)^{1/4} \quad (2)$$

where: FR is the fire risk; EP is the erosion protection; DR is the drought resistance; PC is the plant cover.

The DW land cover maps are used for assessing the FR, EP and DR parameters: a different value is assigned to each land cover class according to the model described in [4], with some slight modifications needed to use EO data as main input source. The PC parameter is simply derived from the VEA products obtained with SMA technique.

The MQI is defined as follows in [4]:

$$MQI = (LUI * PP)^{1/2} \quad (3)$$

where: LUI is the land use intensity; PP indicates the protection policies.

The LUI is calculated on the basis of the DW land cover, using a weighting procedure similar to that described above. Regarding PP calculation, information should be provided by the users, regarding administrative limits of protected areas (National Parks, nature reserves, etc.). Thereafter, a weighting system assigns different score to areas covered by natural or semi-natural vegetation in DW land cover map which are protected through different policies and rules.

6. CONCLUSIONS

The obtained results are in line with requirements defined by the project. Goodness of input data, including ancillary ones, obviously influences the final results: the flexibility of the DW IS permits to update the products in terms of frequency, producing new information at low cost, and in terms of quality, using better ancillary data as they become available. The validation phase has been a chance to evaluate the DW IS and the products with an active end user involvement. The registered level of satisfaction for the system and the indicators and maps produced has been very high. The DW IS will be soon installed in the appropriate head offices (Ministries, Local territorial authorities etc.) and routinely used to report desertification trends. At present, an extension of the DW project to extra European countries is under evaluation, to adapt the system to different data and environments, with a special focus on developing countries where the majority of land desertification occurs.

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