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Short communication

Performance evaluation and cost assessment of a key indicator system to monitor desertification vulnerability

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ABSTRACT

A number of studies have dealt with the assessment of potential and actual desertification risk using composite indices. The Environmental Sensitivity Areas (ESA) approach, developed in the framework of MEDALUS project funded by the European Community, is one of the most used procedures to monitor land vulnerability to degradation in the Mediterranean region. The final output of this procedure is an index (ESI) composing four indicators of climate, soil, vegetation, and land management based on 14 elementary variables. Although applied to a number of case studies throughout southern Europe, northern Africa and the Middle East, the performance of this monitoring system has never been assessed. The present study evaluates the robustness of the ESI through an original procedure incorporating sensitivity analysis and data cost analysis. For each variable, the standard error of the estimate, the correlation coefficient with the ESI, the sensitivity score, and the estimated costs of data collection and handling were calculated in order to evaluate the stability of the final index and the relative importance of each composing variable. The overall performance of the ESI was computed by averaging the score of the four indicators. Variables such as vegetation cover, climate aridity, rainfall, and the degree of land protection provided the largest contribution to the ESI. The illustrated approach is suited to evaluate the overall performance of a set of variables composing a synthetic index. Moreover, to our knowledge, this is the first attempt to consider explicitly the monetary costs of data collection and handling within a composite index evaluation procedure.

1. Introduction

Land vulnerability to desertification is the result of several interacting factors (directly or indirectly) linked to ecosystem degradation phenomena. Land vulnerability mainly depends on climate, soil properties, vegetation cover, landscape quality, and socioeconomic factors (Helldén and Tottrup, 2008). A number of studies have dealt with the assessment of the potential and actual risk of desertification using composite indices (e.g. Sommer et al., 2011). The Environmental Sensitivity Areas (ESA) approach, developed under the framework of MEDALUS and DESERTLINKS projects, is one of the most used procedures to estimate land vulnerability to desertification in the Mediterranean basin, northern Africa, and the Middle East (see Fraser et al., 2005; Sepehr et al., 2007; Ali and El Baroudy, 2008; Spilanis et al., 2008, among others). The final output of this procedure is a key indicator system producing an index (ESI) that comprises 14 variables assessing climate, soil, vegetation, and land management (Salvati and Zitti, 2008a).

Recent studies have successfully validated on the ground, at both local and regional scales, the responsiveness of the ESI to different levels of land vulnerability and actual degradation (Kosmas et al., 1999; Basso et al., 2000; Ferrara et al., 2005; Salvati and Zitti, 2008b; Lavado Contador et al., 2009). However, the input variables to the ESI were selected through a subjective process and, till now, the statistical performance of this information system has never been assessed (Salvati and Zitti, 2009a). Moreover, few studies evaluated the importance of the individual variables and their contribution to the ESI, and no attempts have been made to evaluate costs of data collection and handling and to incorporate this variable in global performance evaluations (Salvati and Zitti, 2008b). Especially when working with complex phenomena like desertification, the use of indicators that are (i) reliable, (ii) regularly updatable, (iii) available at low cost, and (iv) readable to cover large areas at high spatial resolution, is crucial to support permanent monitoring systems that are informative for policy implementation.

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Table 1
Description of the ESI themes and data source used in the study site application.

Theme	Layer name	Data source
Pedology	Parent material, rock fragments, soil depth, slope angle, drainage and soil texture	Soil maps at 1:100,000 scale and field samplings
Climate	Rainfall, aspect, aridity index	Climatic maps at 1:250,000 scale and 20 m ASTER Digital Elevation Model
Vegetation	Fire risk, protection against soil erosion drought resistance, vegetation cover	Remote sensing and land cover maps at 1:25,000 scale
Land management	Land use intensity, policy enforcement	Statistical data at municipal and infra-municipal level

This paper illustrates a global performance evaluation of the ESI through an original procedure incorporating sensitivity analysis and cost analysis. For each considered variable, the standard error of the estimate, the observed correlation coefficient with the ESI, the maximum sensitivity score, and the estimated costs of data collection and handling were calculated to assess the stability of the final index and to evaluate the relative importance of each composing variable. A final performance index was obtained by averaging the score of the above-mentioned indicators. The illustrated procedure is suited to evaluate the overall performance of a variables' set composing a synthetic index. The incorporation of costs for data collection and handling in a composite index evaluation procedure represents a novelty of the approach. The obtained results were discussed with a view to establish a permanent monitoring observatory for land and ecosystem degradation in the Mediterranean region using the ESI approach.

2. Methods

2.1. Theoretical framework

The reference framework of the present study is the Key Indicator Set (KIS) that was developed under MEDALUS III and DESERTLINKS projects as an input to the ESA composite index. The KIS includes indicators describing four environmental themes (hereafter 'quality'): soil properties, climate, vegetation characteristics, and land management (Kosmas et al., 1999; Basso et al., 2000; Ferrara et al., 2005). We developed a study site application to calculate the ESI in the Agri basin, southern Italy (see below), where extensive analyses on land degradation and desertification were carried out in recent years (Ferrara, 2005).

The variables used to evaluate the ESI (hereafter called 'layers') at land unit scale (30 m × 30 m) are listed in Table 1 and fully described by Kosmas et al. (1999), Ferrara et al. (1999) and Basso et al. (2000). In the MEDALUS project, layers were selected according to the following criteria: (i) documented relationship with desertification processes, (ii) easy updating, and (iii) availability at the highest spatial resolution as possible.

The ESA methodology used a two-step approach. In the first step, four quality layers (hereafter 'partial indicators') were derived from the basic layers. A score was attributed to each layer's value (Kosmas et al., 2003) to obtain a classification of the study area based on the layer's contribution to land vulnerability (Table 2). We used the original score system proposed by Kosmas et al. (1999). At that time, scores were derived from the analysis described in Ferrara et al. (1999) and from additional information gathered from previous studies (Kosmas et al., 2000a, 2000b; Lavado Contador et al., 2009). A correlation analysis and a focus group analysis were finally carried out to indicate the most valid, low-cost, and efficient score set (Salvati and Bajocco, 2011). The score assigned to each layer and contributing to each partial indicator was calculated as the geometric mean of the basic layer scores:

$$\text{indicator}\,(x_{ij}) = (\text{layer\_1}_{ij} \times \text{layer\_2}_{ij} \times \text{layer\_3}_{ij} \times \cdots \times \text{layer\_n}_{ij})^{(1/n)} \quad (1)$$

Each partial indicator ranges from 1 (the lowest contribution to land vulnerability) to 2 (the highest contribution to land vulnerability). In the second step, the land vulnerability to degradation was calculated from the partial indicator layers, where i, j are rows and columns of each evaluated land unit in each layer, and n is the number of layers. Hence the index describing the level of land vulnerability of each land unit (hereafter 'ESI') was calculated as:

$$\text{ESI}_{ij} = (\text{indicator\_1}_{ij} \times \text{indicator\_2}_{ij} \times \text{indicator\_3}_{ij} \times \text{indicator\_4}_{ij})^{(1/4)} \quad (2)$$

The ESI ranges from 1 (the lowest level of vulnerability to degradation) to 2 (the highest level of vulnerability to degradation). The investigated area can be classified according to the ESI score in four categories (ESI < 1.17: non-affected areas; 1.17 < ESI < 1.225: potentially affected areas; 1.225 < ESI < 1.375: 'fragile' areas; and ESI > 1.375: 'critical' areas).

2.2. Study site application

To evaluate the overall statistical performance of the ESI, we calculated the KIS including the final vulnerability index in a potentially affected area located in southern Italy (Agri basin) at land unit scale (30 m × 30 m cells producing a total of 16,138 observation sites placed on a regular grid). The Agri basin is located in Basilicata region and is recognized as one of the most economically disadvantaged and environmentally sensitive areas in southern Europe. The Agri basin covers 1730 km^2 and is divided into three homogeneous regions (Basso et al., 2000). The upper region of the valley has an average elevation higher than 600 m a.s.l. and a surface area extending for 600 km^2 dominated by a valley-floor plain with an average population density of nearly 50 inhabitants/km^2. The middle valley covers 47% of the catchments and was characterized by badlands or 'calanchi' land with lower population density. The lower Agri valley covers nearly 25% of the basin and hosts the highest population density (almost 70 inhabitants/km^2). Climate is typically Mediterranean with summer droughts and mild winters along the Ionian coast and in the lowest hilly areas. In the upper part of the valley the climate is temperate with relatively warm summers and cold winters with some snow. Above 1600 m, climate is cold with long periods of snow and annual rainfall up to 2000 mm. Data used in this study refer to the year 2000. Climate data are long-term average values referring to 1971–2000 (Salvati and Zitti, 2008a).

2.3. Evaluating the overall performance of the ESI

In order to evaluate the contribution of the individual layers to the final index and to estimate the overall performance of the KIS, two aspects were considered here: (i) the capability of each layer to describe the investigated process, and (ii) the cost of data collection, handling, and elaboration. To some extent these targets can be considered as conflicting. As a matter of fact, due to parsimony criteria, environmental assessment needs efficient monitoring systems that implement a minimum number of cost-effective variables. We calculated four indicators in order to evaluate the overall performance of the KIS: the maximum observed sensitivity score, the standard

Table 2
Input layers and related scores (according to Ferrara et al., 2005).

(a) Soil

Variable	Class	Score
Parent material (class)	Shale, schist, basic, ultra basic, conglomerates, unconsolidated, clays	1.0
	Marl with natural vegetation	1.7
	Limestone, marble, granite, rhyolite, ignibrite, gneiss, siltstone, sandstone, dolomite marl, pyroclastics	2.0
Soil texture (class)	L, SCL, SL, LS, CL	1.0
	SC, SiL, SiCL	1.2
	Si, C, SiC	1.6
	S	2.0
Rocky fragments (%)	>60	1.0
	20–60	1.3
	<20	2.0
Soil depth (cm)	Deep (>75)	1.0
	Moderate (30–75)	2.0
	Shallow (15–30)	3.0
	Very shallow (<15)	4.0
Drainage (class)	Well drained	1.0
	Imperfectly drained	1.2
	Poorly drained	2.0
Slope (%)	<6	1.0
	6–18	1.2
	18–35	1.5
	>35	2.0

(b) Climate

Variable	Class	Score
Rainfall (mm/year)	>650	1.0
	280–650	2.0
	<280	4.0
Bagnouls–Gaussen aridity index (mm/mm)	<50	1.0
	50–75	1.1
	75–100	1.2
	100–125	1.4
	125–150	1.8
	>150	2.0
Slope aspect (class)	North, NW, NE, plain	1.0
	South, SW, SE	2.0

(c) Vegetation

Variable	Class	Score
Vegetation cover (%)	>40	1.0
	40–10	1.8
	<10	2.0
Fire risk (class)	Bare soils, bedrocks; almonds, orchards, grapevines, olive groves, irrigated annual crops (maize, tobacco, sunflower), horticulture	1.0
	Perennial grasslands, pastures, cereals, annual grasslands, deciduous forests, evergreen forests (with *Quercus ilex*), shrublands, very low vegetated areas	1.3
	Mediterranean maquis	1.6
	Coniferous forests	2.0
Soil erosion protection (class)	Evergreen forest (except conifers), mixed Mediterranean maquis, evergreen forests (with *Quercus ilex)*, bedrocks	1.0
	Mediterranean mquis, coniferous forests, perennial grasslands, pastures; olive groves, shrubland	1.3
	Deciduous forests	1.6
	Almonds, orchards	1.8
	Grapevines, annual crops (cereals, maize, rice, oats, barley, grasslands), low vegetated areas, bare ground	2.0
Vegetation resistance to drought (class)	Evergreen forest (except conifers), Mediterranean maquis, evergreen forests (with Quercus ilex), bedrocks, bare ground	1.0
	Coniferous and deciduous forests, olive groves	1.2
	Almonds, orchards, grapevines	
	Perennial grasslands, pastures, shrubland	1.7
	Annual crops (annual grassland, cereals, maize, tobacco, sunflower), low vegetated area	2.0

Table 2 (*continued*).

(d) Land management

Class	Description (by land use class)	Score
Cropland		
1	Local varieties are used, fertilizers and pesticides are not applied, yields depends primarily on fertility of soils and environmental conditions. Mechanization is limited. In case of seasonal crops, one crop is cultivated per year or the land remain under fallow.	1
2	Improved varieties are used, insufficient fertilizers are applied and inadequate disease control is undertaken. Mechanization is restricted to the most important such as sowing, fertilizers application, etc.	1.5
3	Application of fertilizers and control of diseases are adequate. Cultivation is highly mechanized.	2.0
Pasture land		
1	Low (ASR < SSR)	1
2	Moderate (ASR = SSR to 1.5 × SSR)	1.5
3	High (ASR > 1.5 × SSR)	2
Natural areas (forests and shrubland)		
1	Low (A/S = 0)	1
2	Moderate (A/S < 1)	1.2
3	High (A/S ≥ 1)	2
Mining areas		
1	Low (Adequate erosion control measures)	1
2	Moderate (moderate control against soil erosion)	1.5
3	High (poor measures against soil erosion)	2
Recreational areas		
1	Low (A/P < 1)	1
2	Moderate (1 < A/P < 2.5)	1.5
3	High (A/P > 2.5)	2

Class	Description	Enforcement level	Score
1	Low	Complete (>75% of the area under protection)	1
2	Moderate	Partial (25–75% of the area under protection)	1.5
3	High	Incomplete (<25% of the area under protection)	2

error of each layer, the correlation between each variable and the ESI, and the estimated costs of data collection and handling.

2.3.1. *Sensitivity analysis*

In the present study the sensitivity of each considered layer was defined as the changes induced in the final ESI value by changes in the value of each individual layer. To estimate the sensitivity of the ESI to each input layer it should be considered that (i) each partial indicator consists of a different number of layers, and (ii) the distribution of some layers shows deviations from the normal distribution. Moreover, sensitivity analysis of a KIS has to be independent from the environmental context and this may reduce the reliability of many sensitivity analyses such as the relative sensitivity criterion (Brylinsky, 1972), the *MA%E* criterion (Mayer and Butler, 1993), and other methods (e.g. Esprey et al., 2004; Dezi and Magnani, 2007). In order to properly consider these points, the following procedure has been developed to analyse the sensitivity of the ESI to the variations of each individual layer.

- For each layer, the observed score was increased progressively by a 0.2 value, until the score was equal to 2; this exercise was repeated, starting from the observed score, reducing it progressively by a −0.2 value, until the score was 1.
- Within each step, the average ESI score was computed. To minimize the effects of the different number of layers contributing to each partial indicator, each pixel was weighted by 1/6 (the maximum number of layers by partial indicator) to give equal weight to each layer.
- For each layer, the third-order moving average was computed and then the sensitivity of each layer was determined from the steepest slope (i.e. as the maximum b value of a linear fit) reached within the variation range. Finally, the maximum observed sensitivity value was considered.

In this way, the evaluated sensitivity can be regarded as the ‘capability to induce changes’ in the system and not as the amount of the observed change.

2.3.2. *Assessing the predictive capability of each layer*

The objective of the KIS is not only to provide an estimation of the level of vulnerability to desertification but also to identify the causes that have determined such level of vulnerability. Based on these considerations, the system can be used as follows:

(i) to define a minimal layer set to achieve a vulnerability evaluation based on the parsimony criterion;
(ii) to estimate the contribution of each layer to the ESI;
(iii) to develop a regional monitoring system capable to identify land hotspots and the related critical factors.

The predictive capability of each layer was evaluated in this study using the SEE (standard error of the estimate) from linear regressions with respect to the ESI values.

2.3.3. *Pair-wise correlation analysis between layers*

In this study, correlation analysis was used to assess the relationship between the final ESI and each of the input layers, and to analyse the pair-wise relationships between layers. When several variables are implemented as input layers in an information system, the correlation matrix (using both linear coefficients, e.g. Pearson’s coefficient, and co-graduation Spearman’s rank coefficient) can be used to assess the relationship between variables. In the present study, Pearson’s correlation coefficients were used.

2.3.4. *Evaluating costs of data collection and handling*

According to Ferrara et al. (1999), the input layers to the ESI were selected according to their relationship with the investigated

Table 3
Layers ranked by maximum sensitivity score, standard error of the estimate, Pearson correlation with the ESI, and estimated costs for data collection and handling.

Layers	Maximum sensitivity score	Standard error of the estimate	Pearson correlation with the ESI	Data cost (Euros per hectare)
Aridity index	0.041	8.37	0.35	0.06
Aspect	0.022	6.01	0.40	0.18
Drainage	0.031	6.83	0.40	0.48
Drought resistance	0.029	5.92	0.42	0.20
Erosion protection	0.031	5.98	0.30	0.20
Fire risk	0.038	7.29	0.15	0.20
Land-use intensity	0.036	6.15	0.52	0.36
Parent material	0.030	7.14	0.08	0.33
Vegetation cover	0.030	5.81	0.57	0.11
Policy enforcement	0.034	5.34	0.28	0.16
Rainfall	0.044	8.74	0.32	0.06
Rock fragments	0.028	6.47	0.20	0.48
Slope angle	0.030	6.75	0.07	0.18
Soil depth	0.025	4.36	0.16	0.33
Soil texture	0.029	6.85	0.21	0.48

phenomenon and as a function of data availability, reliability, and costs of collection and updating. However, establishing a system which requires information that is difficult to obtain, or expensive to update, even if theoretically sound, would be severely restrictive for a permanent monitoring system. It is thus necessary to take into account data costs when selecting an optimal set of key indicators especially when analysing countries (or regions) where data availability is not complete. In this study the monetary costs of data used in the ESI were estimated directly by considering the effective costs sustained during the MEDALUS III and DESERTLINKS projects for data collection, handling and updating in the study area (Agri basin). The cost per layer and hectare of evaluated land were computed. It should be noted that data costs may vary over time and space, mainly depending on their availability in digital form. Even if cost figures are gross estimates, the proposed values could be considered as representative of a southern European basin area.

2.3.5. *Overall performance evaluation*

For each input layer, four performance indicators (sensitivity level, predictive capability, correlation level, and data costs) were calculated as described above. Indicators were ranked from 0 to 1 in sake for comparability. The final performance score was obtained by averaging the scores of the four indicators. Finally, the squared multiple correlation (SMC) was applied to quantify the proportion of variance explained by each variable when variables are progressively introduced into the system. In the analysis we considered some layers together when they were derived from the same data

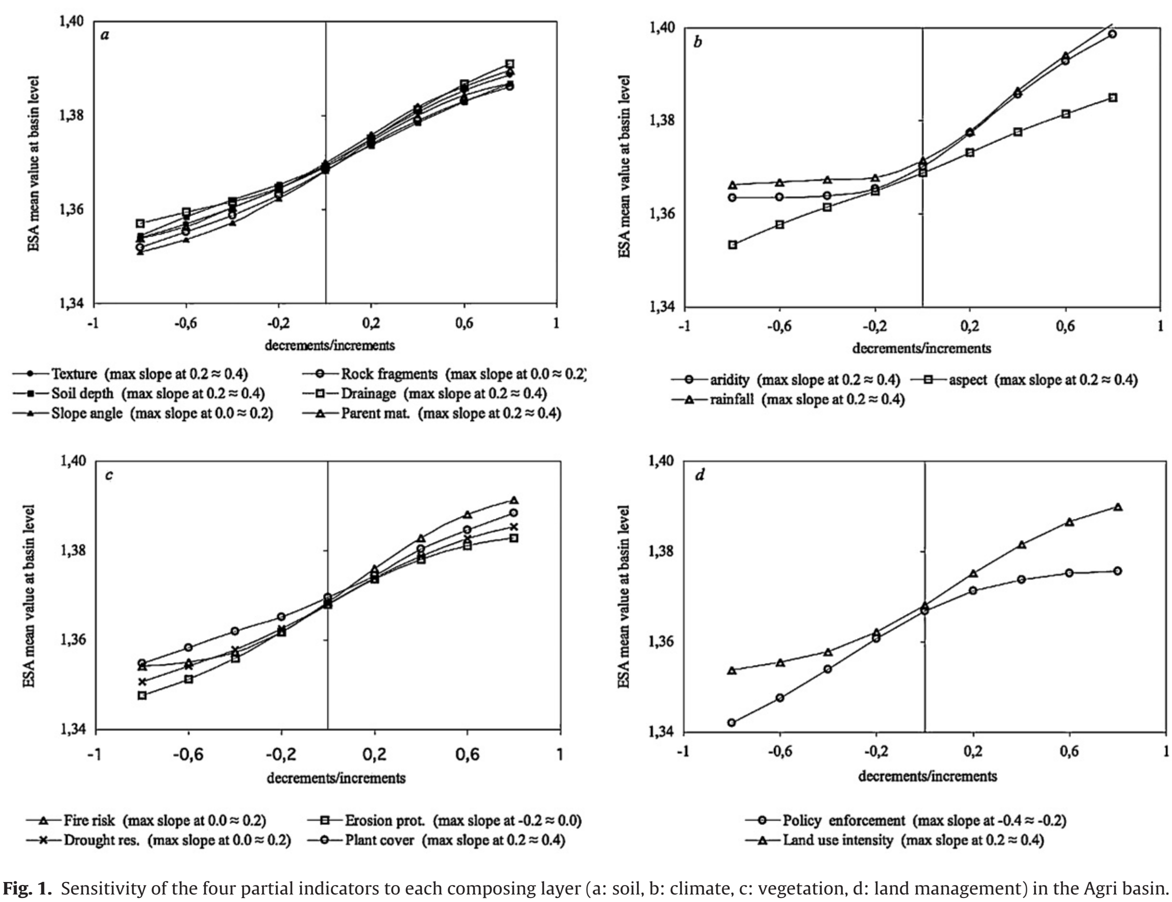

Fig. 1. Sensitivity of the four partial indicators to each composing layer (a: soil, b: climate, c: vegetation, d: land management) in the Agri basin.

Table 4
Indicators rank (0–1 range) and the ESI overall performance evaluation.

Layer		Sensitivity value (1)	Standard error of the estimate (2)	Correlation coefficient with the ESI (3)	Average (1 + 2 + 3)/3	Data costs per hectare (4)	Performance score (5)
13	Vegetation cover	0.36	0.67	1.00	0.94	0.89	0.915
7	Aridity index	0.90	0.08	0.56	0.60	1.00	0.797
9	Rainfall	1.00	0.00	0.49	0.55	1.00	0.777
14	Land protection	0.56	0.78	0.43	0.75	0.75	0.751
12	Drought resistance	0.33	0.64	0.69	0.68	0.66	0.669
15	Land-use intensity	0.62	0.59	0.90	1.00	0.29	0.645
11	Erosion protection	0.39	0.63	0.45	0.54	0.66	0.598
8	Aspect	0.00	0.62	0.66	0.40	0.71	0.557
10	Fire risk	0.72	0.33	0.16	0.35	0.66	0.505
3	Soil depth	0.12	1.00	0.18	0.42	0.36	0.389
5	Slope angle	0.35	0.45	0.00	0.07	0.71	0.388
4	Drainage	0.42	0.43	0.66	0.57	0.00	0.283
6	Parent material	0.35	0.36	0.00	0.00	0.36	0.181
2	Rock fragment	0.25	0.52	0.25	0.22	0.00	0.109
1	Texture	0.30	0.43	0.28	0.21	0.00	0.106

source. In this case the cost for each layer in the group corresponds to the cost of the basic data source.

3. Results and discussion

Table 3 illustrates, for each layer, the absolute values of the four performance indicators (see Section 2.3). As far as the sensitivity analysis is concerned, climate layers including average annual rainfall and the aridity index showed the maximum sensitivity value (respectively 0.044 and 0.041), followed by some of the vegetation and land-use layers (fire risk, land-use intensity). The lowest value was recorded for aspect and soil depth. Fig. 1 shows the sensitivity of the four partial indicators to the composing layers. Climate and land management qualities were the most sensitive indicators to the composing layers.

Moreover, climate layers (coupled with some soil layers, e.g. parent material) showed the highest variability (measured through the standard error of the estimate) while the lowest variability was found for soil depth. To the contrary, the highest correlation with the ESI was recorded for vegetation and land-use layers, including vegetation cover (0.57), land-use intensity (0.52), and vegetation resistance to drought (0.40); interestingly, climate layers showed a relatively low correlation with the ESI. Finally, the highest cost for data collection and handling was estimated for soil and land management layers (soil texture, drainage, rock fragments, and land-use intensity). This was due to the limited availability of secondary statistical and field data at local scale (especially soil maps and information on land tenure and management collected at municipal scale). This problem appears to be relevant in several study areas in the northern Mediterranean basin (see Kosmas et al., 1999; Basso et al., 2000; Salvati and Bajocco, 2011 for a discussion).

The overall performance evaluation is illustrated in Table 4 using normalized indicators. The maximum sensitivity value, the standard error of the estimate and the correlation coefficient with the ESI were averaged to produce a statistical indicator of each layer's performance. Land-use intensity and the vegetation cover showed the highest performance (1.0 and 0.9, respectively) while climate and soil layers ranked bottom (slope angle and soil parent material ranked 0.0). The composite indicator suggests that land management and climate layers have a higher performance than vegetation and soil layers (see also Salvati and Zitti, 2009a).

Fig. 2 compares the cumulated cost curve for data collection and handling with the cumulated SMC curve (see Section 2.3.5) and identifies the layers that contributed more to the ESI. They include climate, land management, and vegetation layers (placed at the left of the intersection between the two curves). These layers may be considered as crucial variables in the ESI–KIS system. Interestingly,

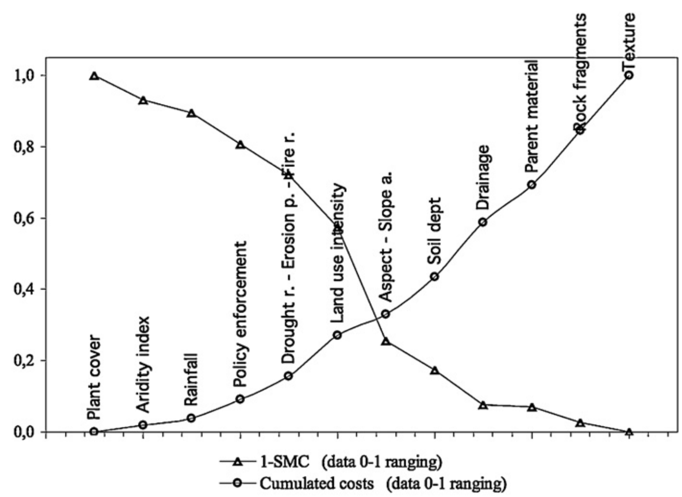

Fig. 2. Comparison between the cumulated curve of data costs and SMC criterion by layer.

this analysis was corroborated by results produced by independent studies that used different conceptual and methodological approaches (Salvati and Zitti, 2008b, 2009b).

4. Conclusions

The performance evaluation illustrated in this paper integrates a traditional sensitivity analysis with assessment of (direct) costs of data collection and handling. This provides a comprehensive framework to assess robustness, reliability, information power, and effectiveness of the variables composing the index under consideration. It could be applied to similar, complex environmental processes that are quantified using large KIS producing composite indices. The procedure can be used to together rank the importance of the different input layers to the KIS and the statistical performance of the composite index as an *ex ante* evaluation system. The approach is simple and runs on spreadsheets or similar calculation tools. Moreover, it allows selecting the most important variables contributing to the KIS based on objective criteria rather than a subjective choice. The procedure is also flexible enough to allow simulation exercises by changing the score system or considering a reduced (or augmented) number of variables when specific environmental processes should be evaluated (Basso et al., 2000).

In conclusion, the proposed approach confirms the potentiality of the ESA system when evaluating the level of land vulnerability to desertification. Since the ESA does not provide an absolute estimation of the relationships existing between dependent and independent variables, it should be used as a robust base for further investigation and refined with findings from *in depth* studies carried out at local scale.

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