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Multi-criteria decision analysis for land suitability mapping in a rural area of Southern Italy

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ABSTRACT

Selection of suitable areas for territorial planning is a complex process and needs many diverse indications on the basis of which a decision may be assumed. This paper focuses on the integration of Geographical Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) to evaluate the potential of a rural coastal area, located in northern Puglia (Southern Italy), to improve its sustainable development through the restoration of manor farms. Comparing the results obtained using the Weighted Linear Combination (WLC) and the Ordered Weighted Averaging (OWA) procedures, suitable sites where the restoration could be implemented were identified. In order to consider the stakeholders' judgments and to reach a shared decision in selecting the preferred alternatives, the Analytical Hierarchy Process (AHP) approach was used for prioritization, due to its relative ease in handling multiple criteria and compensating both qualitative and quantitative data. The results highlight how the spatial distribution of suitable areas is closely linked to the risk assumed and, consequently, to the capability of the methods in varying both risk and tradeoff parameters. Particularly, the OWA procedure shows higher potentialities in performing, with greater detail, the territorial evaluation and generating a wide range of decision strategies. The methodologies described and their application procedures can be extended to similar territorial contexts, in issues in which a notable number of territorial factors should be taken into account.

1. Introduction

In recent years, territorial planning experiences have increasingly focused on aspects related to environmental preservation, protection from natural disasters (safety of population), rural land transformations and sustainable development (Edwards and Llurdés, 1996; Alphonce, 1997; Bernetti and Fagarazzi, 2002; Lütz and Bastian, 2002; Geneletti, 2004; Trisorio Liuzzi et al., 2006; Marsden and Sonnino, 2008; Neri and Sánchez, 2010; Tortora et al., 2015). As regards the Puglia region, regional planning problems are being definitely underestimated (Regione Puglia, 2006) in terms of governance of both municipal and extra-municipal areas. Inadequate programming is more evident in the coastal areas, where overexploitation of resources and anthropic pressure are the main causes of degradation (Picuno et al., 2011).

In the coastal area of *Piana di Macchia* (Monte Sant'Angelo municipality), major physical-environmental aspects are strictly intertwined with anthropic ones, thus generating intricate problems the solution of which is neither easy nor univocal. Indeed, various interests – olive-growing based agricultural activities, conversion and re-industrialization of a large industrial area (ex-petrochemical pole), tourism-accommodation facilities, and protection of natural and environmental resources – co-exist in this area and might conflict with each other.

So, for appropriate land use policies, the main objective to be pursued is to identify management priorities and support decision-making while providing comprehensive information.

Land suitability mapping, based on geographical information systems (GIS), is one of the most useful applications for spatial planning and management (Malczewski, 2004, 2006). In association with multi-criteria decision analysis (MCDA), GIS can be defined as a process that integrates and transforms geographic data (input map criteria) and value judgments (decision makers' preferences and uncertainties) to obtain an overall assessment for choosing between alternative actions (objectives), hypotheses and locations (Eastman et al., 1993; Malczewski, 2004; Boroushaki and Malczewski, 2008).

De Araújo and Macedo, 2001 used GIS techniques and multi-criteria analysis in geologic modelling for mineral favourability mapping in Brazil. A multi-criteria approach for the identification of waste disposal areas was followed by Calijuri et al. (2004) in order to

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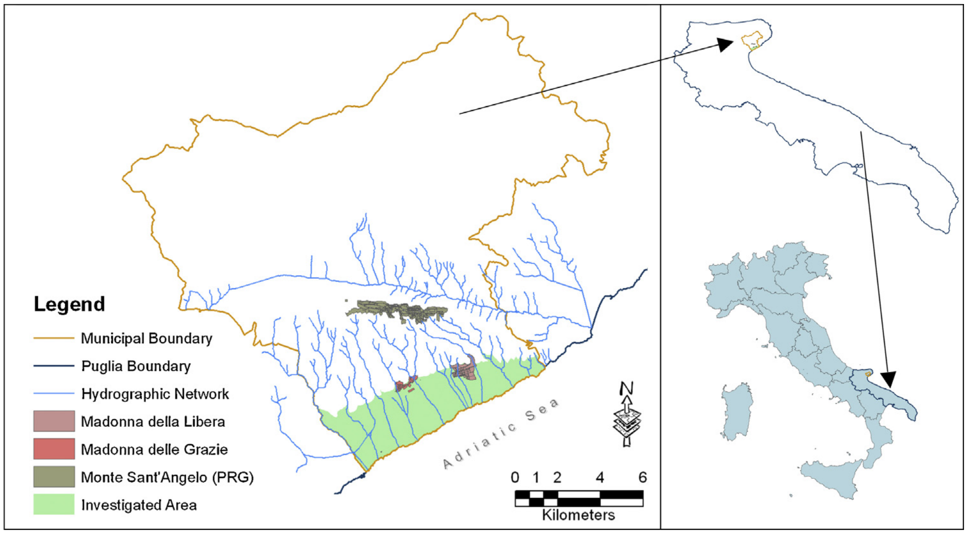

Fig. 1. Geographic position of the municipality of Monte Sant'Angelo and its coastal area.

minimize the harmful effects from rock processing that cause pollution to surface and groundwater resources. Dal Sasso et al. (2012) identified quarry reuse alternatives with the application of a two-step methodology, comprising a multi-criteria analysis related to a site-specific level and territorial indicators checking over the wide area.

Image processing of current and historical maps is carried out, in many papers (Capobianco et al., 2004; Haase et al., 2007; Tortora et al., 2015), in order to analyze landscape changes and to approach environmental issues.

The growing interest in combining GIS capability with MCDA processes is due to the GIS potential of handling (managing, processing, upgrading and storing) large amounts of complex geo-referred data from different sources at multi-spatial, multi-temporal and multi-scale levels, obtaining a time-efficient analysis.

Lastly, another potential advantage of a GIS-based approach for siting arises from the fact that it not only reduces the cost of site selection but also provides a digital database for long-term monitoring of the area (Moeinaddini et al., 2010).

Along with the increase of GIS technology, some MCDA methods have evolved as a fundamental tool to assist decision makers in either ranking a set of alternatives for problem solving or making a choice among these while considering the conflicting criteria. The integration of GIS-MCDA procedures has, in fact, considerably advanced the map overlay approaches (McHarg, 1969) to site suitability analysis, with the result of transforming spatial and alphanumeric data into a best decision (Sumathi et al., 2008). The decision rules can be classified into *multiobjective* and *multiattribute* decision making methods (Malczewski, 2004). In the multiobjective methods the alternatives are to be generated, taking into account the factors and the constraints imposed. *Factors* are commonly measured by a numerical scale that is continuous (slopes, distances, altitudes, climatic factors) or discontinuous (land use, physical or administrative boundaries). They can enhance or reduce the land suitability to the target objective. *Constraints* are instead real impediments, if any, to achieve a specific objective planning (hydro-geological constraint, minimum safe distances, exposure, etc.).

Multiattribute techniques assume that the number of alternatives (plans) is given explicitly (Malczewski, 1999). Multicriteria procedures are carried out to check land allocation decisions or the suitability of a unique predetermined objective (land policies, territorial guidelines).

This work uses a multi-disciplinary approach to generate a suitability composite map, with the aid of GIS–MCDA techniques, emphasizing the effects of environmental, socio-economic and territorial management features. It is aimed at identifying, in a coastal territory of northern Puglia, the sites where structural measures could be performed to support the socio-economic development, based on a rural tourism that can integrate the agricultural, natural and architectural resources.

The analysis refers to the area of Piana di Macchia, Monte Sant'Angelo, where many manor farms are present, that could be restored and used with a view to targeted agro-environmental tourism. The identification of the areas that appear to be more suitable is affected by the limited financial resources and, consequently, by the need to select the sites in a rational way. To reach the above mentioned aim different analysis approaches were used and compared: Boolean overlay, Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA).

2. Materials and methods

2.1. Site description

2.1.1. Study area

The site investigated is the coastal strip of the municipal territory of Monte Sant'Angelo, which is located on the south-eastern hillside of the Gargano promontory and falls within the province of Foggia (Fig. 1). This well-known agricultural area in the Puglia region features a remarkable concentration of valuable historical and cultural sites, combined with a very interesting natural landscape.

The analyzed territory, named *Piana di Macchia*, is a flat area, sub-triangular in shape, with a surface of 21.85 km^2 and 11 km long. To the west it borders the Pulsano stream, which represents the boundary with the municipality of Manfredonia, to the east the rocky promontory of Puntarola, in close proximity to the boundary with the municipality of Mattinata and to the north the rocky cliff, on which the town rises 843 m a.s.l.

The area enjoys a typically Mediterranean climate, with mild and scarcely rainy winters and hot and dry summers.

The geology of the area consists of alluvial flood plain deposits of the Quaternary period that form a 100 m thick blanket. Such low permeability deposits are formed by sub-rounded pebbles and are almost always buried in a matrix of residual soils easily washed

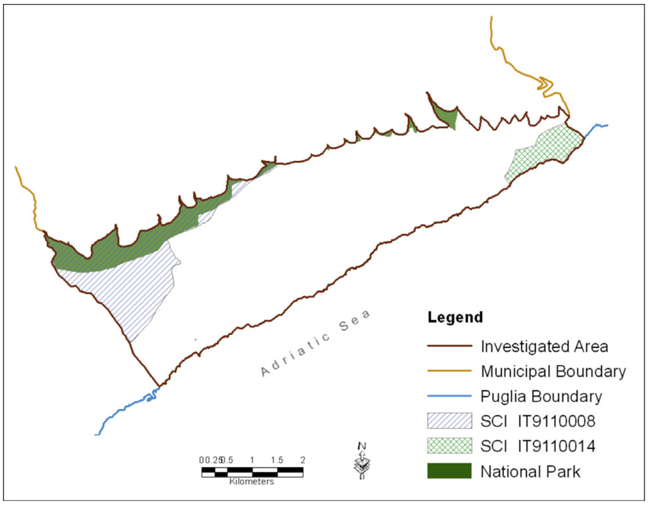

Fig. 2. Zoning of Sites of Community Importance (SCI) and Special Protection Areas (SPA).

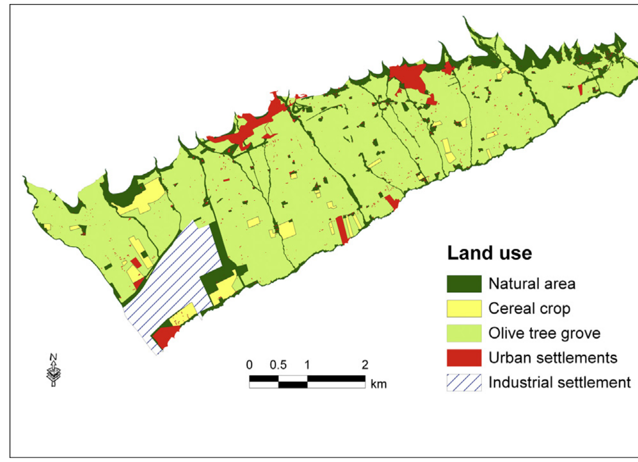

Fig. 3. Land use in the area of *Piana di Macchia.*

away by runoff during rainfall events (Gentile et al., 2006). The main streams are the Pulsano, Petrulo, Malpasso and Varcaro torrents. Elevation ranges between 0 and 175 m a.s.l. Slope angles range between 0° and 63° with an average of about 5°, while the slope aspect is generally toward the S–SE direction (Gentile et al., 2008).

One of the major problems of the investigated area is the instability of the sandy-conglomerate cliffs, subject to frequent failures that cause retrogradation and restrict bathing.

The chemical–physical and microbiological conditions of the coastal waters are good, as they do not exceed the threshold values established by national and regional regulations, except for the area of the Gulf of Manfredonia, in the proximity of the Enichem factory.

Two types of vegetation are present on the south-eastern hillside of Gargano: the evergreen schlerophytes, with Mediterranean vegetation, and the broad-leaved eliophylous plants with sub-Mediterranean and sub-mountain vegetation. On the south-western hillside of the promontory, there are grassland, steppes of xero-graminete ridged by deep calcareous valleys (falling within the proposed Sites of Community Importance, pSCI, and Special Protection Areas, SPA). Canals and deep, narrow valleys act as ecological corridors between the coastal ecosystems and the piedmont and mountain strips.

The investigated area includes three important protected areas (Fig. 2):

- The pSCI of *Monte Saraceno* (code IT9110014);
- The pSCI and SPA of *Valloni and steppe pedegarganiche* (code IT9110008);
- The National Gargano Park, whose southern boundary is marked by the layout of "*Tratturo Foggia*".

The area is characterized by olive growing (Fig. 3), which is largely the predominant form of land use (70.19% of the total area). An industrial settlement is still present in the area despite the closure of the Enichem factory in recent years (7.82%); the natural area, the urban settlements and the cereal crops occupy 13.69%, 4.18% and 4.11% of the area, respectively.

2.1.2. Socio-economic aspects

Monte Sant'Angelo has been historically considered the capital of *Gargano*, being the socio-cultural and economic heart of the promontory. However, in the last few decades this town has been experiencing a gradual decline (ISTAT, 2001).

The decrease in population is basically due to the high migration towards towns in northern Italy and neighbouring municipalities. *Manfredonia* in particular has exerted great attraction over the population of *Monte Sant'Angelo* because of its position close to the industrial area and to roads and railway infrastructures that connect the area with the rest of the region (Trisorio Liuzzi et al., 2006). The National Road 89th Garganica connects *Foggia* and *Manfredonia* and from here, crossing *Piana di Macchia*, it leads to *Mattinata* and then to the main tourist locations of *Gargano*. Furthermore, a dense network of municipal and farm roads serves all the housing and tourist infrastructures, bathing facilities and farms of the area.

Industrial activities were started in the area in 1971 with the construction of the *Enichem* factory for the production of synthetic fibres and fertilizers for agriculture. Although the factory stood out as the main business in the area, it stopped its activities a few years later (in 1987) because of its high environmental impact.

The closure of the *Enichem* factory caused notable damage to employment but, on the other hand, had a favourable impact on ecosystems and on those production sectors that had been strongly affected by the presence of the chemical pole, mainly agriculture, but also tourism and fishing.

Today the area is involved in national and regional plans and programs.

To face the negative effects on employment of *Enichem* shutting down, the Government intervened through a Contract Area to relaunch the economy of the municipalities of *Manfredonia*, *Monte Sant'Angelo* and *Mattinata*.

The Integrated Sector Plan provides a general approach to a tourism development based on local and environmental resources while also including actions targeting the coastal area of *Piana di Macchia*. The objective of the plan is to establish a real Integrated Tourism Plan in *Gargano* that should allow all the municipalities involved to work in synergy to give value to their main territorial resources.

The Rural Development Plan follows animation and concertation activities in the territory, on the initiative of *Ente Parco Nazionale del Gargano* and the *Comunità Montana del Gargano*. The plan covers the territory of 11 municipalities of the promontory (*Monte Sant'Angelo* is one of them) and its main objective is to enhance local typical products, especially in the agri-food sector, but also handicraft and tourism.

In this context, the presence of manor farms, which could be restored and used, poses a very interesting opportunity of combining the rural development of the area (olive based agriculture) with sustainable, agro-environmental targeted tourism. As a matter of

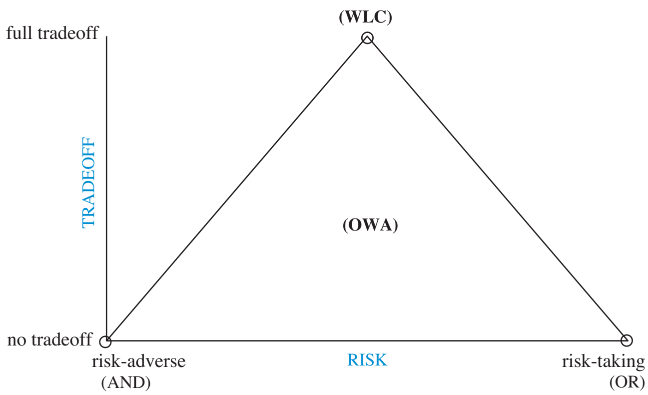

Fig. 4. Decision strategy triangle.

fact, the manor farms that speckle the plain could host agri-tourist and accommodation facilities and offer additional accommodation during the summer; to date, very few of them are engaged in such a business. A major issue to reach this goal, taking into account the limited financial resources, lies in the choice of the most suitable areas where the proposed restorations could be carried out, based on both the constraints and the potential of the territory.

2.2. Methodological approach

The GIS-based multi-criteria analysis was carried out using three procedures: Boolean overlay, Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA). Furthermore, the Analytical Hierarchy Process was implemented for the determination of criteria weights.

2.2.1. Boolean overlay

The Boolean method implies for all the criteria (*factors* and *constraints*) to be combined by logical operators, such as intersection (*and*) and union (*or*), to produce discrete Boolean maps. The intersection operator (*and*) is very restrictive (risk adverse); an area will be excluded from the suitability maps if any single criterion fails to meet its threshold. Conversely, with the second, the union operator (*or*), there is a risk involved and an entire area could be chosen as long as a single criterion meets its threshold (Jiang and Eastman, 2000). Intermediate levels of risk are not contemplated (Fig. 4).

Boolean overlay leads to the selection of suitable sites and the exclusion of others without knowing the level of suitability of the identified sites. All factors have indeed equal importance in the final composite suitability map and a factor with high importance cannot compensate for a marginal factor (*tradeoff*) to determine the suitability of a site Malczewski and Rinner (2005).

These limitations can be overcome by weighting the factors and aggregating them by using procedures based on a weighted average (WLC and OWA methods).

2.2.2. Weighted Linear Combination

Weighted Linear Combination (WLC) is an aggregation method that allows the variability of continuous and discrete factors to be retained. It requires that factors are standardized to a common numeric range, and then combined by weighted averaging.

WLC is characterized by full *tradeoff* and average risk, exactly halfway between the *and* and *or* operations, i.e., neither extreme risk aversion nor extreme risk taking (Fig. 4).

The degrees of site suitability, once a territorial objective is fixed, and, consequently, the choice of the most suitable ones, can be continuously mapped using the following expression:

$$S_j = \sum_{i=1}^{n} w_i x_i \cdot \prod_{j=1}^{m} c_j \quad (1)$$

where S_j = suitability (of the jth pixel or area); w_i = weight of factor i; x_i = criterion score of factor i; c_j = constraints; n = total number of factors; m = total number of constraints.

As the criteria are measured in different unit scales, it is necessary for the factors to be standardized and transformed into comparable units. There are many procedures for standardization, the simplest being linear scaling:

$$x_i = \frac{R_i - R_{\min}}{R_{\max} - R_{\min}} \quad (2)$$

where R represents the value of the factor x_i in its units.

In this case, standardization procedures based on the theory of fuzzy sets (Eastman, 2006) can be used.

Fuzzy membership functions, implemented in GIS for map layer standardization, are, in this study, sigmoidal, J-shaped and linear (Eastman, 2003).

2.2.3. Ordered Weighted Averaging

The WLC method does not always suit the territorial analysis because of the risk, inbuilt in that method, of concealing a limiting factor among between the high values of the other criteria. Likewise, the non-compensating methods can prove limiting, for a complex territorial analysis, as they take into account only the limiting factors or the prevailing ones (Lazzari, 2013).

The Ordered Weighted Averaging (OWA) proposed by Yager (1988) is a parameterized family of combination operators that allows for the continuous adjustment of both the intake level of risk and the *tradeoff* between the criteria, giving complete control along both the risk and the *tradeoff* axes, which delimit the decision strategy triangle (Fig. 4).

It involves two sets of weights: criterion importance weights and order weights. By changing the order weights, it has enough flexibility to generate a complete range of decision support maps (including the cases of the WLC and Boolean overlay) (Boroushaki and Malczewski, 2008) and a large variety of decision strategies.

The OWA combination operator for the jth location (point or pixel) is defined as follows (Boroushaki and Malczewski, 2008):

$$OWA_j = \sum_{i=1}^{n} \left(\frac{u_i v_i}{\sum_{i=1}^{n} u_i v_i} \right) z_{ij} \quad (3)$$

where u_i is the reordered ith criterion weight (w_i); v_i is the ith element of a set of order weights $V = (v_1, v_2, \ldots, v_n)$ such that $v_i \in [0,1]$ and $\sum_{(i=1,n)} v_i = 1$; $z_{1j} \geq z_{2j} \geq \ldots \geq zn_j$ is obtained by reordering the criterion values x_{1j}, x_{2j}, x_{nj}.

2.2.4. Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) (Saaty, 1977, 1980) is crucial in MCDA for the determination of the criteria weights. It can be used in two ways within the GIS environment. The first one is used to calculate the factor weights in association with criterion map layers with the help of a preference matrix, where all of the relevant criteria identified are compared one with the other using preference factors (pairwise comparison). Second, the AHP method can aggregate the priority for all the levels of the hierarchy

Table 1
The continuous rating scale for pairwise comparison.

Relative importance	Degree of preferences
1	Equally
3	Moderately
5	Strongly
7	Very strongly
9	Extremely
2, 4 ,6 ,8	Intermediate
Reciprocals	Less importance

1/9 1/7 1/5 1/3 1 3 5 7 9

less importance more

structure, including the level representing alternatives (Jankowski and Richard, 1994, in Boroushaki and Malczewski, 2008).

Yager and Kelman (1999) improved the AHP procedure with the integration of the fuzzy OWA operators.

In the MCDA procedure, using the weighted linear combination outlined above, it is necessary that the criterion weights (w_i) to sum to one.

The weight values can be derived by taking the principal eigenvector of the square reciprocal matrix of pairwise comparison, and then normalising the sum of the components to a unity.

An importance scale is proposed for these comparisons (Table 1).

The pairwise comparison matrix was formed by taking into account the reports on the meetings with several stakeholders, who expressed their opinions on the criteria already selected, using the continuous rating scale reported in Table 1.

The stakeholders involved were the municipality of *Monte Sant'Angelo*, representatives of the local population, tour operators, farmers' confederations, associations for environmental protection, associations for territorial development.

After the most suitable set of weights is produced, it is necessary to verify the degree of consistency used in developing the ratings. It is judged on the basis of a consistency ratio index CR:

$$\mathrm{CR} = \frac{\lambda_{\max} - n}{(n-1)RI} \tag{4}$$

where λ_{max} is the largest or principal eigenvalue of the matrix A, n is the order of the matrix and RI corresponds to the average of resulting consistency index depending on the order n.

The consistency ratio indicates the probability that the matrix ratings were randomly generated. A standard CR threshold value of 0.1 was adopted in literature as a measure of the judgements' consistency in AHP applications (Boroushaki and Malczewski, 2008; Chen et al., 2010; Eastman, 2006). If CR < 0.1, it means that the pairwise comparison matrix has acceptable consistency and the weight values obtained can be utilized. If CR ≥ 0.1, the matrix is deemed to lack consistency and needs to be adjusted, modifying the element values.

2.3. Data sets

To find out the most appropriate sites where manor farms could be restored, an extensive data base was built from different sources.

The primary data sources, already available, included: the Technical Regional Map (TRM) (2006), the Regional colour orthophotos (2006) and the Corine Land Cover map (2006), which were used to prepare the base map for multicriteria evaluation. Checks and secondary data were collected from control points or training sites at the concerned area.

The Technical Map of the Puglia Region (1:5000) provides detailed information, in vector format, about the altimetry (contour lines with equidistance of 5 m and the vertices of the National Geodetic Network), roads and railways, perimeter of settlements and anthropic structures, administrative boundaries. A DTM and, consequently, a DEM were created from the contour lines and the elevation points.

In GIS environment, all the spatial data were converted into raster layers with 10 m resolution, geo referred to (UTM) WGS-84 coordinate system and processed using the Idrisi Kilimanjaro software. A pixel resolution corresponding to 10 m was chosen to better combine an exhaustive representation of the factors analyzed with a reasonable amount of data processing.

The evaluation criteria were chosen based on the study's objective and data availability.

The investigated area was delimited by overlaying the coast contour line and the contour line with elevation of 175 m a.s.l. with the municipal boundaries of Monte Sant'Angelo, starting from the TRM.

Manor farms (some of which of historical value) were all identified along the territory and digitalized with their GPS coordinate on orthophotos.

Orthophotos (scale 1:10,000, minimum mapping unit 1:100,000) were displayed from the WMS server of the National Cartographic Geoportal.

The blue lines map indicating the watercourses and the coastline was prepared through the identification of water lines on the technical map and comparison with the orthophotos. The area is drained by several torrents named, from west to east, Pulsano, Fazzino, Petrulo, Malpasso, Vallone San Pasquale, Varcaro, Stamporlando, Vallone dei Porci.

A DEM was generated from the elevation points and the contour lines with equidistance of 5 m. Slope gradient and slope aspect maps were originated from the 10 m resolution DEM.

For this study, the land use map was derived from the classification of the Corine Land Cover project, the interpretation of orthophotos and the verification of some control points on the territory.

The road network map outlines the main (state, provincial, municipal) roads, the farm roads and the walking paths. The main roads were identified through orthophotos and TRM, the farm roads and the walking path through orthophotos and field investigations. The main road in the area is the National Road no. 89.

The constraint and limitations map graphically reports each legislation tool governing the environmental integrity of the region. It was created by a logical operation overlaying different layers that represent the numerous legislative tools that determine the nature–environment constraints of the national territory (L. 1497/39 'Protection of natural beauties', L. 431/85 'Galasso Law' and Galasso decrees, L. 394/91 Institutive decree of the National Park of Gargano, EEC Directives 'Habitat' and 'Birds'). The constraint related to the Hydraulic Risk (L. 183/89, L. 493/93, L. 267/98), the one that heavily affects the possibility of new industrial and/or tourist settlements, was derived from the thematic maps of the Hydro-geological Structure Plan devised by the Basin Authority of Puglia.

Lastly, the infrastructure map shows the sewerage plant recently completed.

According to Sumathi et al. (2008) and Charabi and Gastli (2011), five main steps were taken to attain the aim of the paper:

(i) creation of a constraint layer regrouping all the unsuitable areas;
(ii) definition of criteria to evaluate the site suitability;
(iii) evaluation of criteria and setting-up of a GIS database;
(iv) multicriteria analysis and priority ranking;
(v) generation and analysis of suitability maps.

Table 2
The evaluation criteria with fuzzy membership function type, control points and function shape.

Main Criteria	Sub-criteria	Control points				Type of fuzzy function	Shape of fuzzy membership
		a	b	c	d		
Physical	Slope gradient			0	30	Sigmoidal	Monotically decreasing
	Slope aspect			1	9	Linear	Monotically decreasing
Distances from	Fast roads	0	500	500	2719	Linear	Symmetric
	Slow roads			0	528	Linear	Monotically decreasing
	Urban dwellings	0	1200			Sigmoidal	Monotically increasing
	Streams	0	780			Linear	Monotically increasing
	Coastal line			200	2000	J-shaped	Monotically decreasing
	Industrial area	0	2000			Linear	Monotically increasing
	Sewer			0	3242	Sigmoidal	Monotically decreasing
	Historical sites			0	1451	Sigmoidal	Monotically decreasing
Land use	Land use	0	9			Linear	Monotically increasing

To implement the first of the steps listed above, a GIS-based constraint mapping was used to eliminate the environmentally unsuitable sites, i.e., all those physical elements of the area for which no development is feasible.

The constraints layer map was obtained from an overlay of the industrial area map, the National Road no. 89, the watercourses of the plain and the cemetery, whose actual area was enlarged with a buffer zone traced all along its perimeter.

To define the criteria, the variability of their attributes within the territory considered was taken into account. All the criteria with a variability inside the study area were chosen while those that are constant at any location of the plain (geology, climate, drought indices, ecology, National and Community Plans) were not considered.

The selected criteria were divided into discrete and qualitative criteria (land use, slope aspect) and continuous ones (the others), depending on whether their attributes vary in a discontinuous or continuous way.

The evaluation criteria were grouped into four main categories, namely: the physical characteristics of the land, buffer and distances, the land use or land cover. (Table 2).

The physical characteristics concern the slope gradient and the slope aspect (Fig. 5). Both maps were derived from the analysis of the DEM (with 10 m pixel size) obtained, in turn, from the contour lines of the area, having an equidistance of 5 m.

The slope aspect map contains nine qualitative data classes such as N, NE, E, . . ., and plain. A progressive number was assigned to each class, starting from the exposed areas that allow a better view of the coast.

Distance maps were created using a distance operator. The fuzzy membership shape of the distance from fast roads was defined symmetrically, in order to consider both the negative effects of noise and pollution, decreasing from the National Road, and the increasing negative effects of distance. The first section of the fuzzy graph indicates an increasing suitability due to the noise reduction progressing with the distance; the last symmetric graph section shows a decreasing trend because, once the effect of pollution is considered tackled at 500 m, the suitability is only affected by the distance from fast roads.

The type of fuzzy function and the shape of fuzzy membership for the slow roads, along which the speed of vehicles is reduced, were influenced only by the distances.

Distances from urban dwellings and the industrial area were considered positive for the development of rural tourism, so the fuzzy memberships have a monotically increasing shape. As for the watercourses, it was the hydraulic hazard that determined the shape choice, increasing with distance.

Finally, the influence of the coastline was maximized for the first 200 m, before declining with the distance from the sea, while the proximity to the sewage network and areas with natural value was considered favorable.

The land use map (Fig. 3) derives from the Corine Land Cover (2006) and from the Regione Puglia Information System (www.sit.puglia.it), which can be considered appropriate for this study.

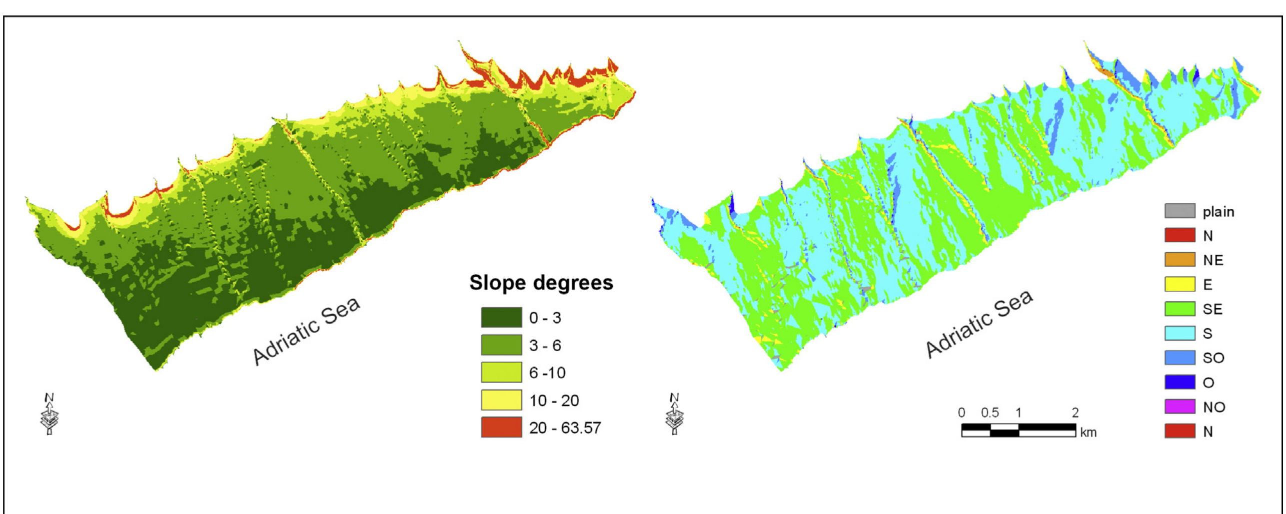

Fig. 5. Slope gradient and slope aspect of the investigated area.

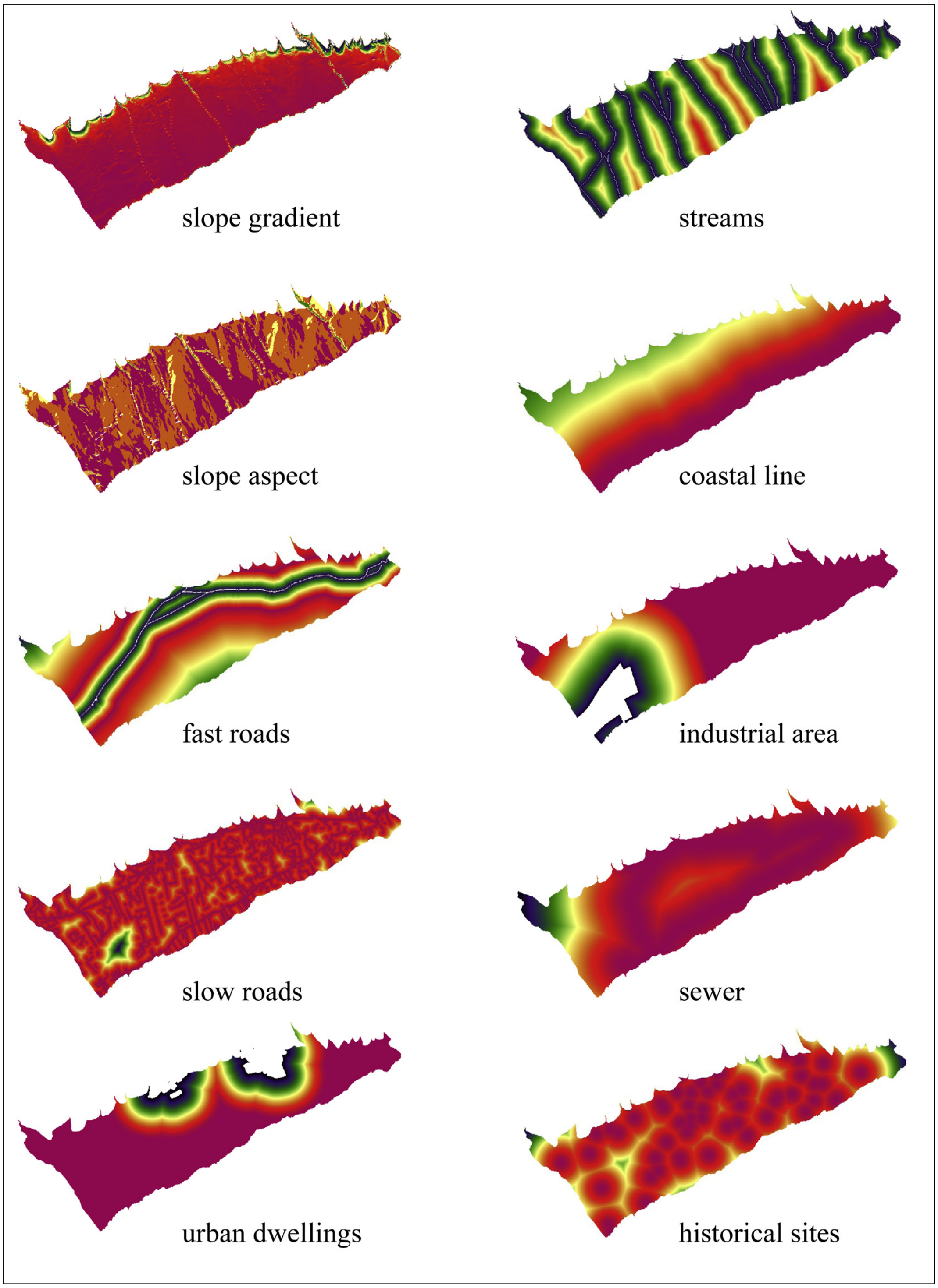

Fig. 6. Fuzzy standardization of continuous and discrete criteria.

A sensitive sites map was developed through the digitization of the major cultural and historical sites identified on the orthophotos and confirmed on the territory.

Following the procedure reported by several Authors (Malczewski, 2004; Chen et al., 2010) the above listed layers were used to run the MCDA modules according to the following phases:

(i) fuzzy standardization of the raster criteria;
(ii) hierarchical structure of the decision problem;
(iii) pair-wise comparison for the objective;
(iv) fuzzy logic quantifiers definition.

3. Results and discussion

A raster-based tool for multi-criteria GIS analysis was used to run the procedures proposed and produce the suitability maps. Once the constraint layer regrouping all the unsuitable areas was settled, the first step concerned the procedure of fuzzy criteria standardization. The type of fuzzy function and the membership

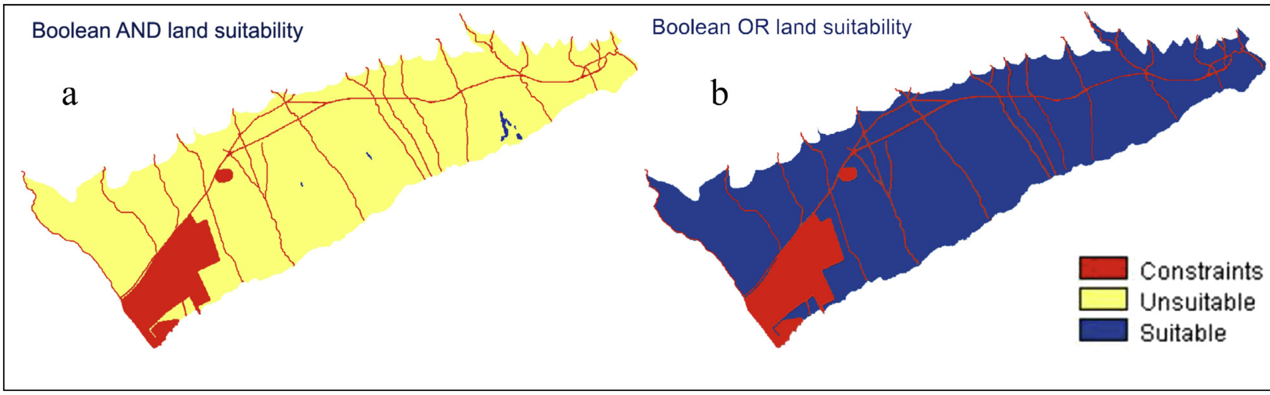

Fig. 7. Suitability maps obtained by applying the Boolean method.

function shape are reported in Table 2. The result maps, with the exception of the land use map, are shown in Fig. 6.

As for the *Boolean* approach, a double overlay operation between the criteria suitability maps was performed. With the *and* operator (intersection), the suitable sites were identified and mapped there where all the criteria meet their thresholds. As shown in Fig. 7a, the resulting suitability map is very restrictive since only 0.20% of the territory is suitable. The application of the *or* operator produces, conversely, the suitability map of Fig. 7b, in which all the sites are potentially suitable. In both cases no tradeoff is provided, therefore no land suitability degree is represented.

In order to produce a land suitability map using the WLC model, the criteria weights (w_i) were determined using the AHP method (Moeinaddini et al., 2010) as a result of the computation of the principal eigenvector (Table 3).

The principal eigenvalue (λ_{max}) of the matrix and its consistency ratio index (CR) were calculated, the last one being equal to 0.03, thus confirming the logical consistency of the judgments expressed and the acceptability of the results.

After assigning the weights, the criteria were combined to obtain the WLC suitability map, characterized by an intermediate value of risk and a maximum tradeoff.

In this way, an index map showing the spatial distribution of the land suitability was obtained (Fig. 8a).

It represents the values of appropriateness of each elementary territorial unit (pixel), expressed in a scale of values from 0 to 255, where zero represents the constraint areas, the values closer to zero (dark blue) represent the areas less suitable and the values closer to 255 (purple red) those more suitable for the restoration of manor farms (Fig. 8a).

To provide a visual interpretation, the range of values from 0 to 255 were grouped into four suitability classes as low, marginal, moderate and high (Fig. 8b) (Charabi and Gastli, 2011). Thus, the suitability classes were more clearly identified and, according to

Table 3
Criteria pairwise comparison matrix and principal eigenvector.

Criteria	Farms	Land use	Sewer	Coastal line	Industrial area	Streams	Slow roads	Fast roads	Urban dwellings	Slope aspect	Slope gradient	Weights
Farms	1											0.2526
Land use	1	1										0.2198
Sewer	1/4	1/2	1									0.1425
Coastal line	1/4	1/4	1/3	1								0.0699
Industrial area	1/5	1/4	1/3	1	1							0.0688
Streams	1/5	1/4	1/4	1	1	1						0.0642
Slow roads	1/4	1/4	1/3	1/2	1/2	1/2	1					0.047
Fast roads	1/5	1/5	1/3	1/2	1/2	1/2	1	1				0.0432
Urban dwellings	1/5	1/6	1/4	1/2	1/2	1	1	1	1			0.0416
Slope aspect	1/6	1/6	1/3	1/3	1/3	1/3	1/2	1/2	1	1		0.0305
Slope gradient	1/6	1/6	1/6	1/4	1/4	1/4	1/4	1/3	1/3	1/2	1	0.0199

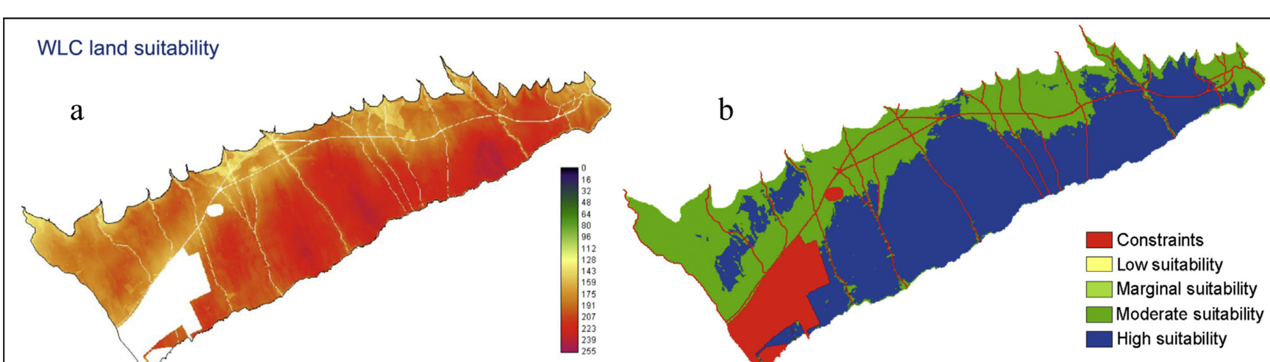

Fig. 8. Spatial distribution of land suitability (a) for environmental tourism and land suitability levels (b) obtained with WLC procedure.

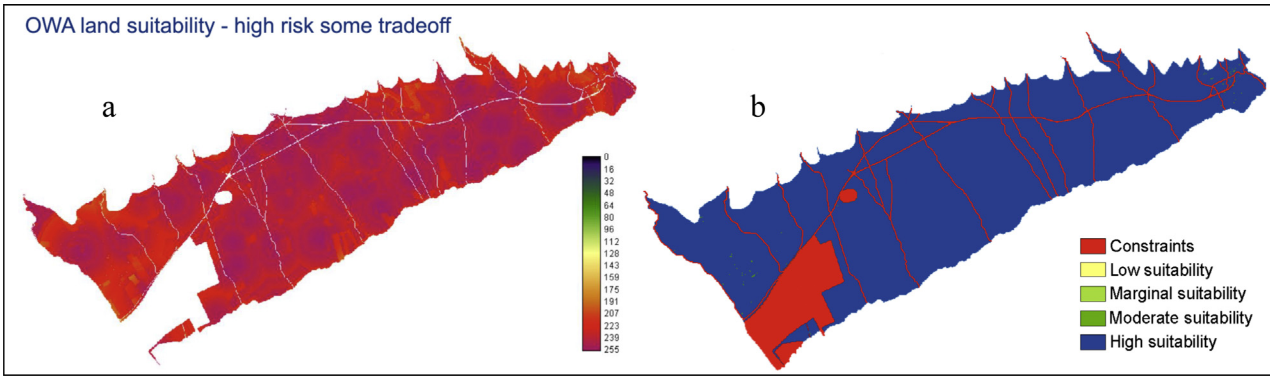

Fig. 9. Spatial distribution of land suitability (a) and land suitability classes (b) obtained with the OWA procedure for high level of risk and some tradeoff.

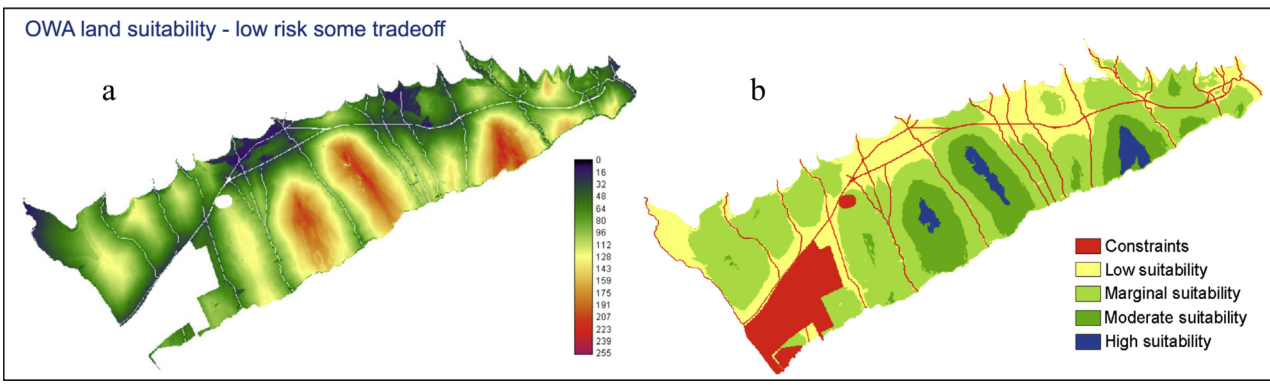

Fig. 10. Spatial distribution of land suitability (a) and land suitability classes (b) obtained with the OWA procedure for low level of risk and some tradeoff.

this approach, the moderately and highly suitable zones account for 42.15% and 57.81% of the study area without constraints, respectively.

The last procedure used was the OWA method. The aim was to investigate scenarios that differ from those identified with the methodologies above described. To contemplate levels of risk and tradeoff that differ from the minimum and maximum values, the following two assumptions were taken into account (two goals were pursued): identification of a suitability map in which a high level of risk taking and some tradeoff is contemplated, and a suitability map with a low level of risk and some tradeoff.

The order weights were ranked using the following schemes for the two cases, respectively:

High level of risk – Some tradeoff (OWA)

Order weights:	0.0009	0.001	0.002	0.004	0.008	0.016	0.031	0.0625	0.125	0.25	0.5
Rank:	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th

Low level of risk – Some tradeoff (OWA)

Order weights:	0.5	0.25	0.125	0.0625	0.031	0.016	0.008	0.004	0.002	0.001	0.0009
Rank:	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th

The first result, high level of risk and some tradeoff (Fig. 9a), shows a high suitability of the entire study area and the positive influence of the sensitive sites on the suitability level. When the land suitability is arranged into level classes (Fig. 9b), a map almost completely overlapped with that obtained using the more permissive approach (*or* operator) of the Boolean method (Fig. 7b) is achieved.

With regard to the last hypothesis (low risk and some tradeoff), the resulting maps are shown in Fig. 10. In both maps (Fig. 10a and b) it is highlighted that the sites having the highest suitability are those that stretch between the streams, delimited towards N–NE by the National Road no. 89 and towards SO by the coastal line.

In this case about 2.95% of the area without constraints is estimated to be highly suitable and 16.61% has a moderate level of suitability.

Both methodologies applied (WLC and OWA) are able to locate areas of the territory with a specific vocation (Fig. 8–10). During the process of territorial planning, it will be exclusively the level of risk to be assumed that will influence the choice of the method to adopt.

Anyway, greater differentiation on the territorial suitability levels derives, in this study, from the application of MCDA methods in which the risk assumed is minimum. The OWA model with low risk

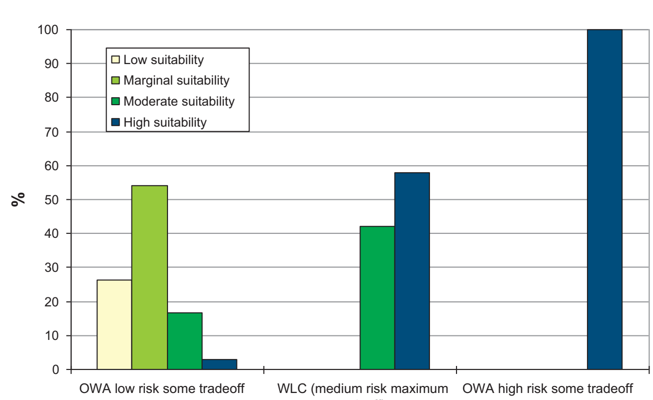

Fig. 11. Spatial distribution of land suitability for levels of risk increasing.

Table 4
Cross-correlation of the WLC (columns) against OWA (rows) land suitability maps and the statistical data obtained.

Suitability classes	marginal	moderate	high	Total	KIA	Statistical data
Low	0.0004	0.2451	0.0172	0.2627	0	$\chi^2 = 86444.2$
Marginal	0	0.1754	0.3664	0.5417	0.0004	Cramer's $V = 0.48$
Moderate	0	0.001	0.165	0.1661	0.718	
High	0	0	0.0295	0.0295	1	
Total	0.0004	0.4215	0.5781	1	Overall 0.0622	

and some tradeoff was able to make entirely explicit the classed suitability scale from the sites with low suitability to those with high suitability or the continuous 0–255 scale.

With risk aversion decreasing, information about intermediate suitability levels is progressively lost (Fig. 11). The final stage is represented by the Boolean approach where the territory can result to be completely suitable or not, depending on the selected operator.

Looking at the last OWA map (low risk and some tradeoff) (Fig. 10) and the one obtained with the WLC method (average risk and maximum tradeoff) (Fig. 8), some similarities and also differences are perceived. In order to make a quantitative comparison between the two maps, a cross-correlation method was used. Two operations were performed. The first was the image cross-tabulation in which the categories of one image are compared with those of a second image and a tabulation of the number of cells in each combination is kept (Eastman, 2003). With this operation, some measures of association between the images were obtained. The first of these measures was the Cramer's V coefficient, a correlation coefficient that ranges from 0.0 (indicating no correlation) to 1.0 (perfect correlation, Ott et al., 1983). In addition, a chi-square value (χ^2) was also determined to test the significance of Cramer's V. The second measure obtained from the image cross-correlation was the Kappa Index of Agreement (KIA) value. KIA is used if the images considered have the same kind of data with the same number of classes (Eastman, 2003). It ranges from 0.0 to 1.0 with the same significance as above. Because of these reasons, KIA value is considered an index that shows the similarity between the two suitability maps.

The results of the cross-tabulation process are given in Table 4 showing the Cramer's V coefficient and overall KIA to be 0.48 and 0.0622, respectively. The Cramer's V value shows a moderate similarity between the suitability maps, whereas the overall KIA value indicates a very low similarity. However, upon a closer inspection of the KIA values for each separate suitability class, it can be observed that moderate and high classes have 0.718 and 1 KIA values respectively, thus indicating a good similarity between these classes in both maps, while there is an evident dissimilarity between the low and marginal suitability classes, with a consequent decrease in the overall KIA value.

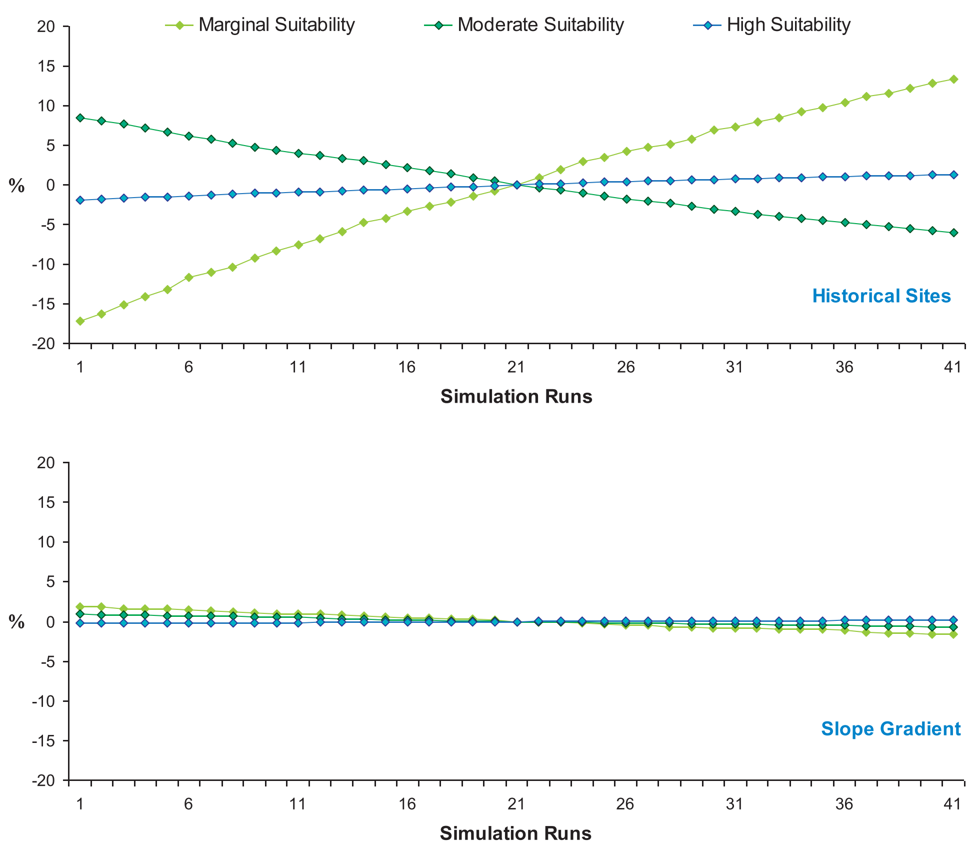

Fig. 12. Summary results from 82 simulations (41 runs for each criterion).
Simulation 1 = −20% weight change.
Simulation 21 = Base Run (0% weight change).
Simulation 41 = +20% weight change.

Table 5
Example of summary table generated from the 40 sensitivity analysis simulation runs for criterion “Historical Sites” plus the base run (bold).

Change (%)	Suitability (km^2)			Changes in suitability (km^2)			Changes in suitability (%)		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
−20	15.2377	4.1309	0.14	−0.2933	0.3223	−0.029	−1.89	8.46	−17.18
−19	15.2523	4.1148	0.1415	−2787	0.3062	−0.0275	−1.79	8.04	−16.29
−18	15.266	4.0992	0.1434	−0.265	0.2906	−0.0256	−1.71	7.63	−15.17
−17	15.2823	4.0811	0.1452	−0.2486	0.2725	−0.0238	−1.6	7.15	−14.1
−16	15.2982	4.0636	0.1469	−0.2328	0.255	−0.0222	−1.5	6.7	−13.15
−15	15.3149	4.0445	0.1493	−0.2161	0.2359	−198	−1.39	6.19	−11.73
−14	15.3323	4.026	0.1504	−0.1986	0.2174	−0.0187	−1.28	5.71	−11.08
−13	15.3475	4.0096	0.1515	.0.1834	0.201	−0.0176	−1.18	5.28	−10.43
−12	15.3636	3.9916	0.1535	−0.1674	0.183	−0.0156	−1.08	4.81	−9.24
−11	15.3772	3.9765	0.155	−0.1538	0.1679	−0.0141	−0.99	4.41	−8.35
−10	15.3899	3.9624	0.1564	−0.141	0.1538	−0.0127	−0.91	4.04	−7.52
−9	15.3999	3.951	0.1577	−0.131	0.1424	−0.0114	−0.84	3.74	−6.75
−8	15.412	3.9376	0.1591	−0.119	0.129	−0.01	−0.77	3.39	−5.92
−7	15.4223	3.9254	0.161	−0.1087	0.1168	−0.0081	−0.7	3.07	−4.8
−6	15.4388	3.9079	0.162	−0.0922	0.0993	−0.0071	−0.59	2.61	−4.21
−5	15.4536	3.8915	0.1635	−0.0773	0.0829	−0.0056	−0.5	2.18	−3.32
−4	15.4676	3.8765	0.1646	−0.0634	0.0679	−0.0045	−0.41	1.78	−2.67
−3	15.4829	3.8604	0.1654	−0.0481	0.0518	−0.0037	−0.31	1.36	−2.19
−2	15.5006	3.8413	0.1667	−0.0304	0.0328	−0.0024	−0.2	0.86	−1.42
−1	15.5148	3.826	0.1678	−0.0161	0.0174	−0.0013	−0.1	0.46	−0.77
0	15.531	3.8086	0.1691	0	0	0	0	0	0
1	15.543	3.795	0.1707	0.012	−0.0136	0.0016	0.08	−0.36	0.95
2	15.5524	3.7839	0.1723	0.0214	−0.0246	0.0032	0.14	−0.65	1.9
3	15.5671	3.7675	0.174	0.0362	−0.0411	0.0049	0.23	−1.08	2.9
4	15.5807	3.7529	0.175	0.0498	−0.0557	0.0059	0.32	−1.46	3.5
5	15.591	3.7415	0.1762	0.06	−0.0671	0.0071	0.39	−1.76	4.21
6	15.6029	3.7288	0.177	0.0719	−0.0798	0.0079	0.46	−2.1	4.68
7	15.6121	3.7187	0.1778	0.0811	−0.0899	0.0087	0.52	−2.36	5.15
8	15.6226	3.7071	0.1789	0.0917	−0.1015	0.0098	0.59	−2.66	5.81
9	15.6348	3.6931	0.1807	0.1039	−0.1155	0.0116	0.67	−3.03	6.87
10	15.6474	3.6799	0.1814	0.1164	−0.1287	0.0123	0.75	−3.38	7.29
11	15.6573	3.6689	0.1825	0.1263	−0.1397	0.0134	0.81	−3.67	7.94
12	15.6671	3.6581	0.1834	0.1361	−0.1505	0.0143	0.88	−3.95	8.47
13	15.6765	3.6475	0.1846	0.1455	−0.1611	0.0155	0.94	−4.23	9.18
14	15.6848	3.6382	0.1856	0.1539	−0.1704	0.0165	0.99	−4.47	9.77
15	15.6923	3.6296	0.1867	0.1614	−0.179	0.0176	1.04	−4.7	10.43
16	15.7006	3.62	0.188	0.1697	−0.1886	0.0189	1.09	−4.95	11.2
17	15.7096	3.6106	0.1885	0.1786	−0.198	0.0194	1.15	−5.2	11.49
18	15.7188	3.6002	0.1896	0.1878	−0.2084	0.0205	1.21	−5.47	12.14
19	15.729	3.5888	0.1908	0.198	−0.2198	0.0217	1.28	−5.77	12.86
20	15.7383	3.5788	0.1915	0.2074	−0.2298	0.0224	1.34	−6.03	13.27

3.1. Sensitivity analysis

A sensitivity analysis was performed first for the WLC method. Results for the criteria with the highest and the lowest weight (historical sites and slope gradient, respectively) are reported.

Afterwards, the analysis was conducted for the OWA method, for the examined cases (high level of risk – some tradeoff, low level of risk – some tradeoff), and, last, for the order weights.

With regard to the WLC method, the procedure proposed is the One-At-a-Time (OAT) method adopted by Chen et al. (2010).

A series of evaluation runs was conducted where each criterion weight was altered in percentage increments (e.g., ±1%) and the weights of the other criteria were adjusted proportionally to satisfy the additivity constraint which requires all criterion weights (wi) to sum to one.

The range of percentage changes, from the original criterion weight value, was from −20% to +20%.

The sensitivity analysis simulation consists of two sets of 41 evaluation runs where each run generates a single new suitability map. The 1st simulation run corresponds to the range of −20%, the 21st one to the initial value and the 41st one to the range of +20%.

In Fig. 12 the suitability variations (as a percentage of the initial values) obtained from 82 simulation runs for the WLC method are summarized. Table 5 is an example for the criterion historical sites, which gives: surface suitability (in km^2) in each ranking class (S_1 = high suitability, S_2 moderate suitability, S_3 marginal suitability), with the exception of S_4 (low suitability) that was zero in each examined case; changes in surface suitability (in km^2 and in %) between different ranking classes.

Table 6 reports the extreme cases corresponding to −20% and +20% of the initial values.

It can be noted that:

Table 6
Results generated from the sensitivity analysis simulation runs 1 and 41 for criterion “Historical Sites” and “Slope Gradient”.

Historical sites	km^2				(%)			
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
−20%	−0.2933	0.3223	−0.029	–	−1.89	8.46	−17.18	–
20%	0.2074	−0.2298	0.0224	–	1.34	−6.03	13.27	–
D	0.5007	0.5521	0.0514	–				

Slope gradient	km^2				(%)			
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
−20%	−0.0381	0.0349	0.0032	–	−0.25	0.92	1.9	–
20%	0.0286	−0.026	−0.0026	–	0.18	−0.68	−1.54	–
D	0.0667	0.0609	0.0058	–				

Table 7
Sensitivity analysis simulation runs for order weights.

	Rank	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
Weight	Suitability	km^2										
0.2526	Low	11.63	11.05	7.37	1.15	0.56	0.46	0.01	–	–	–	–
	Marginal	4.73	6.39	9.36	13.98	11.71	6.02	1.52	0.79	0.61	0.19	0.02
	Moderate	1.59	1.91	2.48	3.88	6.36	11.5	15.46	13.73	8	4.02	2.57
	High	0.04	0.16	0.29	0.5	0.88	1.52	2.51	4.99	10.9	15.3	16.92
0.2198	Low	5.55	4.45	2.55	0.82	0.1	0.02	–	–	–	–	–
	Marginal	7.08	7.65	8.15	8.01	6.36	3.46	1.4	0.78	0.33	0.18	0.03
	Moderate	5.5	5.15	6.09	7.42	9.08	11.04	11.59	9.72	6.75	4	2.86
	High	1	2.26	2.72	3.25	3.96	4.99	6.52	9.01	12.43	15.33	16.62
0.1425	Low	1.98	1.33	0.69	0.25	0.03	–	–	–	–	–	–
	Marginal	5.08	4.94	4.45	3.74	2.79	1.51	0.82	0.51	0.25	0.17	0.05
	Moderate	8.3	6.58	7.11	7.73	8.3	8.79	8.27	6.85	5.52	3.92	3.5
	High	4.13	6.67	7.26	7.8	8.39	9.21	10.42	12.15	13.74	15.41	15.96
0.0699	Low	0.28	0.17	0.1	0.04	0.01	–	–	–	–	–	–
	Marginal	2.26	1.95	1.61	1.24	0.86	0.63	0.46	0.28	0.15	0.17	0.14
	Moderate	8.9	7.76	7.41	7.21	6.74	6.16	5.73	5.35	4.7	3.87	3.95
	High	8.07	9.63	10.4	11.02	11.9	12.71	13.32	13.88	14.65	15.47	15.42
0.0688	Low	0.07	0.05	0.04	0.04	0.03	0.02	0.01	–	–	–	–
	Marginal	0.53	0.54	0.5	0.41	0.39	0.35	0.33	0.17	0.13	0.17	0.14
	Moderate	6.43	6.06	5.28	4.94	4.62	4.23	4.3	4.67	4.61	3.86	4.02
	High	12.48	12.85	13.69	14.12	14.47	14.91	14.87	14.67	14.77	15.48	15.35
0.0642	Low	–	–	–	–	–	–	–	–	–	–	–
	Marginal	0.05	0.08	0.16	0.2	0.15	0.11	0.07	0.07	0.09	0.17	0.17
	Moderate	3.07	3.16	2.62	2.25	2.56	3.14	3.65	4.32	4.34	3.86	3.99
	High	16.39	16.27	16.73	17.06	16.79	16.26	15.8	15.12	15.07	15.48	15.35
0.047	Low	–	–	–	–	–	–	–	–	–	–	–
	Marginal	–	0.01	0.02	0.08	0.07	0.07	0.07	0.06	0.06	0.16	0.17
	Moderate	0.56	0.94	1.06	0.93	1.23	1.9	2.8	3.32	3.69	3.82	4.44
	High	18.94	18.56	18.42	18.5	18.21	17.54	16.64	16.13	15.76	15.53	14.89
0.0432	Low	–	–	–	–	–	–	–	–	–	–	–
	Marginal	–	–	–	0.02	0.04	0.03	0.02	0.01	0.04	0.16	0.2
	Moderate	0.08	0.27	0.6	0.7	0.78	1.31	1.92	2.69	3.44	3.79	4.79
	High	19.43	19.24	18.9	18.79	18.69	18.17	17.57	16.8	16.03	15.56	14.51
0.0416	Low	–	–	–	–	–	–	–	–	–	–	–
	Marginal	–	–	–	–	0.06	0.1	0.07	0.05	0.07	0.16	0.21
	Moderate	–	0.05	1.05	1.88	2.19	2.76	3.38	3.76	3.87	3.84	4.79
	High	19.51	19.46	18.46	17.63	17.26	16.65	16.06	15.7	15.57	15.51	14.51
0.0305	Low	–	–	–	–	–	–	–	–	–	–	–
	Marginal	–	–	–	–	0.01	0.05	0.1	0.12	0.13	0.17	0.27
	Moderate	–	–	0.65	1.29	2.08	2.79	3.27	3.48	3.56	3.76	5.61
	High	19.51	19.51	18.86	18.22	17.42	16.67	16.15	15.91	15.82	15.58	13.63
0.0199	Low	–	–	–	–	–	–	–	–	–	–	–
	Marginal	–	–	–	–	–	–	–	–	–	0.14	0.68
	Moderate	–	–	–	0.03	0.07	0.12	0.5	1.03	1.8	3.56	6.97
	High	19.51	19.51	19.5	19.48	19.44	19.39	19.01	18.48	17.71	15.81	11.86

- The criterion with the highest weight value (historical sites) is the most sensitive. It can cause, within the ±20% of changes, slight suitability class modifications for the moderate and marginal levels (+8.46% and −17.18%, respectively) while high class is relatively stable (less than ±2%).
- The percentage variation of the decision weights has a small impact on the ranking of most cells in S_1 and this reveals that the degree of domination of these cells is almost independent of changes in the decision weights associated with these selected criteria.
- Suitability variation due to changes of slope gradient weights is irrelevant both in terms of area than percentage values.

The sensitivity analysis conducted for OWA method showed very low suitability variations: the surface variations, from −20% to +20% of the initial values, do not exceed 0.057 km^2, in the different classes.

Lastly, the results of sensitivity analyses conducted for the order weights are reported in Table 7.

The first case, printed in blue, represents the endpoint of the decision triangle, where there is no tradeoff and the level of risk is maximum. In this case the area with high suitability is next to zero (0.04 km^2). It reaches the highest values (in red in Table 7) when the order rank is 1 for the criteria with the lowest weight (high risk and no tradeoff), where all the other suitability classes are equal to zero. The surface suitability derived from the application of the WLC method is illustrated with the yellow background.

As regards the other results summarized in Table 7, they do not deviate from the expected ones: the higher the level of risk taken the greater the surfaces that show the highest level of suitability. The results obtained confirm what Boroushaki and Malczewski (2008) report about the flexibility of the OWA method in generating a large range of decision support maps.

4. Conclusions

The coastal area of the Municipality of Monte Sant'Angelo, in northwest Puglia, boasts a valuable cultural and natural heritage, with conflicting land uses (agriculture, industry and tourism). Despite its small surface, this area is a kind of laboratory embracing the problems shared by many coastal territories of the Mediterranean region.

This paper examines different approaches to identify the appropriate sites for the restoration of manor farms, a key issue for the development of agro-environmental tourism activities in this Mediterranean area. The MCDA methods, the Boolean, the WLC and the OWA models, are used in a GIS environment, giving outcomes that can be useful and applicable in other similar territorial contexts.

In the risk averse Boolean map, high suitability classes cover small strips of the area, whereas when using the risk-taking approach the entire study area results to be suitable for the hypothesized goal. The same result is reached when using the OWA method with a high level of risk and some tradeoff between the selected criteria. The WLC method and the OWA method with low risk are the procedures which provide a more detailed mapping of the suitable areas.

The OWA method with low risk and some tradeoff is the method that gives the best results, as it better defines the areas that are (or not) suitable for the expected development. According to the maps produced, the central part of the study area, between the main streams of the territory, is more adequate for restoration purposes.

They give similar results with respect to the areas characterized by moderate and high suitability, while the two methods differ very much when we consider low and marginal suitability areas.

The site suitability maps obtained are expected to be utilized by the local authorities as they can help them in their decision-making and policy planning efforts in the near future.

Apart from the use of the obtained results, the importance of using decision-support systems for land analysis, in combination with GIS, should be pointed out. Indeed, such type of analysis better combines the potentials of modern GIS techniques, capable of identifying and elaborate the territorial features of a site, with the MCDA procedures, whose aim is to increase the democratization of the planning process via public participation.

The application limits can derive from a misuse of the method or from an excessively generalized use, as it tends to be applied in various fields of planning and territorial sciences. It is necessary, however, to avoid a reckless use, transforming it into an instrument in the hands of evaluators or modellers to endorse pre-packaged planning decisions. In this sense, the weak link in the process is essentially the method of construction of the preference matrix. A solution to this passage can be offered by performing the sensitivity analysis on all the criteria weights to examine carefully the accuracy in estimating weights.

Lastly, the method's potential is lower in those fields of application in which the definition of the weights to be assigned to the criteria assumes a complex character, defined with insufficient precision. It is the case of the environmental issues that highlight the more detailed ecological aspects, where the criteria do not vary in a discrete or continuous manner but according to physical laws that can not be adequately represented by using the fuzzy logic.

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