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Ranking desertification indicators using TOPSIS algorithm

A. Sepehr · C. Zucca

Abstract Desertification is the result of natural and anthropogenic processes, leading to degradation or loss of the land's productivity and complexity. To assess the desertification status, integrated set of indicators must be identified. Indicators must provide synthetic information on threshold levels, status and evolution of relevant physical, chemical, biological and anthropogenic processes. Multi-criteria decision-making (MCDM) is a collection of methodologies to compare, select, or rank multiple alternatives that involve incommensurate attributes. Technique for order preference by similarity to ideal solution (TOPSIS) method is a multiple criteria method to identify solutions from a finite set. TOPSIS is an algorithm for determining the most preferable choices among the possible indicators that can be developed. The aim of this paper is to introduce TOPSIS as a decision-making method for the selection and integration of desertification indicators. The simulation case study presented here is related to the selection of the best set of indicators to monitor land degradation by remote sensing in three different countries (Brazil, Mozambique and Portugal), within the framework defined by the DesertWatch Extension project.

Keywords MCDM · TOPSIS · Desertification · Indicator system · DesertWatch

1 Introduction

Desertification is regarded as one of the most serious social–economic–environmental issues in arid, semi-arid and dry sub-humid areas. Desertification is the result of complex

A. Sepehr (✉)
Assistant Professor at the Faculty of Natural Resources and Environment,
Ferdowsi University of Mashhad (FUM), Mashhad, Iran
e-mail: adelsepehr@aol.com

C. Zucca
Department of Territorial Engineering, NRD (Nucleo Ricerca Desertificazione), University of Sassari,
Sardinia, Italy

interactions among various factors, including climate change and human activities (Thomas 1997; UNCCD 1994).

To combat desertification, affected countries must create Desertification Monitoring Systems based on "integrated series of physical, biological, social and economic indicators" aimed at allowing "systematic observation of land degradation in affected areas and to gain a better understanding of the processes and the effects of drought and Desertification" (UNCCD 1994).

Specific desertification research has been promoted by the European Commission since the early 1990s, including projects such as EFEDA, MEDALUS, MODMED, MODULUS, MEDACTION, DESERTLINKS, the more recent DeSurvey, and several others (Zucca et al. 2004). These projects have focused their efforts on providing reliable data and information, understanding the causes of desertification and identifying desertification indicators, to forecast future desertification, as well as to mitigate ongoing processes. The FAO-LADA project is developing specific integrated and multi-scale sets of indicators for the assessment of land degradation (http://www.fao.org/nr/lada).

The DesertWatch Extension project is indentifying the main indicators to assess and monitor desertification through remote sensing in three affected countries: Brazil, Mozambique, and Portugal (Armas et al. 2010). The main purpose of DesertWatch Extension is to define, implement, validate, and integrate in the user facilities a user-tailored information system to support national and regional authorities in implementing the UNCCD and monitoring desertification processes and their trends over time.

These projects are related to the identification of desertification indicators and, in particular, to the methods to select, rank, integrate, and weight them, in view of specific purposes. These aspects are really at the center of the present day discussion on indicators (Sommer et al. 2011; Zucca et al. 2010, 2012).

As an example, the very popular ESAs[1] method (Kosmas et al. 1999) proposes an index of sensitivity to desertification based on a selection of 15 indicators. A system of weights is defined both to derive parametric scores for single indicators and to set the relative importance of each one. Other methods were developed in several countries in the frame of the UNCCD, following a similar approach.

In many of these cases, numerical scores are assigned to qualitative land properties, through "expert decision" (e.g., "quality of soil drainage" or "type of land use"). Furthermore, these systems may need changes and adaptations to fit different environmental conditions and spatial scales. Experts may face the necessity to add or substitute indicators or to modify the weighting system, and these "expert decisions" are taken in uncertainty conditions.

Uncertainty prevails in real-world decision problems due to incomplete or non-obtainable information (such as fuzziness, imprecision, vagueness, incompleteness and ignorance; Shen and Jensen 2007). In addition, many decision problems involve the opinions of a group of decision makers (DMs) instead of an individual DM. Uncertainty is one of the main problems in desertification indicator studies, involving selection, weighing and preference of indicators to develop a desertification indicator system. As an example of qualitative parameters, drainage quality of soil is defined by ESA as "poor, moderate, or

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[1] Environmental Sensitive Areas (in this method, different types of ESAs to desertification can be analyzed in terms of various parameters such as landforms, soil, geology, vegetation, climate and human actions. Each of these parameters is grouped into various uniform classes and a weighting factor is assigned to each class. Then four layers are evaluated: soil quality, climate quality, vegetation quality and management quality. For more information, see Kosmas et al. 1999).

good." The question is: Where is the border of poor? What is the meaning of bad or good? It can be in relation to many aspects, such as soil fertility, infiltration, water retention.

One expert on desertification identifies it according to his/her specific background and experience, gives it a score and ultimately judges about its role on desertification. Another expert would decide and judge differently.

Concerning adaptations, as for mathematical models, an indicator system could in principle be adapted, calibrated, and validated to fit specific local conditions, on the basis of research outcomes. In practice, the number of factors involved in the desertification processes and the very changing local conditions and scales can make experts decision unavoidable. Furthermore, it is increasingly recognized that an indicator system aimed at the local scale land monitoring should incorporate local knowledge and perceptions, by combining participatory and science-driven approaches (Reed et al. 2008).

Appropriate tools and methods are needed in order to reduce uncertainty and to synthesize potentially diverging experts' opinions. The success of a decision-making process depends on both data collection and on the effective processing of the knowledge extracted from data.

The purpose of this paper is to discuss the role of MCDM methods and TOPSIS[2], in particular, as a decision-making tool for the selection of desertification indicators. In this research, MCDM and TOPSIS methods were applied to rank and select the main indicators of desertification starting from the enquiries made by the DesertWatch Extension project with national experts and users, by using questionnaires and collecting the experts' opinions.

1.1 MCDM (multi-criteria decision-making)

Multi-criteria decision-making (MCDM) problems arise in situations where a (group of) decision maker(s) faces a problem of choosing the best alternative among several possible alternatives. The rapid growth of MCDM over the past three decades is due to a number of reasons, including dissatisfaction with conventional "single criterion" methods and the emergence of software and algorithms for solving complex environmental problems. MCDM can help decision makers to formulate their preferences, to rank priorities, and to apply them to a particular decision context. This process often involves reconciling quantities that are not commensurate. For example, in desertification problem, the units of one attribute such as soil depth may be in centimeters, while vegetation cover may be measured as lost biomass, etc. MCDM techniques are widely used to identify alternatives that are dominated by at least one other alternative (i.e., have poorer values on some criteria, and no better values on another criterion). In general, such dominated (inefficient) alternatives should not be further considered as they fall below the efficient frontier.

The main steps of MCDM can be stated as (Opricovic and Tzeng 2004):

(a) Establishing system evaluation criteria that relate system capabilities to goals.
(b) Developing alternative systems for attaining the goals (generating alternative).
(c) Evaluating alternatives in terms of criteria (the values of the criterion functions).
(d) Applying a normative multi-criteria analysis method.
(e) Accepting one point as "optimal."
(f) If the final solution is not accepted, gather new information and go into the next iteration of multi-criteria optimization.

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[2] Technique for Order Preference by Similarity to Ideal Solution (Hwang and Yoon, 1981).

Steps (a) and (e) are performed at the upper level, where decision makers have the central role, while the others are mostly engineering tasks. For steps (d) and (a), decision makers should express their idea about the importance of the criteria to determine the criteria's weights.

Some of these methods, such as TOPSIS (Hwang and Yoon 1981), VIKOR (Opricovic 1998), AHP (Saaty 1980), PROMETHEE (Brans et al. 1984; Olson 2001), and ELECTRE (Roy 1990), among others, have recently been applied to the management of natural resources, but not yet to desertification-related research.

The MCDM techniques can be categorized into multiple objective mathematical programming (MOMP) and multi-attribute decision-making (MADM). MADM applies to a discrete set of explicit alternatives (i.e., when the set of alternatives can be defined by listing its finite, and usually small, members). On the other hand, in MOMP, a set of alternatives are implicitly defined by a set of constraints to be satisfied, resulting in a large (or infinite) set of decision alternatives. MOMP problems are often formulated as linear, integer, or nonlinear mathematical programming problems. For example, multiple objective linear programming selects the best of the efficient solutions using Goal Programming and other procedures (a set of decision variables, constrained to remain within a feasible region, is optimized).

1.1.1 MADM in studying desertification indicators

In MADM problems, the highest objective is usually a broadly defined goal that may be broken down into a hierarchy of criteria or objectives, with the lower levels becoming more detailed and measurable, but more conflicting. Performance criteria (also referred to as attributes) measure the degree to which these objectives are achieved. A critical phase of MADM involves the construction of the decision matrix (also called the product matrix, payoff matrix, performance matrix, decision table, etc.).

Table 1 is an example of decision matrix applied to the case of desertification indicators. Entries of this matrix represent scores (ratings) r_{ij} of desertification indicators alternatives (A_1, …, A_m) with respect to selection criteria (C_1, …, C_n), such as technical quality, data availability. Values (w_1, …, w_n) in the top row are the criteria weights.

In Table 1, simple additive weighting is applied to scale the scores. One applies criteria weights, adds the r_{ij} values in each row of the matrix, and selects the top-ranked alternative. A related approach is simple product weighting which uses the products of r_{ij}

Table 1 MADM matrix applied to desertification indicators: alternatives, criteria, and weights

Matrix of desertification indicators alternatives and weights				
Alternatives (indicators)	Weights			
	w_1	w_2	w_3	w_n
	Decision criteria examples: data availability, RS potential, users preference			
	C_1	C_2	C_3	C_{nn}
	Indicators scores			
A_1 (e.g., decreased in canopy cover)	r_{11}	r_{12}	r_{13}	r_n
A_2 (e.g., decrease in number of species)	r_{21}	r_{22}	r_{23}	r_n
A_m	r_{m1}	r_{m2}	r_{m3}	r_{mn}

values in each row (instead of summations). Hwang and Yoon (1981) also use the same decision matrix in the TOPSIS approach.

In TOPSIS, the most preferred alternative is not only the shortest Euclidean distance from the "ideal" solution, but also the farthest from the undesirable solution (nadir point),[3] across all criteria. Compromise programming (Zeleny 1982) constitutes a further development of the method: it uses a decision matrix like Table 1, ranking alternatives according to their closeness to the so-called utopia point.

In other words, to identify desertification indicators, based on local conditions and preference, MCDM methods and weights matrix can be used for scoring indicators. The applications of MCDM methods in desertification studies could be grouped into four categories:

- Identifying desertification indicators
- Scoring desertification indicators
- Comparing and ranking indicators relevance to desertification monitoring
- Choosing indicators

1.2 TOPSIS method (Techniques for Order Preference by Similarity to an Ideal Solution)

TOPSIS basic concept is that the selected best solution from a finite set of alternatives should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution in a geometrical sense (Triantaphyllou and Lin 1996; Olson 2004). TOPSIS assumes that each attribute (or alternative) has a tendency toward monotonically increasing or decreasing utility. Therefore, it is easy to locate the (positive/negative) ideal solutions (Triantaphyllou and Lin 1996). The present study meets this requirement. For example, if the final objective is to combat desertification, indicators could be grouped and ranked according to specific criteria: indicators related to "degree of protection" may highlight good land status and low priority for intervention, while "severity" indicators may point to high degradation conditions or risk and high priority for action.

TOPSIS can be implemented through the following six steps listed below:

Step 1 Establish a decision matrix for the ranking. The structure of the matrix can be expressed as follows:

$$
D = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdot \\ \cdot \\ \cdot \\ A_n \end{array}
\begin{array}{cccccc} F_1 & F_2 & . & . & . & F_n \end{array} \\
\begin{bmatrix}
f_{11} & f_{12} & . & . & . & f_{1n} \\
f_{21} & f_{22} & . & . & . & f_{2n} \\
. & . & & & & . \\
. & . & & & & . \\
. & . & & & & . \\
f_{m1} & f_{m2} & . & . & . & f_{mn}
\end{bmatrix}
$$

where A_i denotes the alternatives i, $i = 1, ..., m$; F_j represents jth attribute or criterion, $j = 1, ..., n$, related to ith alternative; and f_{ij} is a crisp value indicating the performance rating of each alternative A_i with respect to each criterion F_j.

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[3] NADIR point is a geometric *allegory* for distance of preferred indicators from desirable and undesirable solutions which has shortest distance from positive solution and farthest distance from negative solution.

Step 2 Calculate the normalized decision matrix R (=$[r_{ij}]$). The normalized value r_{ij} is calculated as:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}}$$

where $j = 1, \ldots, n; i = 1, \ldots, m$.

Step 3 Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value V_{ij} is calculated as:

$$v_{ij} = w_{ij} r_{ij}$$

where w_j represents the weight of the *j*th attribute or criterion.

Step 4 Determine the positive ideal solution (PIS) and negative ideal solution (NIS), respectively:

$$v^+ = \{v_1^+, \ldots, v_n^+\} = \{(\mathrm{Max} v_{ij} | j \in J), (\mathrm{Min} v_{ij} | j \in J^-)\}$$
$$v^+ = \{v_1^-, \ldots, v_n^-\} = \{(\mathrm{Min} v_{ij} | j \in J), (\mathrm{Max} v_{ij} | j \in J^-)\}$$

where J is associated with the positive criteria and J^- is associated with the negative criteria.

Step 5 Calculate the separation measures, using the m-dimensional Euclidean distance. The separation measure D_i^+ of each alternative from the PIS is given as:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij-v_j^+}\right)^2}, \quad i = 1, \ldots, m.$$

Similarly, the separation measure D_i^- of each alternative from the NIS is as follows:

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij-v_j^+}\right)^2}, \quad i = 1, \ldots, m.$$

Step 6 Calculate the relative closeness to the ideal solution and rank the alternatives in descending order. The relative closeness of the alternative A_i with respect to PIS V^+ can be expressed as:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

where the index values of C_i lies between 0 and 1. The larger the index value, the better the performance of the alternatives.

Then, based on experts' opinions, the higher the score from TOPSIS, the higher is the priority of the indicators for selection.

2 Materials and methods

The DesertWatch Extension (DW-E) system is being designed on the basis of the specific requirements expressed by the user groups during the project preparation phase. It is based

on Earth Observation processing tools, models, and GIS facilities that will combine bio-physical parameters to provide users with the required information.

In order to illustrate the method proposed above (TOPSIS algorithm), the experts' consultation questionnaires produced by DW-E in Brazil, Mozambique and Portugal were acquired and processed. The project proposed a list of 29 candidate indicators to the local experts and institutional users in each of the three countries involved. The indicators were categorized based on the DPSIR (driving force, pressure, state, impact and response) framework (Gentile 1998), to highlight their "role" in the system according to a causal network approach (Niemeijer and de Groot 2008).

In the course of local participatory workshops, the users provided their feedback in relation to their perception of the indicators relevance and feasibility (Table 2). A variable number of users and experts filled in the questionnaires (7–9 answers were received in each country).

Three criteria were considered to rank the indicators: local relevance (users' prefer-ence), scale suitability (to national mapping purposes), and RS potential or technical quality. Values of 1–5 were given to determine the indicator relevance. Values ranging between 0 and 2 were assigned for scale suitability (2 to the indicators specifically matching the national requirements, 1 to the indicators generally applicable to national and/or other scales, and 0 to the ones considered as not feasible at the national scale). Finally, a "technical quality" score (0–5) was assigned based on the indicators' suitability to be mapped by means of remote sensing.

In order to rank the indicators, a decision matrix including 29 columns containing the candidate indicators (alternatives) and 7 rows with the criteria was prepared as follows:

$$
\begin{array}{c}
\begin{array}{ccccccc} A_1 & A_2 & A_3 & . & . & . & A_{29} \end{array} \\
\begin{array}{c} C_1 \\ C_2 \\ . \\ . \\ . \\ C_n \end{array}
\begin{bmatrix}
w_{11} & w_{12} & . & . & . & w_{1n} \\
w_{21} & w_{22} & . & . & . & w_{2n} \\
. & . & & & & . \\
. & . & & & & . \\
. & . & & & & . \\
w_{m1} & w_{m2} & . & . & . & w_{mn}
\end{bmatrix} .
\end{array}
$$

The considered criteria are: the users' preference in each country (3 rows); the scale suitability as evaluated by the users in each country (3 rows); and the overall technical quality score (1 row).

Since, in some cases, lack of response to weight of criteria by experts has been caused problem in the actual weights estimation, so to determine the final weights of indicators, the weighting mean has been applied:

$$\bar{X} = \frac{\sum(w \times n)}{N} \tag{1}$$

where $\bar{X}$ means weighting mean, w is the preference level assigned by the local experts, n is the number of experts who responded for each indicator, and N is the total number of responses. As an example, the "decrease in species number" in Brazil, after application of the weighing mean, was assigned a final weight of 4.5, a relatively high preference.

Regret means that when one indicator is chosen according to the regret amount, we have more certainty for the selection and less remorse and regret in future.

In this research after calculation of weighting mean (Eq. 1), which describes the average considering scores based on experts opinions, the most perfect alternatives with minimum regret and maximum preference were selected.

Table 2 The used dataset: indicator scoring according to the preference of the experts of the local project users in Brazil, Mozambique and Portugal

Grade of preference: 1 to 5 (1, inexistent; 2, small; 3, medium; 4, high; 5, very high)

		Number of answers (Bra)						Number of answers (Moz)							Number of answers (Por)						
		Grade					Scale	Grade						Scale	Grade						Scale
		1	2	3	4	5		NA	1	2	3	4	5		NA	1	2	3	4	5	
Major ecosystem state variables																					
Degradation of vegetation	Decrease in number of species	0	0	1	2	6	R, N	3	0	0	0	3	3	N	1	0	1	2	1	3	–
	Modification in the composition of species or in the "plant functional types"	0	1	2	3	3	N	3	0	1	2	1	2	N	1	0	1	1	3	2	–
	Decrease in the canopy cover and/or biomass	0	0	0	2	7	N, L	3	0	1	1	0	4	N	1	0	1	1	2	3	R, N, L
Degradation of soils	Water erosion	0	0	0	1	8	R, N, L	2	0	0	0	1	6	R	1	0	0	1	0	6	N, L
	Wind erosion	2	2	3	0	2	L	3	0	1	1	2	2	R	2	1	1	2	0	2	–
	Salinization and overexploitation of groundwater	0	0	2	5	2	N	3	0	0	2	1	3	L	1	0	0	3	2	2	R, N, L, L
	Soil compaction	0	1	4	2	2	N	2	0	1	3	2	1	N	1	0	1	2	1	3	L
	Soil organic matter and soil biodiversity losses	0	0	0	4	5	L	2	0	0	0	3	4	N	1	0	0	1	0	6	R, N, L
Proximate causes of desertification																					
Overgrazing	Depletion of valuable perennial grasses and replacement by less valuable species	0	1	2	4	2	N	2	0	1	3	1	2	N	2	0	2	2	2	0	L
	Reduction in vegetation density	0	0	1	1	7	R, N	2	0	0	2	2	3	N	1	0	0	4	1	2	L
	Soil compaction	0	1	2	1	5	N	2	1	1	1	2	2	R	1	0	1	2	1	3	L
Over cropping, poor irrigation practices	Loss of soil fertility	0	0	1	5	3	N, L	2	0	0	0	0	7	N	1	0	0	2	2	3	N, L

Table 2 continued

Grade of preference: 1 to 5 (1, inexistent; 2, small; 3, medium; 4, high; 5, very high)

		Number of answers (Bra)						Number of answers (Moz)							Number of answers (Por)						
		Grade					Scale	Grade						Scale	Grade						Scale
		1	2	3	4	5		NA	1	2	3	4	5		NA	1	2	3	4	5	
Deforestation and woodland degradation	Expansion of cultivated areas	0	1	1	2	5	R, N, L	2	0	0	1	3	3	R	2	1	0	3	1	1	N, L
	Fuel wood and charcoal production	0	0	0	2	7	R, N, L	2	0	0	3	1	3	N	2	1	0	2	2	1	L
	Wood cut for fodder	0	0	3	2	4	N, L	2	2	1	3	1	0	N	2	0	1	5	0	0	L
	Fires	2	0	1	0	6	R, N	2	0	1	1	0	5	N	2	0	0	1	0	5	R, N, L
Underlying causes of desertification																					
Population decrease	Fields abandonment	0	1	3	4	1	R, N	2	1	1	3	0	2	N	1	0	1	1	1	4	R, N, L
Population growth	Increase in food demand	1	1	3	3	1	R, N	2	0	0	3	2	2	N	1	1	1	3	1	1	R, N, L
Economic development	Alteration of the land use	0	0	1	1	7	N, L	4	0	0	2	0	3	N	1	0	0	0	2	5	R, N, L
Civil and political conflicts	Migration of populations	1	0	2	4	1	R, N	2	0	1	5	0	1	N	2	1	0	1	2	2	R, N, L
Extension of modern infrastructures	Increase in human impacts	0	0	2	3	3	N	3	0	2	2	1	1	N	1	1	0	1	3	2	R, N, L
Policy and institutional factors	Spread of market economies	0	0	4	3	2	R, N	2	0	1	2	2	2	N	1	1	0	0	2	4	N, L
	Resetting of populations	1	0	4	1	1	R, N	3	1	0	3	0	2	N	1	1	1	2	2	1	N, L
Recovery and mitigation measures																					
Re-naturalization of agricultural areas	Increase in vegetation cover	0	1	0	1	7	N	3	1	0	1	1	3	L	1	0	0	2	1	4	R, N, L

Table 2 continued

Grade of preference: 1 to 5 (1, inexistent; 2, small; 3, medium; 4, high; 5, very high)

		Number of answers (Bra)						Number of answers (Moz)							Number of answers (Por)						
		Grade					Scale	Grade						Scale	Grade						Scale
		1	2	3	4	5		NA	1	2	3	4	5		NA	1	2	3	4	5	
Irrigation	Improvement of irrigation system	0	1	1	4	3	N	3	0	2	0	1	3	N	1	1	0	1	1	4	R, N, L
Increase in forest areas	Increase in forest areas	0	1	1	1	6	N	3	0	0	1	1	4	R	2	1	0	0	0	5	R, N, L
Soil protection	Alteration of water runoff	1	2	0	3	3	N	3	1	1	0	2	2	R	1	1	0	1	1	4	N, L
Soil rehabilitation	Soil reclamation/improvement	0	1	2	3	3	N	3	1	0	1	2	2	N	3	0	0	1	1	3	N, L
Control of livestock	Decrease in the number of cattle to prevent the ecosystem degradation	1	0	3	1	4	N	3	2	2	0	1	1	R	3	1	0	0	1	3	–

NA No Answer; Scales: Regional (*R*), National (*N*), Local (*L*)

Data processing was carried out through the SDI software (version 3, Statistical Design Institute, Mckinney, Texas 2009). The SDI Tools operate as an add-into Microsoft Excel. Triptych is the SDI utility that provides easy-to-use tools to process experts' opinions and selects the best design option that meets multiple criteria, such as TOPSIS and AHP methods.

To process the considered dataset through SDI, according to the specific software terminology, the indicators were considered as "options." RS potential (technical quality), preference degree and scale were the "criteria." For each option (indicator) and criterion, the corresponding numerical value was entered and the program was run. The option with the resulting highest score is the closest to the ideal solution.

3 Results and discussion

Local experts in the three countries were questioned about the most suitable set of EO-based desertification indicators to be adopted for the respective project study areas. The indicators proposed are related to the major state variables, the proximate and underlying causes of desertification, as well as the possible measures of mitigation.

The answers were of course different country by country (Table 2). They were more concentrated in the case of Brazil, clearly pointing to some major desertification factors. The decrease in vegetation canopy coverage and/or biomass is the most relevant factor of desertification (7/9 high-grade answers), second was the loss of biodiversity. In terms of soil degradation, water erosion (8/9 high-grade answers), and the loss of organic matter and biodiversity are the most important factors to be monitored. Their perception is that the immediate causes are primarily, the reduction in vegetation density (7/9) and soil compaction caused by overgrazing and deforestation. Other major cause is woodland degradation due to fuel wood collection and charcoal production (7/9), fires (6/9), and expansion of cultivated areas (5/9). The alterations of land use (7/9) mainly due to the socio-economic development dynamics are seen as the underlying causes. The main mitigation measures elected by the users to be monitored are the re-naturalization of agricultural areas and the increase in forest areas. The answers given by the experts in Mozambique and Portugal were more dispersed, probably suggesting that a greater number of factors are thought to contribute, although some of them, such as water erosion, loss of soil organic matter and biodiversity, wild fires, and increase in forest areas, are confirmed as the main aspects to be monitored.

Concerning the spatial scale, the users have very different perceptions in the 3 countries and likely had difficulty in choosing an option, since several users did not answer this question (or always chose the same answer). Furthermore, it is known that the same factor can be linked to different scales in different countries. That can be related to different reasons, such as the different extent of the specific land degradation processes in their countries, the different data availability, or a different understanding of the technical definition of the candidate indicators.

The heterogeneity of the questionnaires outcome suggested implementing a TOPSIS simulation with the objective of finding the best minimum set of indicators satisfying the monitoring requirements of the three countries at the same time. The simulation also took into account the project capacity in relation to RS data processing (available sensors and data), expressed in the form of "technical quality" criterion, already mentioned. Although the project will provide tailored options to each country, the simulation could help to

Table 3 Analysis and simulation of indicators by TOPSIS method

	1 Decrease in number of species	2 Modification in the composition of species or in the "plant functional types"	3 Decrease in the canopy cover and/or biomass	4 Water erosion	5 Wind erosion	6 Salinization and overexploitation of groundwater	7 Soil crusting	8 Soil organic matter and soil biodiversity losses	9 Depletion of valuable perennial grasses and replacement by less valuable species	10 Reduction of vegetation density
Criteria										
1 User Prefer. (M)	4.5	3.7	4.2	4.8	3.8	4.2	3.4	4.6	3.6	4.1
2 User Prefer. (B)	4.5	3.8	4.8	4.9	2.7	4	3.5	4.5	3.7	4.6
3 User Prefer. (P)	3.8	3.8	4	4.7	3.2	3.8	3.8	4.7	3	3.7
4 Scale (M)	2	2	2	0	0	0	2	2	2	0
5 Scale (B)	1	2	1	1	0	2	2	0	2	1
6 Scale (P)	0	0	1	1	0	1	0	1	0	0
7 RS Potential	1	2	5	2	2	3	1	1	3	5
TOPSIS Score	0.45	0.54	0.77	0.50	0.17	0.58	0.50	0.51	0.56	0.46

	11 Soil compaction	12 Loss of soil fertility	13 Expansion of cultivated areas	14 Fuel wood and charcoal production	15 Wood cut for fodder	16 Fires	17 Fields abandonment	18 Increase in food demand	19 Alteration of the land use	20 Migration of populations
Criteria										
1 User Prefer. (M)	3.4	5	4.3	4	2.4	4.3	3.1	3.8	4.2	3.1
2 User Prefer. (B)	4.1	4.2	4.2	4.8	4.1	3.9	3.5	3.2	4.7	3.1

Table 3 continued

		11 Soil compaction	12 Loss of soil fertility	13 Expansion of cultivated areas	14 Fuel wood and charcoal production	15 Wood cut for fodder	16 Fires	17 Fields abandonment	18 Increase in food demand	19 Alteration of the land use	20 Migration of populations
3	User Prefer. (P)	3.8	4.1	3.2	3.3	2.8	4.7	4.1	3	4.7	3.7
4	Scale (M)	2	0	2	2	2	2	2	2	2	2
5	Scale (B)	2	1	1	1	1	1	1	1	1	1
6	Scale (P)	0	1	1	0	0	1	1	1	1	1
7	RS Potential	1	1	5	2	1	5	4	1	5	2
	TOPSIS Score	0.50	0.46	0.74	0.47	0.41	0.77	0.69	0.54	0.78	0.58

		21 Increase in human impacts	22 Spread of market economies	23 Resettling of populations	24 Increase in vegetation cover	25 Improvement of Irrigation System	26 Increase in forest areas	27 Alteration of water runoff	28 Soil reclamation/ improvement	29 Decrease in the number of cattle to prevent the ecosystem degradation
Criteria										
1	User Prefer. (M)	3.2	3.7	3.3	3.8	3.8	4.5	3.5	3.7	2.5
2	User Prefer. (B)	3.7	3.8	2.7	4.5	4	4.3	3.5	3.9	3.8
3	User Prefer. (P)	3.7	4.1	3.1	4.3	4	4.3	4	4.4	3.8
4	Scale (M)	2	2	0	2	0	0	2	0	0
5	Scale (B)	2	1	1	2	2	2	2	2	2
6	Scale (P)	1	1	1	1	1	1	1	1	0
7	RS Potential	2	1	3	5	1	5	1	2	1
	TOPSIS Score	0.66	0.55	0.47	0.89	0.51	0.66	0.61	0.54	0.38

optimize the overall system, suggesting the solutions characterized by a wider global applicability.

The TOPSIS simulation results are shown in Table 3. Five "headline" indicators received the highest scores, above 0.70 (0.74–0.89):

- Increase in vegetation cover (response; 0.89);
- Alteration of land use (underlying cause; 0.78);
- Fires (proximate cause; 0.77);
- Decrease in the canopy cover and/or biomass (state; 0.77);
- Expansion of cultivated areas (proximate cause; 0.74).

These indicators cover most of the key factors related to the main dimensions of desertification. They offer the possibility to develop common products for the three countries based on sound RS data processing. They could thus constitute a core set of monitoring indicators.

Other three indicators obtained slightly lower scores compared with the previous ones (0.66–0.69):

- Fields abandonment (underlying cause; 0.69);
- Increase in human impacts (underlying cause; 0.66);
- Increase in forest area (response; 0.66).

The above indicators cover another range of significant aspects related to causal factors, usually more interlinked with socio-economic issues and less readily captured through RS alone.

Some fundamental state indicators related to soil (e.g., erosion and salinization) as well as impact indicators such as "alteration of water runoff" obtained lower scores due to the relatively higher complexity of mapping them through RS at the considered scale. They should nevertheless be part of a national monitoring systems adapted to the specific local requirements in terms of scales and processes.
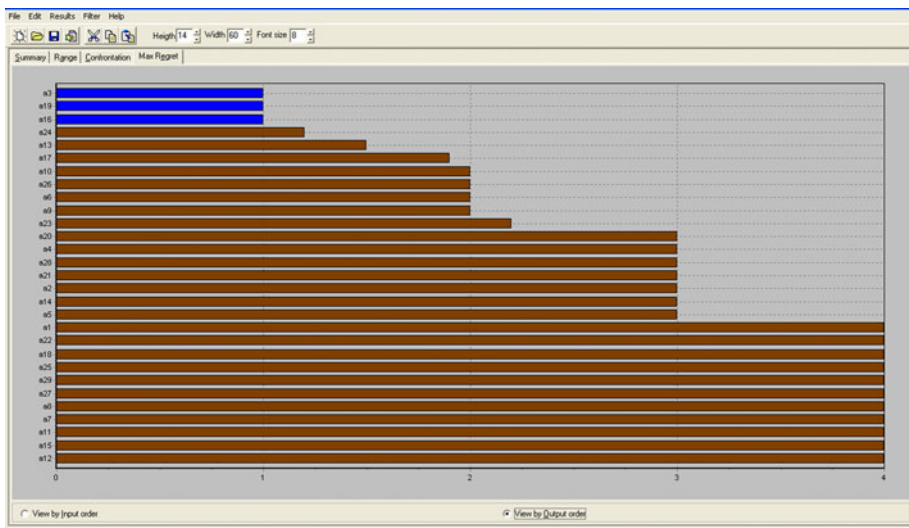
Fig. 1 Selection of indicators considering regret amount (indicators with minimum regret are distinguished by blue color involving biomass decreasing (a_1), alteration of land use (a_2) and fire (a_3))

The results obtained can be considered as consistent with the assumptions and satisfying in relation to the objectives. TOPSIS provided a sound basis to compare and optimize options in a context characterized by multiple and heterogeneous perceptions.

TOPSIS also provided a repeatable and objective model to rank and select desertification indicators.

In this research, the use of the TOPSIS method to rank desertification monitoring indicators highlighted that response indicators are given by the users the highest role in desertification risk management. Figure 1 shows the selection of indicators base on maximum regret. Indicators with minimum regret are distinguishable by blue color. Therefore, as the indicator of decrease in biomass (a_3 in Fig. 1), alteration of land use (a_{19} in Fig. 1) and fire (a_{16} in Fig. 1) gained minimum regret in the study, the selection of these indicators as main factors brings less uncertainty and risk in management.

4 Conclusions

Problems arising in environmental management tend to be complex and interdisciplinary in nature. For example, the forests cutting for commercial purposes can have tremendous impacts on the natural environment as well as on the economical, political, and social structures of the affected communities. Land degradation can be one of the consequences of forest cutting, which leads to desertification phenomenon. Moreover, the various interest groups such as the leaders of the forestry industry, environmental groups, and political organizations may interpret the activity from radically different viewpoints according to their own multiple objectives and interests. Therefore, MCDM techniques can be effectively employed to assist decision makers in reaching fair and equitable solutions within a sustainable development framework.

In a number of studies to identify indicators, many uncertainties are related to the selection of the indicator weights and to the methods of distance calculation and data normalization. Weights are to be given to each individual indicator to reflect its relevance to the overall objective of the assessment considering the different users' perceptions.

In TOPSIS, the set of weights derives from consultation with relevant experts. It does not mean that any weighting can be used for an individual indicator. But the weighting for an indicator depends on the experts' understanding of the relative importance of that indicator to the overall objective and to the involved interest.

In the present study, as a part of a more complex project, the TOPSIS method was tested to select a common set of desertification indicators potentially applicable in three countries (Brazil, Mozambique, and Portugal) by means of Earth observation data.

The exercise was carried out through local participatory workshops organized with the support of the local institutional bodies in charge for desertification-related policies. The indicator selection process was based on multiple criteria: relevance of the indicators in relation to the local conditions in the involved countries; compatibility with regard to the considered spatial scales; suitability in relation to the adopted measurement approach (remote sensing).

The results obtained reflect the users' perception and constituted an important input for the project. They can contribute to ensure that the final products will be tailored to the user needs. Furthermore, the methodological value of the exercise will remain, as it could be replicated to meet changing requirements. As an example, among the several indicators which were given high relevance score, some were socio-economic and were discarded because not suited to RS. In future applications, aimed at generating more integrated and

interdisciplinary indicator sets, the criteria could be easily adapted to the new objectives. In this regard, it has to be considered that the number and composition of the participants to the workshops can influence the quality of the results. Care has to be taken to ensure the representative of the "sample," in terms of groups of experts and DMs involved.

TOPSIS proved to be a cost-effective and flexible method, as it provides a screening tool to identify, prefer, and weight indicators for further investigation. However, this approach is not intended to substitute a scientific analysis of the indicators based on experimental research. After ranking indicators based on expert (and policy) relevance, they have then to be transformed into operational indicators, by conducting field research where necessary, to actually develop and integrate them into structured indicator sets. Furthermore, indicators can be selected and substituted to match the specific characteristics of each region. Since the land degradation conditions are various in different regions, the method can be applied with proper adjustment, provided the principal factors affecting desertification are identified and the relevant data layers are available.

Finally, TOPSIS proved to be a valuable method to face the increasing complexity of the land management and monitoring decisions. Its implicit participatory approach make it easier to consider the usually conflicting goals of all parties involved, to include decision makers' preferences and, last but not least, to stimulate communication and discussion among the users.

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