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A desertification risk assessment decision support tool (DRAST)

Christos A. Karavitis^{a,*}, Demetrios E. Tsesmelis^a, Panagiotis D. Oikonomou^b, Orestis Kairis^a, Constantinos Kosmas^a, Vassilia Fassouli^a, Coen Ritsema^c, Rudi Hessel^d, Victor Jetten^e, Nikolaos Moustakas^a, Branislav Todorovic^a, Nikolaos A. Skondras^a, Constantina G. Vasilakou^a, Stavros Alexandris^a, Elpida Kolokytha^f, Demetrios V. Stamatakis^a, Ruzica Stricevic^g, Emmanuel Chatzigeorgiadis^h, Jane Brandtⁱ, Nicky Geesonⁱ, Giovanni Quarantaⁱ

^a Department of Natural Resources Development & Agricultural Engineering, Agricultural University of Athens, 11855 Athens, Greece

^b Colorado Water Institute, Colorado State University, Campus Delivery 1033, Fort Collins, CO 80523-1033, USA

^c Soil Physics and Land Management Group, Wageningen University & Research, Droevendaalsesteeg 4, 6708 PB Wageningen, the Netherlands

^d Soil Physics and Land Use, Alterra, Wageningen University & Research, P.O. Box 47, 6700 AA Wageningen, the Netherlands

^e Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, PO Box 217, 7500 AE Enschede, the Netherlands

^f Division of Hydraulics and Environmental Engineering, Department of Civil Engineering, Aristotle University of Thessaloniki, University Campus, 54124 Thessaloniki, Greece

^g Faculty of Agriculture, University of Belgrade, Nemanjina 6, 11080 Zemun, Serbia

^h Agricultural University of Athens, 11855 Athens, Greece

ⁱ Osservatorio Mediterraneo per lo Studio delle Soluzioni dei Problemi Economici della area a Rischio Desertificazione (MEDES), Via Fossa del Lupo n.1, Sicignano degli Alburni, 84029 Salerno, Italy

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ABSTRACT

Desertification constantly and diachronically manifested itself as one of the most critical environmental issues to be confronted and mitigated by society. This work presents the development of a land desertification risk Expert System (ES) for assessing the application of different land management practices by utilizing indicators through a desertification risk index (DRI). The DRI was developed by a desertification risk assessment framework generated in seventeen study sites worldwide. This assessment was performed through a methodological process incorporating indicators suited to a plethora of physical, social and economic characteristics. Then, the Desertification Risk Assessment Support Tool (DRAST) was created using the indicators' methodology in an effort to efficiently handle complexity and variability in soil and water resources management. To demonstrate DRAST's applicability, an independent data base of indicators was used, and the tool was employed in all the seventeen study sites. Five indicative sites, experiencing different desertification processes, are selected as key representatives of the methodological process implementation. Overall, the assessment depicted that DRAST performs appropriately in demarcating existing desertification risk as well as in portraying how the desertification risk changes after the application of pertinent mitigation actions. Thus, the current approach may lead towards a standardized procedure, which is using the advantages of information technology to assess the effectiveness of various land management practices and facilitate stakeholders and decision-makers to produce and implement timely and appropriate responses to combat desertification.

1. Introduction

Within the last few decades, the geopolitical nature of land use rests on a combination of geography and technology. Across the world, there are different historical and cultural traits influencing ecological adaptations and capabilities, as well as exhibiting various degrees of power and command over natural resources. The degradation of national,

regional, and local land resources, advancing desertification, and expanding socio-economic demands have fueled confrontations and they have also forced international exchanges and cooperation. As a result, desertification constantly and diachronically manifested itself as one of the most critical environmental issues to be confronted and mitigated by society (Briassoulis, 2019; Thomas, 1997; UNEP, 1992). Efficient land desertification mitigation measures require appropriate land

* Corresponding author.

E-mail address: ckaravitis@aua.gr (C.A. Karavitis).

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management practices accompanied by policy that promotes sustainability and improves ecosystem services. For any desertification-affected areas, cumulative efforts and pertinent research indicate that it is essential to focus on protection, prevention, and anticipatory planning efforts rather than on post hoc restoration and/or rehabilitation options. Each time these options are applied and since these areas are usually at a high stage of deterioration, the expected results may be ambiguous or minimally effective (Hessel et al., 2014; Kairis et al., 2014; Kosmas et al., 2003, 2014; Salvati et al., 2015, 2016; Tsesmelis et al., 2019a).

Furthermore, desertification is a continuously controversial issue both temporally and spatially, with complex interrelations between the societal impacts and the natural environment (Peters et al., 2015; Vlachos, 1982). Such a controversial issue is principally arisen by the absence of a universally accepted methodological framework of “what to measure” and “how to measure it”. This framework should simultaneously operate in a complex system full of interrelations. One of the main avenues to represent such interrelations and communicate them with policymakers is through indicators. Indicators assist with monitoring the implementation of systemic policy objectives, and they represent trends and developments in the state of a system. Numerous and diverse system interrelations may be reflected in the corresponding number and diversity of the indicators used. Furthermore, whenever new sets of interrelations are analyzed they usually need to be represented by new sets of indicators. Overall, indicators are growing to be increasingly valuable means for conveying information about the state of the environment to the decision makers and the lay public (Karavitis et al., 2014; Kibblewhite et al., 2007; Kosmas et al., 2003; Oikonomou, 2017; Tsesmelis et al., 2019b). They can be used to assess environmental performance and to evaluate the changes made by anthropogenic actions and/or physical processes. Thus, they constitute as a useful tool in land management efforts (Kairis et al., 2014; Kosmas et al., 2014; Tsesmelis, 2017). However, particularly in environmental sciences, a sole indicator may not effectively portray a complex process such as soil erosion, which is a key driver of land desertification. Indicators forming a composite index may allow the derivation of multiple options in land management. Hence, they may successfully monitor the existing or the resulting from pertinent interventions state of the environment (Basso et al., 2000; Karavitis et al., 2015, 2014; Kosmas et al., 2003, 1999; Oikonomou et al., 2019; Oikonomou and Waskom, 2018; Skondras et al., 2011; Tsesmelis et al., 2019a).

Desertification manifests when land and water resources are degraded beyond certain thresholds. Such degradation is leading to irreversible changes and to a new non-desirable state (Briassoulis, 2005; Kosmas et al., 1999). Desertification indicators may clearly illustrate that the phenomenon per se has already progressed to its endpoint creating an irreversibly unproductive land. Dating back to the 1970s, the desertification indicators usually were generated to evaluate desert advances. In the 1980s, the need for holistic and adaptable desertification combating approaches was greatly intensified. As a result, indicator frameworks were proposed. Initially, Rubio and Bochet (1998) presented a detailed desertification indicator framework and synthesized lists of criteria including a methodology for the selection, assessment, and application of pertinent indicators. A part of this arsenal was the significant attempt to produce an Environmentally Sensitive Areas Index (ESAI) made by the European Commission's (EC) “MEDALUS III” research project (Kosmas et al., 1999). In this effort, a set of dominant indicators depicting various desertification drivers (soil, climate, vegetation, management) synthesized a composite land desertification index. The ESAI methodology was extensively applied for more than a decade directly or indirectly (e.g. Salvati, 2012; Tsesmelis et al., 2019a). However, it was argued that it exhibited an absence of social and economic components related to parameters such as population growth rate, economic conditions, and population density (Salvati et al., 2016, 2007; Salvati and Bajocco, 2011).

Recatala et al. (2002) employed environmental indicators to

evaluate and monitor desertification and its pressure in the Mediterranean region. In this regard, the stocking rate universal indicator was found to be an important one incorporating all the factors affecting the impacts of grazers on soil, land degradation, and desertification processes (Pulina et al. (1998). Furthermore, Fierotti and Zanchi (1998) proposed as a global indicator the degree of soil erosion. However, this requires field observations for its rapid and easy assessment. They have also suggested that other specific indicators may contribute to the estimation of soil erosion such as the degree of vegetation cover, the vegetation productivity, the trend of various soil physical characteristics, the vegetation growth rate, the organic matter content and development, and the intensity of erosive forms. The EC ENVASSO project for three threats namely: decline of organic matter, soil erosion and soil salinization, chose the corresponding indicators as the most relevant ones to describe the land desertification in arid, semi-arid, and dry sub-humid zones (Kibblewhite et al., 2007). One of the objectives of the DESIRE project was to investigate the use of indicators as a means to assess the processes of land degradation and desertification at a global scale (DESIRE, 2012). To achieve this, indicators were selected that proved to be more appropriate to assess the variety of land management practices to confront desertification. In addition to that, they should also be applicable on a broad spectrum of natural, environmental, social, and economic characteristics portrayed in the carefully chosen project's study sites as exemplified by Kosmas et al (2014). However, one should keep in mind that similar mechanisms or interrelated driving forces, mostly of anthropogenic nature, generally drive different desertification processes. Although the indicators to be used for each of such processes are different, this similarity in driving forces may allow for the development of a broad enough indicator approach that can be used to assess desertification (Kosmas et al., 2014).

Land users or land policymakers typically need straightforward tools to identify the current state of a socioeconomic and ecological system and to foresee trends and problems due to land desertification caused by such processes or causes. In this context, the information technology, in the form of Expert Systems (ES) and other related Decision Support Systems (DSS), may offer some ubiquitous advantages as a part of desertification mitigation strategies. Throughout the last decades, ES have been widely used by a variety of managers and researchers in a multidisciplinary context of decision making in different disciplines and natural regimes. The contribution of ES in natural resources and environmental management is of great significance and it advances more and more rapidly. Early on in the literature, Rykiel (1989) described the use of Artificial Intelligence and ES in ecology and natural resources management, while Mohan and Arumugam (1997) provided an overview of expert systems application in irrigation management. Karavitis (1999) reported an expert system developing since 1992 and applied for drought management in various locales, whereas Brandt and Geeson (2005) included a simple web-based ES for Desertification Risk estimation in the DIS4ME Desertification Information System. Witlox (2005) provided an overview of expert systems application in land use planning. López et al. (2008) presented expert systems in soil characterization, and furthermore, Genske and Heinrich (2009) described an ES for degraded terrain analysis. Thus, the development of a DSS in the form of a risk estimation ES should present an essential tool in desertification mitigation efforts. All in all, an ES used in Desertification Risk estimation should, above all, serve as a “common language” among the different groups involved in the decision-making process. It should serve as a communication “bridge” among managers, politicians, scientists, and administrators. At the same time, apart from being a communication tool, it should also provide an analysis of the various components of the problem. In addition, some special features should be included such as simplicity, interactive ability, and credibility.

In this quest, the advantages of computer technology for the development of an indicator based DSS are unambiguous. They include the possibility to: analyze a wide spectrum of alternative options for

land management practices; assess and select the main indicators through which desertification risk may be categorized in various locales worldwide; and develop consensus among different groups (politicians, managers, experts, etc.) in assessing desertification risks. In this context, the DSS may allow stakeholders and decision-makers to arrive at timely, efficient, and appropriate desertification mitigation responses. It may also provide a standard to evaluate the effectiveness of various land management practices.

In this regard, relevant assessment methods have been derived for the different processes or causes of desertification by using an indicator approach, which tried to incorporate both physical and anthropogenic parameters. Previously, this methodological procedure was tested mostly within the Mediterranean Region (Benabderrahmane and Chenchouni, 2010; Brandt and Geeson, 2005; Kosmas et al., 2000a, 2000b, 1999; Parvari et al., 2011; Salvati et al., 2015, 2007). Hence, the DESIRE project application in a worldwide scale offered quite a challenge and it has led in innovative progress by assessing desertification risk according to a variety of physical characteristics, environmental impacts, social structure, as well as economic and land management conditions. This approach presented a composite desertification risk index based on all the above-mentioned parameters (Kairis et al., 2014; Kosmas et al., 2014). Overall, the novelty of the current effort is two-fold. The first one was to develop an ES based on the derived algorithms from the pertinent novel desertification methodology stemming from the research of the DESIRE project. This novel ES should offer decision support to various stakeholders' groups, in an effort to assess land desertification risk under multiple physical, environmental, economic, and social conditions. In continuation, the second novel objective was to apply this ES using two different databases in the DESIRE Project diverse study sites worldwide. To this end, the next methodological step was to present, visualize, and assess the outcomes. Such assessment may prove the worldwide applicability of the ES and thus aid in decision making focused on delineating suitable land management practices and techniques to combat desertification on both a regional and a global scale.

2. Methodology

2.1. Desertification risk estimation using indicators

An integrated approach towards assessing the desertification stages through the incorporation of various indicators was applied within the framework of the DESIRE project (Hessel et al., 2014). Kosmas et al. (2014) reported an array of candidate indicators that was compiled by: (a) an extensive literature review, (b) stakeholders consultation such as groups of land users, managers, decision makers, and research groups on desertification and land degradation both locally or regionally in every study site, as well as internationally; and (c) applying existing research already performed in projects on land degradation and desertification (Medalus, 1996; Kosmas et al., 1999; Enne and Zucca, 2000; Wascher, 2000; DESERTLINKS, 2004; OECD, 2004; MEDRAP, 2004; Liniger et al., 2007). Details about the literature review, the pertinent research, and the stakeholders participation processes are available in the DESIRE-HIS (DESIRE, 2012). Kosmas et al. (2014) produced an indicator list that was combining robust indicators, as aridity index, with indicators that the stakeholders felt that they were relevant as soil depth, water quality, etc. A detailed presentation of all the indicators employed in this effort is also available on the DESIRE project deliverables and website (DESIRE, 2012).

In summarizing, according to Kosmas et al. (2014) and Kairis et al. (2014), the principal processes-drivers or causes of land desertification were: soil erosion including water and tillage erosion, soil salinization, water stress, forest fires, and overgrazing, as found in the DESIRE study sites in the Mediterranean and Eastern Europe, Latin America, Africa, and Asia. It should be noted that aeolian erosion was encountered in only one study site, the Karapınar Plain, Konya, Turkey (Fig. 3). In addition to the limiting factor of obtain data from only one area, these existing in situ data were very sparse, non-dependable, and fragmented. Thus, they could not be used in the indicators derivation process (DESIRE, 2012). It is suggested that in a future research effort, pertinent study sites including a significant number of aeolian erosion suffering

Fig. 1. Schematic of the flow among land uses, processes, causes of land desertification, and the corresponding effective indicators as developed and used in the decision support tool.

Fig. 2. The methodological framework for desertification risk estimation and Expert System (ES) development.

areas should be incorporated, so that the indicator methodology could be applicable, and then the results to be imbedded in a revised ES. Thus, in the current effort, the candidate indicators were categorized among the various processes-drivers or causes of land desertification apart from aeolian erosion and then analyzed. Kosmas et al. (2014) described in detail such an analysis. Briefly, for every indicator, its range of potential values was categorized into four or five classes. The indicators values were computed in an annual time step (e.g. potential evapotranspiration, rainfall, water scarcity, etc.) or from a series of in situ measurements (e.g. soil parent material, slope gradient, soil depth, etc.) through the course of the DESIRE project (Kairis et al., 2014; Kosmas et al., 2014). All the values, their time, and space resolution are presented in detail in the DESIRE deliverables (DESIRE, 2012). The first step for this categorization was the use of existing classification systems such as the European geo-referenced soil database (Finke et al., 1998; Kosmas et al., 1999; Liniger et al., 2007; van Engelen and Wen, 1995; van Engelen et al., 2005). The second step was to utilize existing pertinent research data (Brandt and Geeson, 2005; Kosmas et al., 2000a, 2000b, 1999). For reference comparison purposes among the various regions, a common weighting system was applied. Hence, five classes of desertification risk demarcated as none, low, moderate, high, and very high. Coefficients were assigned for every class of desertification risk ranging from 1 (none) to 5 (very high) and explicitly presented by Kosmas et al. (2014) and Kairis et al. (2014). Based on these, a similar classification scheme was followed for the visualization of the desertification risk in the ES (Fig. 4). Since various case studies exhibited

Fig. 3. Study sites and the various desertification processes namely: (1) Rendina Basin, Basilicata, Italy, (2) Maggana, Nestos Basin, Greece, (3) Messara Area, Crete, Greece, (4) Mação Area, Santarém, Portugal, (5) Gois Area, Coimbra, Portugal, (6) Torrealvilla Area, Murcia, Spain, (7) Karapınar Plain, Konya, Turkey, (8) Eskişehir Plain, Eskişehir, Turkey, (9) Dzhaniyek Area, Russia, (10) Novy, Saratov, Russia, (11) Zeuss-Koutine, Tunisia, (12) Boteti Area, Botswana, (13) Santiago Area, Santiago, Cape Verde, (14) Sehou, Morocco, (15) Kelaigou, Loess Plateau, China, (16) Cauquenes Area, Maule, Chile, and (17) Cointzio Catchment, Michoacán, Mexico.

Fig. 4. Desertification risk in Mação (Portugal), Sehoui (Morocco), Kelaigou (China), Eskişehir (Turkey), and Dzhanibek (Russia).

various risk values in between the above-mentioned integer numbers, the ES visualization used ranges of values from 1 to 5 as portrayed in the legend of Fig. 4. Overall, the concept of desertification risk underlines the exposure to desertification. Then, it may lead towards an estimate of the vulnerability to desertification, if land, social, economic, and management practices impacts are assessed. Moreover, the approach may define the encountered phases of desertification. Such phases were categorized and evaluated by climate, vegetation, soil, and management indicators that are new, existing ones, and those already incorporated from the antecedent methodology of ESAs. As pointed out, the ESA system has been extensively employed in the Mediterranean area and other similar locations (Benabderrahmane and Chenchouni, 2010; Parvari et al., 2011; Salvati et al., 2007; Tsesmelis et al., 2019a). However, since it has been developed following the DPSIR approach, the impacts on the state variables are usually multifaceted and inter-related and they may have different outcomes subject to the state indicators that are employed to describe those (Kosmas et al., 2003). Hence, a new combined system of indicators was essential to be developed in order to portray and evaluate the desertification risk according to physical characteristics, environmental ramifications, as well as the social, economic, and land management conditions. The next step was to run the stepwise multiple regression analysis with the desertification risk as the dependent variable and the candidate indicators assigned for each driver (process) as independent variables. The following linear equation was utilized (Steel et al., 1996):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k \quad (1)$$

where Y is the dependent variable, β_0 is the Y intercept, $\beta_1, \beta_2, \dots, \beta_k$ are the slopes of the regression plane, and X_1, X_2, X_k are the independent

variables. Kosmas et al. (2014) give in detail the significant beta values of the stepwise linear regression for every indicator and for the algorithms processes assessing desertification risk. The majority of the indicators defining desertification risk were related to a combination of the physical characteristics (water, soil, vegetation, and climate), land management, social, and economic conditions in each sampling point. This resulted from the “effective” indicators influencing desertification risk in the various land uses that were related to the following land degradation and desertification drivers (Kosmas et al., 2014): agricultural areas—water erosion, pastures—water erosion, forested areas—water erosion, agricultural areas—tillage erosion, agricultural areas—soil salinization, agricultural or natural areas—water stress, pastures—overgrazing, and natural areas—wildfires. Fig. 1 portrays the flow among such land uses, processes, causes of land desertification and the number of effective indicators retained after the described statistical assessment for each degradation process. The next step was to incorporate the selected indicators and methodology from Kosmas et al. (2014) to a Drought Risk Assessment Tool (DRAST).

2.2. Decision support tool development

DRAST was developed as an expert system. It was created to provide an estimation of land desertification risk through the selection of the corresponding degradation processes and the pertinent indicators. The first step was to develop the corresponding equations in the form of Eq. (1), in order to estimate the desertification risk for distinct degradation processes in the predominant land uses, incorporating the created indicator database (Kosmas et al., 2014). DRAST includes all the identified indicators to suit a full spectrum of natural physical, social, and

economic conditions. Moreover, it helps assess the efficiency and efficacy of different land management practices in various land uses and landscapes vulnerable to desertification (Kairis et al., 2014; Kosmas et al., 2014). In an effort to demonstrate its applicability, the expert system was applied to case studies using data from the World Overview of Conservation Approaches and Technologies – Mapping Questionnaire (WOCAT QM) database (WOCAT et al., 2008). The WOCAT QM database was independently generated from data collected with different protocols than those used to develop the indicators database at another task of the DESIRE project (Schwilch et al., 2012). This approach was chosen in order to avoid autocorrelation problems, since the indicator-filled database was already used to develop the coefficients of the linear models used to assess the land desertification risk. The Desertification Risk Index (DRI) values, which are the output of DRAST, were color-coded as described in detail on the following sections and they are visualized in the pertinent maps. The overall methodological steps and framework are delineated in Fig. 2. This methodology evaluates the applicability of the developed risk desertification index.

It is believed that the applied methodology offers a series of appropriate and efficient indicators that could aid farmers, stakeholders and decision-makers to detect where land desertification is an existing or a potential threat, and which may be the options to alleviate such an issue at a given time period. For the DRAST utilization the following steps have to be followed: (a) select the suitable land use (agriculture, forest, or pasture); (b) methodologically determine the land degradation drivers-processes as tillage erosion, water erosion, soil salinization, etc., so to derive the corresponding relation from equation (1); (c) input the data to compute the values of the corresponding indicators and then introduce such values to the developed distinct equation; and (d) compute the DRI. The user has the option to change the input values of the indicators pertained to any land use and/or land management practices and to visualize alternative options or scenarios. DRAST has two versions, one produced to run on a Windows operating system and the other as a web-based tool. The architecture and the description of both versions are presented in the following sections. In both versions, an effort was made to develop a user-friendly and self-explanatory ES, which systematically step-by-step guides the user.

2.2.1. Windows operating version

The standalone version of DRAST with all the corresponding files is freely available and included in the deliverables of the EC DESIRE project (<http://www.desire-his.eu/en/assessment-with-indicators/desertification-risk-assessment/570-offline-desertification-risk-assessment-tool>). The ES was developed using the Visual Basic.NET (VB.NET) VB 11.00 (2012). The Windows operating version produces the main screen shown in the background of Fig. 1A in the Appendix A. The main screen contains the following menus: **-File** – for saving and opening of the sessions; **-Option** – for selecting a type of erosion-degradation processes; **-Indicators** – for defining Indicator values and viewing results; **-Help** – for information related to DRAST application and instructions for use. Each menu consists of the corresponding actions, explained in detail in the Help file. The **Option** menu contains the Land Use-Degradation Processes Selection command. The Land Use-Degradation Processes Selection opens a dialog box, where all the pertinent land use-degradation processes for the specific case should be selected by clicking on the appropriate boxes. The selection of the required Degradation Processes is saved by clicking on the OK button. A message box appears which indicates the next step as also shown in Fig. 1A. The **Indicators** menu is the main menu for the Desertification Risk Assessment. It consists of the following modes: (1) **Calculate** – The dialog box for the Indicators input Appendix A, Fig. 2A) and (2) **View** – the dialog box to view and export the results (Appendix A, Fig. 3A). The selection of indicators for Desertification Risk Assessment is performed

through the **Calculate** dialog box. The pre-selected Land Use-Degradation Processes activate the corresponding indicators, which are automatically included in the calculation of significant indicators per process and are ticked by the system in the view screen (Fig. 3A). It is noted that the number of indicators depends on the selection of degradation processes and it may vary from 8 to 17 for the individual processes (as indicated in Fig. 1). If several processes are assessed simultaneously, the number can be considerably higher. For example, 40 indicators are needed to assess water erosion (all three processes), tillage erosion, and water stress. Dialog boxes are available for each indicator that guides the user to assign the corresponding class based on its value. The various indicator value ranges and classes are included in the ES. For example, if water erosion, tillage erosion, and water stress degradation processes have been selected, then, some of the corresponding indicators values are presented in a form of the calculate dialog box (Appendix A, Fig. 2A). To offer an initial evaluation to the user, when selected, neutral indicator values are shown with white background, values contributing to high desertification risk are marked with red and values causing a low desertification risk with a green background. The **View** interface presents the results of the calculation of the effective indicators per process for Desertification Risk Assessment. A recalculate button is also provided for updating the results after performing changes in the selection of indicators. Fig. 3A presents an example of one calculation where all the degradation processes are selected except soil salinization. Thus, soil salinization process has a zero value assigned, since it is not selected, and the Desertification class risk field is empty and without color.

2.2.2. Web-based tool version

The system is loaded on the website: desire.aua.gr. The main screen gives the user the option to go through a comprehensive set of information regarding the tool and the EC DESIRE project. The menu on the left hand-side of the main page prompts the user to select between: (a) introduction of the tool, (b) information about the work carried out in DESIRE Project, (c) the applicability of the developed methodology, (d) the description of effective indicators affecting DRI, (e) general information about the tool, (f) the processes and causes of land degradation and desertification, (g) the application of the DRI software, and (h) pertinent references. The user starts a DRI estimation session by selecting the menu application in the DRAST software. As in the Windows operating version of the tool, in order to assess desertification risk, the user is prompted to select from various processes or causes of land degradation. Similarly, a new window is shown with the list of relevant indicators. Again, the number of the included indicators depends on the selected process, as has been previously explained.

After inserting the values for all the indicators, the DRI and all the indicators' classes are produced (Appendix A, Fig. 4A). The user maintains the option to go back and change any of the previously inputted indicators' value per process and to recalculate the DRI with the corresponding classes. The web-based tool does not provide a chart like the Windows-based operating based application. Therefore, the web-based expert system gives only a quick and handy assessment of the efficiency of various management practices to combat desertification.

2.3. Desertification risk assessment tool application

The presented methodology to describe land desertification risk by employing indicators was indicatively assessed on a smaller scale using independently collected data on soil organic matter content and erosion. These data were collected in the DESIRE study sites in Crete Island, Greece during the course of the project (Kosmas et al., 2014). In this context, the collected indicator data originated from the same country, thus, they exhibited no significant variation particularly for

the indicators depicting social and economic conditions. The delineated DESIRE methodology was created using data from a whole spectrum of natural, environmental, social, and economic conditions worldwide (Kosmas et al., 2014; Kairis et al., 2014; Hessel et al., 2014; Schwilch et al., 2012). In this regard, the indicators data gathered could not be inserted for the DRAST evaluation, as they were already utilized for its creation. Hence, the use of independent databases was necessary. The DESIRE project had 17 study sites located in areas prone to desertification in various locales around the world (Fig. 3). For the indicators development, in all the study areas, field surveys were performed in various land uses such as cereals, almonds, vineyards, olive groves, cotton, deciduous forests, pine forests, and pastures to acquire pertinent indicators values at more than 1100 sampling points (DESIRE, 2012; Kairis et al., 2014; Kosmas et al., 2014). The study sites exhibited a plethora of natural, environmental, social, and economic characteristics (Hessel et al., 2014; Kosmas et al., 2014; Kairis et al., 2014). They are locales suffered by or being vulnerable to desertification due to a variety of processes, such as water stress, overgrazing, soil salinization, wildfires, and urbanization. These processes usually combined and exacerbated by the erosive power of water and air are ultimately leading to land desertification. However, the selected study site of Karapınar Plain, Konya, Turkey could not produce reliable wind erosion data, as stated, and thus, since aeolian erosion was not encountered in the other study sites the pertinent indicators have been excluded.

In this context, the DRI computation and evaluation was achieved using independent databases from two distinct approaches. The first approach contained indicator values computed for every site, using the independent WOCAT QM database (Fig. 2), which is also a product of the DESIRE project (Hessel et al., 2014; Schwilch et al., 2012; WOCAT et al., 2008). The DRI estimation was performed for all the 17 DESIRE case study areas as presented in Fig. 3. However, given the current effort constrains, for the various desertification process, five representative case study areas were chosen among the DESIRE case study sites to be illustrated. Thus, the desertification processes and assessment results are presented for these case studies including: Se-houl, Morocco (high- pressure agriculture and overgrazing resulting in water erosion), Mação, Portugal (wildfires and water erosion), Kelaigou, China (tillage practices resulting in increased water erosion), Eskişehir, Turkey (increasing water erosion in: pastures and shrubs, forests, and agricultural lands), and Dzhani-bek, Russia (overgrazing, salinization, and water stress) as seen in Table 1. The indicator estimation started by using data from the WOCAT QM database. Then, from the depicted in the WOCAT QM database land use system (LUS), land degradation and sustainable land management (SLM) information as defined for each map unit were retrieved. The starting point for mapping degradation and conservation is land use and land management. Thus, according to the WOCAT procedures, a base map unit is defined by the land use type, then subdivided by crop type as well as geomorphologic processes, and administrative and socio-economic criteria. Furthermore, a map unit is not necessarily limited to a single closed polygon, but it may include several larger and smaller polygons, together establishing a map unit for which degradation and conservation options need to be assessed. The number of mapping units should be more or less similar for all study sites. Each study site should have a number of 30–100 units for which information needs to be inserted to the corresponding matrix tables. Overall, the size of the site and the variability within the area decided the scale of the mapped results and the size of the mapping units (DESIRE, 2012). In the map units with two or more degradation processes, the dominant process was chosen for the entire unit as required by the WOCAT QM database (DESIRE, 2012; Schwilch et al., 2012). Then, the corresponding data were converted into indicators values according to the assigned indicator classes and weights following the harmonized indicator database guidelines (Kairis et al., 2014; Kosmas et al., 2014).

The second approach is to apply and evaluate DRAST as presented by Jetten (2012), using field level experimental results performed in all

Table 1
DRAST application and assessment in the representative study sites.

Study site	Brief description of the site problems	Desertification processes	Assessment by the WOCAT QM database computed indicators DRI values	Assessment by experimental fields DRI values (Jetten, 2012)
Sehoul, Morocco	Extensive gully of the agricultural lands, intensive and high-pressure agriculture with overgrazing and strong annual variation in seasonal rainfall	Water erosion in forests, water erosion in agricultural areas and water erosion in pastures and shrubs, due mainly to vegetation degradation	Moderate to very high desertification risk to water erosion and overgrazing	DRAST application in line with the experimental ones, of water erosion and overgrazing. Less noticeable results when implementing the mitigation techniques.
Mação, Portugal	One of the four United Nations Convention to Combat Desertification (UNCCD) areas. The area has experienced severe droughts combined by catastrophic wildfires.	Wildfires and water erosion in agricultural areas	High desertification risk in forest areas as a result of water erosion and due to the lack of direct reforestation	Greater sensitivity of the DRI results in relation to water erosion than to wildfires
Kelaigou, China	Located in the Loess Plateau area, 250 km north of the city of Xian, comprised of thick aeolian deposits. Acute soil erosion forming large gullies and badlands particularly on the greatest slopes	Tillage practices increasing the downslope movement of the soil and water erosion	The desertification risk was low to moderate due to slope gradient and then to water erosion	Water erosion follows a lesser rate than the lowering of the slope, while the water stress is correctly computed by DRAST to be considerably reduced
Eskişehir, Turkey	Semi-arid area with shallow, stony, and low in organic matter soils. Slopes vary between 10 and 20%, thus the late spring and early summer rainfalls are creating serious erosion problems	Water erosion in agricultural areas and water erosion in pine forests and water erosion in pastures and shrubs	It exhibits the entire range of desertification risk from low to very high depending upon slope gradient. It appropriately estimated that desertification drivers are mainly water erosion and secondarily tillage erosion	The moderate water erosion risk is again correct. The precise experimental mitigation responses (contour ploughing and wicker fences) could not be directly processed in DRAST, they were transformed to runoff impediments and terracing and produced a lesser than the existing conditions DRI
Dzhani-bek, Russia	The area is on the Pallasovsky District at Volgograd Region, which is a dry steppe territory on the left bank in the lower part of the Volga River basin. Lack of irrigation combined with high evaporation rates and shallow groundwater tables lead to soil salinization	The site exhibits overgrazing, water stress, soil salinization, and water erosion in pastures and shrubs	The tool calculated a very high desertification risk due to salinization	The tool dealt fairly well with the actual situation indicating high desertification risk due to salinization and far less risk by the proposed desertification mitigation technology

the DESIRE study areas apart from the Rendina site in Italy, where local social conditions prohibited such an application. Thus, DRI values were computed in every participating experimental site using the existing conditions, and then, DRI values were generated after the application of the mitigation experiments. Subsequently, the differences in desertification risk were assessed against the general outcomes, which in some cases it was an indirect comparison due to the nature of the variable's transformation (local to regional ones). The results from the local field experiments were fed into DRAST in order to pinpoint pitfalls and provide guidance for potential future improvements of the tool. Nevertheless, it is noted that DRAST is applied on a field level mostly out of context, since the tool is not designed to assess individual experiments on a field/plot scale. The DRI method is based on parameters across all the sites and on more regional variables that may not be affected at an experimental scale (Jetten, 2012). The methodological steps followed were straightforward and uncomplicated: in every site and as the first step, the tool has been used to calculate the desertification risk index of the existing conditions. Then, all experiments focused on mitigating land degradation and desertification on a site were incorporated. After that, the difference in DRI was computed and the DRAST performance evaluated. For the application, some field data translation occurred in order to insert certain localized field conditions into the parameter settings of DRAST.

3. Results

The process to calculate DRI began by identifying the land use – degradation process. For the principal evaluation approach, which uses the WOCAT database as described, the pertinent indicators were estimated and inserted into DRAST and the tool calculated DRI for every map unit. Overall, more than 3000 indicators in 382 map units were calculated. For the selected and presented five case study areas, 912 indicators in 70 map units were assigned and their corresponding values were computed. Key characteristics of the application procedure for each study site are summarized in Table 1. Then, the DRI values for every map unit were portrayed in a scale and all the results were pictured in pertinent maps including their scale and color classification scheme (Fig. 4). For the second experimental fields approach, the results for all the presented sites are summarized in Table 1.

4. Discussion

Overall, the results seem to reflect well with the regional variables used. The evaluation on a regional scale using the WOCAT generated data as the input provided good and appropriate outcomes. Such results offer an initial assessment of desertification risk showcasing which areas need the most immediate desertification mitigation measures. At this point, it is again noted that Jetten (2012) has also presented an evaluation of the DRAST with the existing conditions and after the experimental mitigation measures on a field scale for 16 of the 17 case sites. Overall, Jetten (2012) reported that the results are appropriate; the tool shows what it is supposed to show namely that risk becomes lower than the one initially existing, in accordance with the experimental implementation of desertification mitigation responses. As the risk index is produced using multivariate statistics, both the initial computed risk and the change of risk after the implementation of desertification mitigation responses is relatively less than the experimental results usually show. Such a fact is logically expected, since DRAST applies a “mean” of all the study areas and the outcome of pertinent mitigation measure is less prominent on regional than on field level.

4.1. DRAST advantages

As pointed out, DRAST was applied and evaluated for all the 17 DESIRE case study sites, including the five areas presented. This approach and the produced indicators were created based on datasets collected under specific protocols, as described by Kosmas et al (2014). Thus, for the DRAST assessment another independent database had to be used, as previously stated. The WOCAT QM methodology provided maps of land degradation status and existing trends using its own specific protocols of individual expert judgement assessment (WOCAT et al., 2008). In this effort, more qualitative estimates and data translations had to be involved in order to utilize the existing available data input for DRAST from the WOCAT QM database. Despite the differences in the approach, the resulted maps of the DRI by the DRAST application provided similar information as the original maps of the WOCAT QM methodology (Schwilch et al., 2012). Thus, DRAST seems robust enough to produce appropriate risk estimations, if quantitative data as the indicator database described by Kosmas et al (2014) are present, but also when such data are not in abundance and thus having to derive reasonable approximations. Even the use of data and information of a different scale (field-specific instead of regional), as in the Jetten (2012) application, has shown that it describes more than adequately the desertification risk. However, in both cases, the results are transferring the corresponding degree of uncertainty. Overall, creating a completely quantitative indicator dataset is often a labor-intensive effort; hence, it may be a plus that the approach could also be applied with less detailed and more qualitative input datasets. Jetten (2012) also states that the tool is very adaptable and parameters that are not available in an area can be omitted, so it can be easily adjusted to the locally existing data. He has also pointed out that the tool generally does what it is expected to do, and the risk variables reflect well the experiments performed. Thus, the tool may also be utilized in data poor areas allowing land use managers worldwide to have a handy initial estimate of a particular mitigation option on the desertification risk per se. In other words, using it as a quick and handy decision-making tool.

A crucial additional element is to comment on the performance of the individual indicator's behavior pertaining to the DRAST application. In this regard, the most pronounced comparative result is that in almost all the study sites the indicator annual rainfall amount was not a factor influencing water stress risk, as much as the already described as a very important indicator of rainfall seasonality (Kosmas et al., 2014). Such a fact was also delineated in the indicator development phase (Kairis et al., 2014). In this context, water stress may be generated in an area having more than 1500 mm of average annual rainfall, and no water stress in an area with less than 280 mm of average annual rainfall. At this point, it should be noted that water stress is strongly related to water demand (Karavitis et al., 2014; Wu et al., 2007; Yevjevich et al., 1983). For example in many of the Mediterranean countries (Greece, Spain, Tunisia, Italy, South-western Turkey, etc.), the majority of the precipitation falls during the winter months, when the water demand is very low due to the minimal agricultural activities, low tourist needs, less urban water consumption, etc. On the contrary, in the summer months when there is high irrigation and tourism is in full swing, precipitation is often close to zero. Thus, rainfall seasonality is central. For example, if the majority of an average annual rainfall of 1500 mm falls during the winter months, it may have minimal impacts and uses, and through runoff it may end up mostly unused in the various water bodies. Furthermore, the first usually intense rainfall events after the hot dry summer season often result in flooding with considerable erosion and desertification problems of already scorched lands. Rainfall seasonality is an additional reason for the construction of dams and reservoirs in these areas, in order to store the winter excess water and

use it during times of high demand and limited precipitation in the summer. Moreover, it is also an attempt to simultaneously control floods and erosion (Karavitis et al., 2014, 2012; Tsakiris and Vangelis, 2004). On the other hand, in an area where the majority of the 280 mm precipitation coincides with the period of high demand water use, less water stress will be expected, and the corresponding indicator will more closely reflect the regional character. Thus, DRAST based on the performed indicator analyses is promptly portraying the importance of rainfall seasonality for desertification risk assessment (Jetten, 2012; Kairis et al., 2014; Kosmas et al., 2014).

4.2. DRAST limitations

DRAST is performing at its best when a set of quantitative indicators are used. However, certain limitations may be surfaced, when it is used as stated, with more qualitative data. In this case, the quality of the results is directly reflected to the quality of the transformation of the qualitative information to quantitative indicators. Another point is that the tool does not include wind erosion indicators, thus it cannot be applied to aeolian erosion suffering areas for estimating desertification risk. Additionally, land conservation measures indicators are not included, and such measures may be introduced indirectly through the most relevant indicators. Furthermore, it is more appropriate if applied in the spatial context of a region and greater. Its application in a field scale is less accurate; however, it may present more than adequately the desertification risk. As DRI is a product of the inserted indicators, the user sees only the final computed value. The individual sub-products of each parameter are not shown and thus it cannot portray which parameter/indicator effects more than the others do the calculated DRI value. Finally, it should be applied with caution in the southern hemisphere, since seasonality corrections were not included for these climates.

4.3. Future research needs

In regards to future research needs, Jetten (2012) proposes that a future development of the indicator based tool should: (1) include conservation measures in the indicators datasets, and (2) display comparably the relative importance of the parameters, so that it is clear which parameter influences more the results. This may help to understand how DRI is produced and how significant the effect of a desertification mitigation response would be to produce a difference, specifically a sought decrease in risk. Nevertheless, such data on appropriate management measures should be a part of a larger future research effort in order to demonstrate how the choice of certain measures changes the values of certain indicators, and how this impacts desertification risk. In this line, a future research effort should also incorporate sites exhibiting wind erosion problems to test if relevant indicators may be introduced. Up to then DRAST may be applied in areas, where desertification has all the other drivers/causes apart from those of aeolian origin. Finally, another point to be noted may be that since indicator data from the southern hemisphere (Chile) were also used for the indicator methodological application, future research efforts should include seasonality corrections for such climatic zones.

5. Conclusions

The presented methodology for the Decision Support Tool creation was accomplished incorporating data from a wide spectrum of natural and anthropogenic environments, on a worldwide scale. The use of two

different databases, one for development and one for testing may also contribute to the originality and applicability of the whole effort. As a result, the presented DRAST application outcomes may illustrate that the tool is practical in assessing desertification risk at a plethora of locales with a variety of physical, environmental, social, and economic characteristics. In addition, the application of the methodology in areas beyond the Mediterranean ones was largely successful and produced very good results. Generally, to fully utilize the pertinent approach, it may be advisable to have datasets for most of the assigned indicators in each desertification process. However, if the available data are poor or limited, existing similar datasets may be transformed into the corresponding indicators and then applied to DRAST, producing also dependable outcomes. The tool can be utilized for desertification monitoring techniques and to assess the results of desertification combating measures both at field level and at regional level. The developed ES may also enable stakeholders and end users to assess different future scenarios for desertification risk aversion and at the same time to evaluate critical stress parameters, their impacts and consequently it may indirectly to evaluate desertification vulnerability. Thus, DRAST may allow end users and decision-makers to produce dependable, timely, and efficient desertification mitigation responses. It may also assess how desertification risk transforms, if pertinent management options are applied. For such an assessment, DRAST has the following advantages particularly for environmental management: (1) demonstration, computation, visualization, and assessment of a variety of desertification indicators; (2) presentation of the resulting DRI in a concise, comparable, reproducible, and holistic fashion; (3) direct sensitivity of the input to the associated output; and (4) multi-disciplinary criteria and assessment process by incorporating experts, administrators, professionals, farmers and decision makers.

Future research efforts may also lead to include additional conservation/mitigation indicators and help to trim application inconsistencies. The incorporation of aeolian erosion indicators should also be sought. Overall, a future DRI application in pilot areas with a benchmark problem and pertinent reliable databases may help pinpoint potential pitfalls and implementation incongruities. Finally, effective development and application of DSSs for desertification mitigation and generally for natural resources management, requires flexible adaptive options accompanied by corresponding institutions of scale and character. Such a combination may lead to a successful implementation in an evolving, complex, and fast-changing physical and anthropogenic environment. Above all, timely and efficient implementation of the DSS outcomes, calls for an incorporation of the produced management options in a policy framework having its foundations on a well-structured participatory process involving experts, end users, stakeholders, and decision makers.

Declaration of Competing Interest

The authors declare that there is no known conflict of interest.

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Appendix A

See Figs. 1A–4A.

Fig. 1A. Degradation processes selection interface.

Fig. 2A. Calculate dialog box interface with the pertinent indicators per desertification process.

Fig. 3A. Outputs interface with the calculated desertification risk index and the corresponding categories.

TITLE

SELECT DEGRADATIONS RESULTS

CALCULATE

Indicator	Value List	Water stress
Rain seasonality	0.60-0.79	3.0338744
Ground water exploitation	Exploitation>recharge	-
Parent material	other	-
Burned area (ha burned/10 years/10 km2 of territorial surface)	Low (<10 ha)	-
Distance from seashore or other salty water bodies (Km)	<0.25	-
Runoff water storage	adequate	-
Water scarcity (Water available supply per capita / water consumption per capita during the last 10 years) (WAC/WCC = R)	Moderate R=1-1.5	-
Population density	Moderate 50-100	-

Fig. 4A. Interface with the calculated desertification risk index and the corresponding classes.

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