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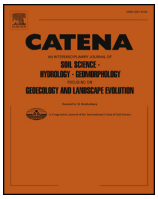

Model-based spatio-temporal analysis of land desertification risk in Greece

Mina Karamesouti[a,c,*], Panos Panagos[b], Costas Kosmas[a]

[a] Department of Natural Resources Management & Agricultural Engineering, Agricultural University of Athens, Iera Odos 75, 118-55 Athens, Greece
[b] European Commission, Joint Research Centre, Directorate of Sustainable Resources, Via E. Fermi, 2749, I-21027 Ispra, VA, Italy
[c] Institut für Geoinformatik, Westfälischen Wilhelms-Universität Münster, Heisenbergstraße 2, 48149 Münster, Germany

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ABSTRACT

Land desertification is recognized as a major threat to soil resources in arid, semi-arid Mediterranean areas. The use of widely applicable methodologies can facilitate the identification of land desertification risk spatio-temporal trends, which allows transnational comparison and support the development of soil management practices and policies, protecting the valuable soil resources. The aim of this study is to improve and use the Environmentally Sensitive Areas (ESAs) MEDALUS methodology, in order to provide a qualitative assessment for desertification risk trends in Greece, within the last 45 years. The Management, Vegetation, Soil and Climate quality indices (MQI, VQI, SQI, CQI) and the sub-sequent Environmental Sensitive Areas Index (ESAI) have been modeled for three periods in the entire Greek territory. The four quality indices are divided in two main categories, based on data availability and inherent characteristics, such as the pace of change during the studied period. Particular emphasis is given to the assessment of MQI, by integrating criteria which derived from national policies and the elaboration of national statistical data. The results show about 9% increase of the areas characterized as Critical to land desertification risk, while Fragile, Potentially affected and Non-affected areas decrease by 3.7%, 3.6%, 2.5% respectively. The applied approach for MQI can reveal areas where particular attention to management practices is required and improves the performance of the overall desertification risk index.

1. Introduction

Human well-being was always highly dependent on the ecosystem, since life itself appeared due to the favorable prevailing conditions on the planet. The exploitation of natural resources safeguarded human survival, with agricultural advances having a key role in ensuring alimentation supplies (Akdemir, 2013; Lu, 2009; Singh, 2006). However, during the last decades, the overexploitation of soil resources puts system's reproductive capacity, and subsequently human's welfare, at risk (Costanza and Daly, 1992; Yassoglou, 2004). In arid and semi-arid Mediterranean environments, the capacity of natural capital (including soil capital) to sustain the ecosystem's functions significantly decreases (Reynolds, 2001). Land degradation and desertification are processes triggered by multiple natural and anthropogenic factors (Avni et al., 2006; Reynolds et al., 2003; Sivakumar, 2007). The accelerated rates of land degradation, especially mentioned during the 20th century, are not only a serious threat for the soil resources, but also for other environmental and socio-economic structures (Kareiva et al., 2007; Montanarella, 2007; Nkonya et al., 2015; Requier-Desjardins et al., 2011; Verheijen et al., 2009). The need to reveal the main drivers of its escalation, is underscored especially due to the severe local as well as global impacts (D'Odorico et al., 2013; Kosmas et al., 2003; Wanders and Wada, 2015).

As a response to these issues, members of the FAO established the Global Soil Partnership (GSP), while the European Union develops the new World Atlas of Desertification (WAD), to answer to a series of questions related to the evolution of the phenomenon, the consequences and possible solutions. The first steps during the assessment of current global soil condition, revealed lack in updated soil information (Montanarella et al., 2016). Indeed, despite the numerous studies on soil threats, many scientists still recognize the lack of evolutionary monitoring of these processes, and suggest temporal analysis as a useful tool for setting the priorities during policy implementation (Diez and McIntosh, 2011; Reynolds et al., 2003; Salvati and Bajocco, 2011). The issue is even more pressing under the particularly high anthropogenic intervention, and the fast changes in vegetation cover type and land management intensification (Karamesouti et al., 2015; Salvati and Bajocco, 2011).

Several approaches to reveal land desertification risk, through various methodologies, have been attempted (Basso et al., 2000; Sommer

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* Corresponding author at: Heisenbergstraße 2, 48149 Münster, Germany.
E-mail address: karamesouti@uni-muenster.de (M. Karamesouti).

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et al., 2011; Symeonakis et al., 2007). The Environmentally Sensitive Areas (ESA) approach, developed under the MEDALUS EU-funded project (Kosmas et al., 1999), has been proven as a sound, widely used and notably user-friendly methodology (Ferrara et al., 2012; Hooke et al., 2005; Warren, 1999). Initially, the methodology was developed, validated and applied under Mediterranean conditions (Basso et al., 2000; Contador et al., 2009; Kosmas et al., 2003; Kosmas et al., 2006; Salvati and Bajocco, 2011), but later, the methodology was also applied in areas under different bio-physical conditions, such as Malaysia, Cabo Verde and Brasilia (Leman et al., 2016; Tavares et al., 2015; Vieira et al., 2015).

The objective of current study is to suggest an improved approach for assessing the impact of human activity, for complementing the MEDALUS methodology. The suggestion includes the integration of actual human activity, officially expressed via policies and depicted through statistical data. To our knowledge, no such an explicit analysis for the Management aspect, based on actual local or national policies and statistical data, is performed so far (Coscarelli et al., 2005; Ferrara et al., 2012; Giordano et al., 2002; Salvati and Bajocco, 2011; Wijitkosum, 2016). Moreover, the study presents for the first time a spatio-temporal analysis of land desertification risk in Greece. As it is explained in the following chapter, the specific country shows significant variability in both environmental and anthropogenic characteristics. Thus, it can be considered as a suitable case study for exposing the strengths and weaknesses of MEDALUS methodology in a future overall validation attempt.

The manuscript includes i) the assessment and mapping of Environmentally Sensitive Areas (ESA) for three periods (first: 1970–1985, second: 1985–2000 and third: 2000–2015), ii) the identification of temporal trends in management, vegetation and ESA index, iii) the evaluation of the most vulnerable areas and identification of possible drivers, and iv) suggestions on improved methodologies and tools for problem identification.

2. Materials and methods

2.1. Study site description

Greece was selected as a study site, since it is one EU-Member State enlisted in the UNCCD Regional Implementation Annex IV. Greece is a south European country covering an area of 131,981 km^2, extending from 19 to 28° E and 35 to 42° N. The country is divided in 13 administrative districts (subdivided in 51 Prefectures) (Fig. 1), and is characterized by variability in geomorphological, environmental, social and economic characteristics. Above 60% of the Greek landscape is mountainous or hilly (Zervas, 1998). The highest mountain (Olympus) is 2917 m high, while the greatest mountain range (Pindus), extending from Northwest to Southeast for almost 230 km, has a maximum elevation of 2637 m. The highly ragged terrain and especially the Pindus mountain range, plays a significant role to the climatic variability of Greece. The climate can be characterized primarily Mediterranean, however four main sub-zones can be identified: a) mountainous, b) humid continental, c) maritime Mediterranean and d) continental Mediterranean (Zabakas, 1981).

Concerning the soil characteristics, Leptosols are the dominant soil group representing about 27.8% of the Greek territory, followed by Luvisols (19%), Cambisols (18.9%, with the 1.8% been characterized as volcanic Cambisols), Fluvisols (13.2%), Regosols (10.2%) and Vertisols (0.6%). The dominant land uses prevailing on Leptosols are forests and pastureland. Agricultural areas, as unique land use or in combination with other land use types are mainly on Fluvisols (100% of these areas are under agricultural land use), on Cambisols (42.3%), on Luvisols (34.7%), on Regosols (33.6%) and on Vertisols (100%) (Yassoglou, 2004).

From a socio-economic perspective, during the period before 1980s, the country is recovering from the WWII and the dictatorship (1967–1974). The primary sector constitutes the main employment sector and exports steadily increase after 1960s (Adelman and Chenery, 1966; Dritsaki, 2013). During the period 1950–1990, an increase of arable land from about 3.6 to about 3.9 million ha, is observed (NSSG, 1958; NSSG, 1995). In 1970 the overall agricultural land (cultivated and grazing) was about 9.2 million ha, while by the year 2000 this area was about 10.5 million ha (NSSG, 1995; NSSG, 2009). However, during the period 2009–2013, a decrease in the used cultivated land (including annual, permanent and irrigated cultivations) by 2.8% is observed.

Agricultural mechanization was introduced in Greece in early 1960s, and by early 1970s traditional agricultural practices were almost replaced by machinery. Agricultural practices were enhanced by the development of irrigation networks, the use of fertilization and the introduction of new, more productive crop varieties. Despite the modernization of agriculture in lowlands, the abandonment of agriculture in hilly marginal areas, already begun in 1950s, due to unfavorable bio-physical and socioeconomic conditions (Kosmas et al., 2015; Lasanta et al., 2017; Rokos, 2005).

In 1981, the accession of Greece in the European Union, was related to a considerable impact on the agricultural sector. With the adoption of the first Development Act (1262/82), which promoted infrastructure plans, and the external financial support (i.e. Delors Packages), significant incentives for private investments in all primary, secondary and tertiary sectors, were provided. In primary sector, investments and subsidies favored the expansion of specific crops and the increase of livestock (Table 1). However, intensification of agriculture in lowlands and abandonment of hilly marginal areas was followed by land degradation phenomena (Hill et al., 2008; Karamesouti et al., 2015; Kosmas et al., 2016; Panagos et al., 2014). Agenda 2000 and the new Common Agricultural Policy (CAP), despite having as a main scope to support the development and reduce unemployment in marginal regions, brought significant turbulences to the agricultural sector (Papadopoulos and Markopoulos, 2015; van Meijl and van Tongeren, 2002).

The aforementioned evolutions were turning points in the agricultural and socioeconomic landscape of the country. Based on those developments, three main periods of consideration can be distinguished for the purpose of our study: (i) 1970–1985, (ii) 1985–2000, and (iii) 2000–2015.

2.2. Methodology

Based on the MEDALUS methodology, the assessment involves two stages. In the first step, four independent indices for soil quality (SQI), climate quality (CQI), vegetation quality (VQI) and land management quality (MQI), are calculated. In the second step, these indices are integrated into the composite ESA index (Kosmas et al., 1999). The geometrical average of the four indices reveals the risk of an area to be affected by desertification (Fig. 2). The current work followed the indices range values as indicated in Kosmas et al. (1999), and implemented by Karamesouti (2011). Summary tables from these works are given in the ‘Supplementary material’ section (S1). The output of the geometrical average of the four indices (namely the ESA index) is classified in eight classes: ‘Non-affected’ (N), ‘Potentially affected’ (P), three ‘Fragile’ classes (F1–F3) and three ‘Critical’ classes (C1–C3). The three Fragile classes characterize areas where even a small external pressure to soil system could cause imbalances, favoring land desertification processes. The three sub-classes (F1, F2, F3) indicate the susceptibility to this risk, with F1 indicating the lower susceptibility and F3 the higher. The same logic applies for the Critical classes, however in this case the areas are already degraded and suggest potential threat to neighboring areas. The range of the ESA index values for each sub-class is Fig. 2, and more details are provided in the ‘Supplementary material’ section (S1).

All input datasets were adjusted in geospatial vector format (shapefile), projected into the Greek Geodetic System EGSA'87. Data were