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Present and future of desertification in Spain: Implementation of a surveillance system to prevent land degradation

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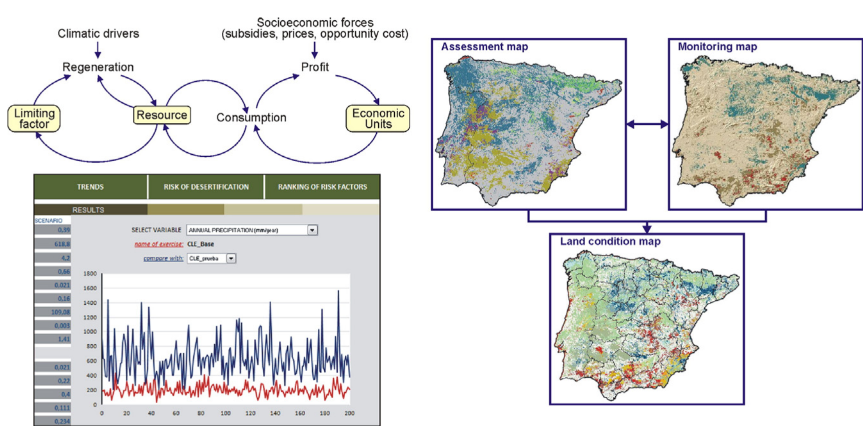
HIGHLIGHTS

- Early warning systems based on simulation models allow to anticipate desertification.
- Land degradation maps help identifying prior areas to implement solutions.
- In Spain 20% of the territory is degraded; an additional 1% is actively degrading.
- The risk of desertification is high in crop systems and low in rangelands.
- Main driving forces in land-uses under study is precipitation.

GRAPHICAL ABSTRACT



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ABSTRACT

Mitigation strategies are crucial for desertification given that once degradation starts, other solutions are extremely expensive or unworkable. Prevention is key to handle this problem and solutions should be based on spotting and deactivating the stressors of the system. Following this topic, the Spanish Plan of Action to Combat Desertification (SPACD) created the basis for implementing two innovative approaches to evaluate the threat of land degradation in the country.

This paper presents tools for preventing desertification in the form of a geomatic approach to enable the periodic assessments of the status and trends of land condition. Also System Dynamics modelling has been used to integrate bio-physical and socio-economic aspects of desertification to explain and analyse degradation in the main hot spots detected in Spain.

The 2dRUE procedure was implemented to map the land-condition status by comparing potential land productivity according to water availability, the limiting factor in arid lands, with plant-biomass data. This assessment showed that 20% of the territory is degraded and an additional 1% is actively degrading. System Dynamics

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2dRUE procedure
System Dynamics modelling

modelling was applied to study the five desertification landscapes identified by the SPACD. The risk analysis, implemented on these models, concluded that 'Herbaceous crops affected by soil erosion' is the landscape most at risk, while the Plackett-Burman sensitivity analysis used to rank the factors highlighted the supremacy of climatic factors above socioeconomic drivers.

1. Introduction

The development of methodologies and tools for monitoring and assessing desertification is encouraged by the United Nations Convention to Combat Desertification (UNCCD) through National Plans of Action (UN, 1994). This is a response to the major threat to drylands with direct impact on human well-being and social welfare, as Millennium Ecosystem Assessment warns (MA, 2005; Vogt et al., 2011).

Following this topic, the Spanish Ministry of Agriculture, Food, and Environment reaffirmed its commitment by preparing its Plan (MAGRAMA, 2008). First, the Spanish Plan of Action to Combat Desertification (SPACD) established desertification landscapes on considering criteria that take into account the definition of desertification given by UNCCD, where land degradation results 'from various factors including climatic variations and human activities'.

Most desertification landscapes have been identified in arid lands according to specific land uses and the natural resource affected by it: (1) irrigated crops that trigger desertification processes linked to groundwater exploitation in inland and coastal areas; (2) agro-silvo-pastoral systems and overgrazing, specifically Dehesa rangelands in western continental areas; (3) degraded shrublands and wastelands distributed throughout the drylands; (4) woody crops affected by soil erosion, such as olive orchards and vineyards in southern continental areas; and (5) extensive rainfed herbaceous crops affected by soil erosion in the Ebro and Guadalquivir river valleys.

In all of these cases, a common pattern can be drawn: sudden land-use changes driven by abrupt transformations of socioeconomic conditions that trigger physical degradation processes, as reported in a large number of studies (see for example Foley et al., 2005 and Upadhyay et al., 2006). These state that land-use changes leading to environmental degradation usually occur where the new use does not match the soil's natural capability, and these changes are referred to as land-use conflicts (Pacheco et al., 2014; Valle Junior et al., 2014).

Secondarily, the risk of desertification was calculated. The methodological approach was based strictly on the principles of the UNCCD. The SPACD considered four indices at the sub-basin level that work additively: aridity, soil erosion, cumulative percentage of surface area burnt by wildfires in the period 1996/2005, and aquifer overexploitation according to the net groundwater balance. Each of these indices was transformed into qualitative classes. The final aggregation yielded the main areas prone to desertification.

The SPACD was the first full assessment of desertification in Spain. However, it has to be considered as a starting point that can be improved. The aim of this paper is to present the most recent developments that followed the SAPCD (Sanjuán et al., 2014; Rojo et al., 2015). They are supported by two methodological approaches that respond to the major concerns of the scientific community: "the lack of sufficient and integrated monitoring and assessment" (Vogt et al., 2011).

On one hand, the 2dRUE tool, as originally was published (del Barrio et al., 2010), is a low-cost methodology that (1) uses open-access data and (2) offers verifiable and easily understood maps of land condition after a complex computational calculation routine. The Integrated Evaluation System and Monitoring of Desertification, an explicit goal of the SAPCD, has updated a methodology based on the Rain-Use Efficiency (RUE) concept to assess land condition for the period 2000–2010 (Sanjuán et al., 2014).

The 2dRUE methodology has been officially adopted by Spain (Sanjuán et al., 2013) and Portugal (Rosario et al., 2015) to report regularly to the UNCCD. It has also been implemented in different regions around the world like the Maghreb, Sahel, north-eastern Brazil, and Mozambique; it is currently being applied to study land degradation in China (Gao et al., 2014).

On the other hand, a collection of multidisciplinary simulation models has been developed to evaluate the risk of desertification with an alternative approach, in the aforementioned landscapes. These integrated assessment models are adaptations of a Generic Desertification Model (GDM; Ibáñez et al., 2008).

These System Dynamics (SD) models are meant to aid in the understanding of desertification landscapes. They highlight the interaction between environmental and socioeconomic variables, clarifying the processes and drivers behind land use and desertification. Each model is intended to be a 'means of exploration' (Oxley et al., 2004) for a better understanding of how systems may behave.

Given the exploratory nature of these models, they are not meant for prediction or forecasting, even though they provide outputs over time periods (Perry and Millington, 2008). Therefore, application in sparse-data areas is even possible in order to reinforce a conceptual model (Alcalá et al., 2015). Thus, the aim is to get qualitative rather than quantitative outputs to answer basic questions such as: is the degradation risk high or low? Do human activities exert a strong influence on degradation?

Specifically, the purposes of this family of models were to assess (1) the risk of degradation that a land-use system is running, giving shape to an early-warning system that can help to prevent desertification; and (2) the degree to which different factors would hasten degradation if they changed from the typical values they show at present.

In our opinion, anticipation should be the main strategy to combat land degradation in drylands. This paper presents tools for preventing desertification in the form of a geomatic approach to enable the periodic assessments of the status and trends of land condition. Also SD models fill knowledge gaps in complex ecological-economic systems (Costanza et al., 1993) and 'integrate bio-physical and socio-economic aspects of desertification through a robust framework that links the drivers, process, and symptoms of desertification' (Vogt et al., 2011).

2. Methods

The technical tools applied here to study and help prevent desertification are Geomatics and SD models, submitted to different analyses. A technical appendix is provided to describe the collection of methods used in this work, while brief description is provided below.

2.1. The 2dRUE procedure

The empirical method 2dRUE was used to assess land condition in Spain. Its rationale, assumptions, and algorithms are fully described in del Barrio et al. (2010). The method has been coded as a free open-source library of functions in R (The program is called r2dRue; Ruiz et al., 2011a), a language for statistical computing and graphics.

The use of RUE for assessing and monitoring land degradation by geomatic methods has become an established approach since Prince et al. (1998) applied it for the first time in the Sahel. RUE is currently the most widely accepted approach to estimate ecosystem conditions in drylands (Veron et al., 2006). It is an appointed metric for the UNCCD mandatory impact indicator on land-cover status (Orr, 2011).

2dRUE is based on the Rain-Use Efficiency (RUE) concept, which was originally defined as the ratio Net Primary Production to precipitation