Applied Geography 31 (2011) 108–118

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Spatial modelling of potential landscape quality

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Keywords:
Landscape quality
Multicriteria analysis
MCE
AHP
GIS
Density analysis
Spatial modelling
Multivariate analysis

ABSTRACT

Quality of landscape directly affects the day to day quality of life of all the people living in it. It is strongly bound to landscape components and features and to their spatial and functional interrelations. Potential quality, in particular, is determined by elements of value that, in relation to their characteristics of integrity and importance, result in an enhancement in landscape quality. More effective analysis and evaluation of quality of landscape elements, and their contribution to landscape quality, are essential for supporting modern landscape analysis and planning. In this regard, multicriteria techniques, and Analytical Hierarchy Processes in particular, can support the definition and development of quantitative methods aimed at the modelling, analysis and evaluation of landscape quality. GIS spatial analysis of quality indicators derived from multicriteria techniques generates map layers of landscape quality based on density and quality level of the landscape elements. Within GIS, progressive multicriteria aggregation of landscape quality layers produces synthetic spatial indicators that can support effective interpretation of the gradients characterising landscape configuration. The methodology has been applied to an internationally recognised historical-cultural area in the territory of Assisi (Umbria, Italy). The specific objective has been validation of the methodology by assessing potential landscape quality in relation to the most important physical-naturalistic, historical-cultural and social-symbolic elements. The results have shown that spatial gradients of landscape quality can be effectively modelled by the combined use of GIS and multicriteria methods.

Introduction

Landscape is the result of an evolving combination of elements and processes linked by functional and spatial relationships. It plays an essential role in determining quality of life for the populations in daily contact with it and, as a consequence, satisfying population landscape quality demands becomes the right, but also the responsibility of everyone (European Council, 2000; Regione Piemonte, 2003; Regione Umbria, 2009). Thus, landscape quality assumes a central role in the contemporary processes aimed at landscape analysis, planning and design (Calcagno Maniglio, 2006; Clementi, 2002; European Council, 2000; Peano & Voghera, 2008; Romani, 2008). The majority of studies on landscape quality evaluation focus mainly on public visual perception of aesthetic components (e.g.: Arriaza, Cañas-Ortega, Cañas-Madueño, & Ruiz-Aviles, 2004; Bulut & Yilmaz, 2008; Cañas, Ayuga, & Ayuga, 2009; Daniel, 2001; Magill, 1990). Approaches range from expert-based ones, through perceptual and experimental approaches obtaining observer responses to landscape photographs, to experiential and humanistic approaches exploring and clarifying landscape significance (Dakin, 2003). However, a comprehensive evaluation of landscape quality should include a more extensive analysis of the composition and the relationships existing between all landscape components. To improve interactions between insiders and disciplines in landscape evaluation processes, and to assist those who care for and manage landscapes, it is important to find ways of achieving a more integrated and comprehensive approach to understanding landscape values (Stephenson, 2008). Such an approach still presents many difficulties due to the lack of reliable quantitative methods for understanding the spatial configuration of natural and cultural elements, their reciprocal interactions and their contribution to landscape quality.

Multicriteria evaluation (MCE) is a multiple criteria comparison procedure applied to decision-making processes. Its purpose is to contribute towards the development of an iterative learning method feeding the evaluation process itself (Roy, 1968; Voogd, 1983). The specificity of MCE lies in the definition of synthetic indicators based on several reference criteria, examined autonomously and interactively. Because of the particular modular structure, it can be very useful in landscape evaluation and planning for the integration of expert and local knowledge (Damart, Dias, & Mousseau, 2007; Kangas, Store, & Kangas, 2005; Rey-Valette,

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doi:10.1016/j.apgeog.2010.03.001

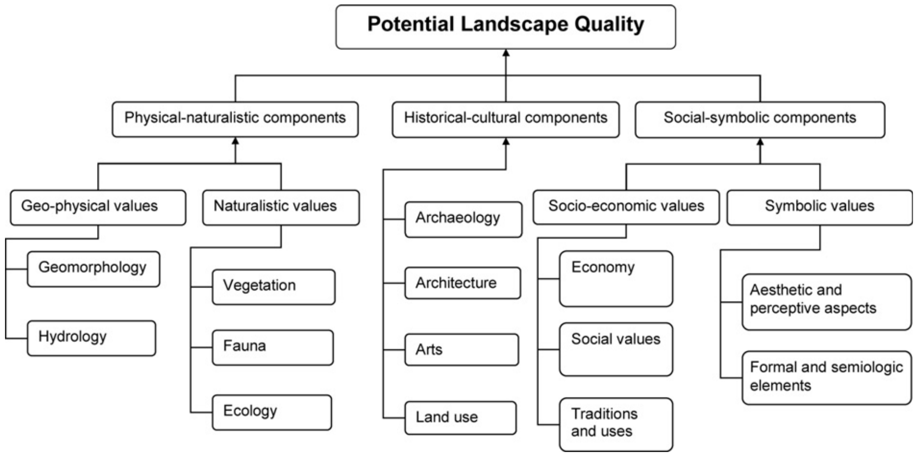


Fig. 1. Example of interpretative model for the evaluation of potential landscape quality.

Damart, & Roussel, 2007; Stagl, 2006). In particular, the Analytical Hierarchy Process (AHP) is a powerful and flexible multicriteria technique that formulates the decisional problem through a hierarchical structure (Saaty, 1980). AHP helps capture both qualitative and quantitative aspects of a decision and provides a powerful yet simple way of weighting selection criteria, thus reducing bias in decision-making (Ma, Scott, DeGloria, & Lembo, 2005).

The majority of problems associated with landscape evaluation require methodologies that can be integrated inside Geographical Information Systems (GIS), powerful tools designed for managing, transforming and representing georeferenced data (Jones, 1997; Murray & Tong, 2009; Smith, Goodchild, & Longley, 2007). A spatial conceptualization, supported by GIS, enables better understanding of the specific characteristics of sites and the nature of the interaction between ongoing or periodic human and natural actions in configuring landscapes (Blaschke, 2006). Even culture and related identity are not only about social relationships, but are also profoundly spatial in nature (Stephenson, 2008). The view of landscapes as continua and spatial gradients represents a challenge to the conventional view of how the natural (and human) environment is organised (Bridges, Crompton, & Schaefer, 2007).

The combined use of GIS and MCE allows, on the one hand, taking advantage of the enormous potential of management, spatial analysis and modelling of landscape data offered by information systems, and on the other, implementing efficient procedures aimed at the analysis of preferences and assessments expressed by the experts and by the other stakeholders (Colombo & Malcevschi, 1999; Jankowski, 1995; Malczewski, 1999). Different multicriteria procedures can be implemented in the GIS environment, but, in particular, weighted linear combination (WLC) of map layers, supported by AHP, is considered the most straightforward and most frequently employed (Eastman, Kyem, Toledano, & Jin, 1993; Malczewski, 2004).

As this study shows, GIS analysis techniques combined with AHP-based MCE methods can support the definition and calculation of spatial indicators allowing better assessment and interpretation of the gradients characterising landscape quality.

Materials and methods

Landscape quality is strongly bound to landscape elements and features and to their spatial and functional interrelationships. Landscape potential quality (LQp), the specific subject of this study, is determined by elements of value (or of quality) that, in relation to their characteristics and positions, result in an enhancement of landscape quality.

Each landscape element inevitably conditions the quality of the surrounding context in which it is placed, in accordance with

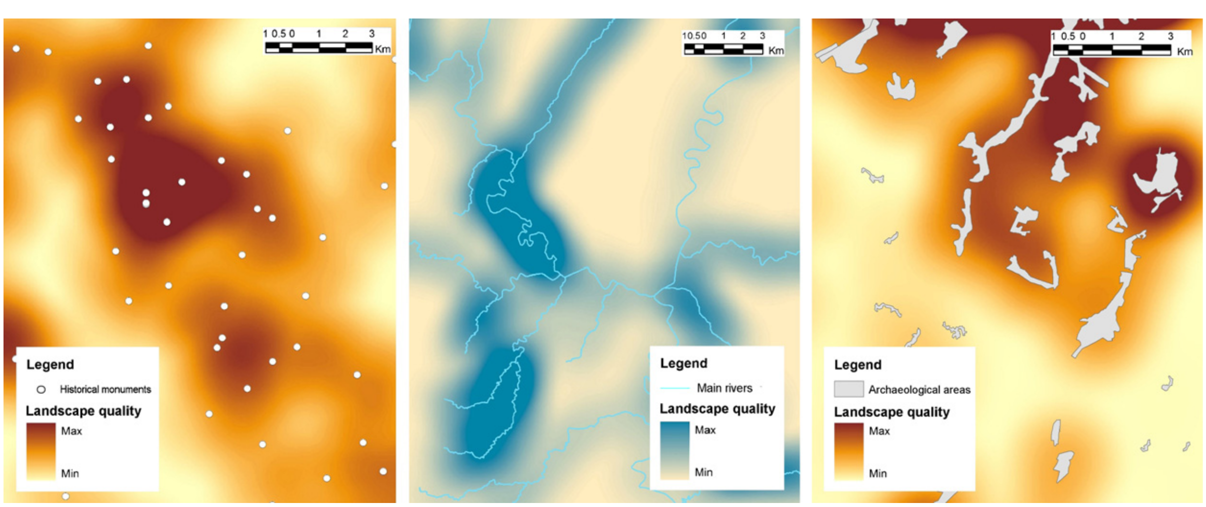


Fig. 2. Landscape quality spatialisation of point (left), linear (centre) and polygonal elements (right) using kernel density analysis.

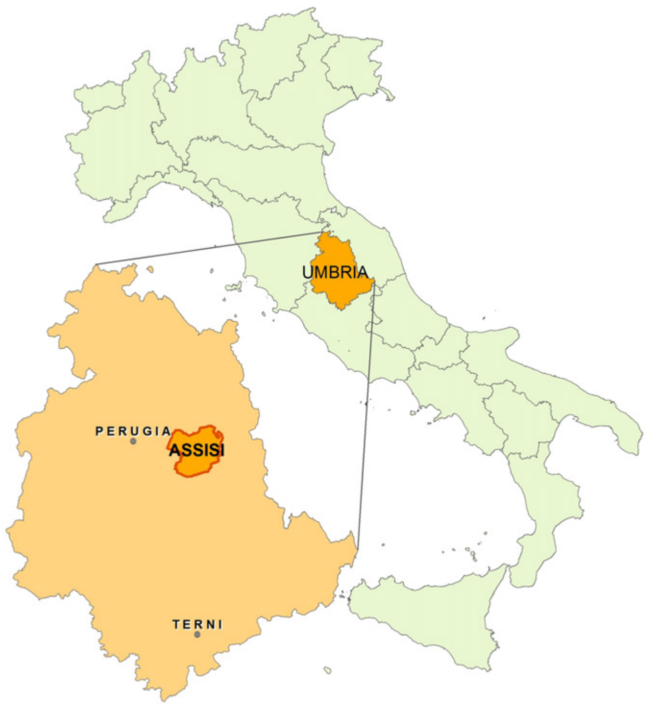


Fig. 3. Location of the area of interest (Municipality of Assisi, Umbria, Italy).

a spatial gradient that is inversely proportional to the distance from itself; indeed, the perception of that element (not only visually, but also by means of other informative vectors) becomes greater as the distance from it decreases. Consequently the LQp depends on the density (but also the variety) of the elements of value existing within a specific context and on the level of quality associated with said elements. Said level of quality can be evaluated according to the criteria of integrity and importance, highlighted in the Italian Cultural Heritage and Landscape Code. Indeed, the two criteria can guide the assignment of values to landscape elements as suggested by the Code itself (Leone & Tarasco, 2006). Integrity can be

Table 1
Physical-naturalistic categories considered in the evaluation.

ID	Code	Layer	Description	Data source	Year of the last update
1	GEO	Protected geological sites	Protected sites of geological interest	Provincial Land Information System of Perugia and subsequent updates	1998
2	pSCIs	pSCIs areas	Sites of Community Importance (Proposals) – Natura 2000 European Network	Regional Land Information System of Umbria	2008
3	RIV	Rivers	Major rivers	Selection of data from Regional Land Information System of Umbria	1998
4	PARKS	Natural parks	National and regional natural parks	Regional Land Information System of Umbria	1998
5	ECONET	Ecological network	Functional elements of the regional ecological network	Regional Land Information System of Umbria	1998

Table 2
Historical-cultural categories considered in the evaluation.

ID	Code	Layer	Description	Data source	Year of the last update
1	ARCH	Archaeological sites	Sites of major archaeological interest	Provincial Land Information System of Perugia and subsequent updates	2004
2	STOR	Historical centres	Urban centres of high historical and cultural interest	Topographic map interpretation	1954
3	REL	Religious architecture	Religious buildings of high historical value (Abbeys, parish churches, monasteries, rural churches)	Regional Land Information System of Umbria	1998
4	MIL	Military architecture	Military buildings of high historical value	Regional Land Information System of Umbria	1998
5	VILLA	Villas	Historical houses of high cultural interest	Regional Land Information System of Umbria	1998

determined not only in terms of the state of conservation of the sites and resources, but also with regard to the consistency of the evolutionary process and the level of congruity and completeness of any transformations observed over time (Gattei & Orlandin, 2006). Importance can be considered as the result of the combination of different evaluation categories: *witness and documentary value* (the availability of historical documents confirming the importance of the element), *peculiarity* (the characteristics distinguishing the element with particular regard to aesthetic value), *recognisability* (the degree of identification of the element by local communities) (Clementi, 2002).

The approach described guides the spatial modelling of LQp obtained by means of four methodological steps: (a) identification of LQp components, (b) evaluation of the quality of individual landscape elements, (c) spatial analysis of landscape quality elements (d) multicriteria aggregation of LQp components.

Identification of LQp components

The first phase of the evaluation process is focused on defining an interpretative scheme aimed at the identification and analysis of

Table 3
Social-symbolic categories considered in the evaluation.

ID	Code	Layer	Description	Data source	Year of the last update
1	TYP	Typical production	Typical local production	Information from different sources georeferenced on topographic map	2007
2	TRAD	Traditional events	Traditional folkloristic events	Information from different sources georeferenced on topographic map	2006
3	PAN	Panoramic viewpoints	Viewpoints of high scenic value	Information from different sources georeferenced on topographic map	2008
4	SYMB	Symbolic elements	Landscape elements with high symbolic value	Selection of main symbolic elements and georeferencing on topographic map	2008

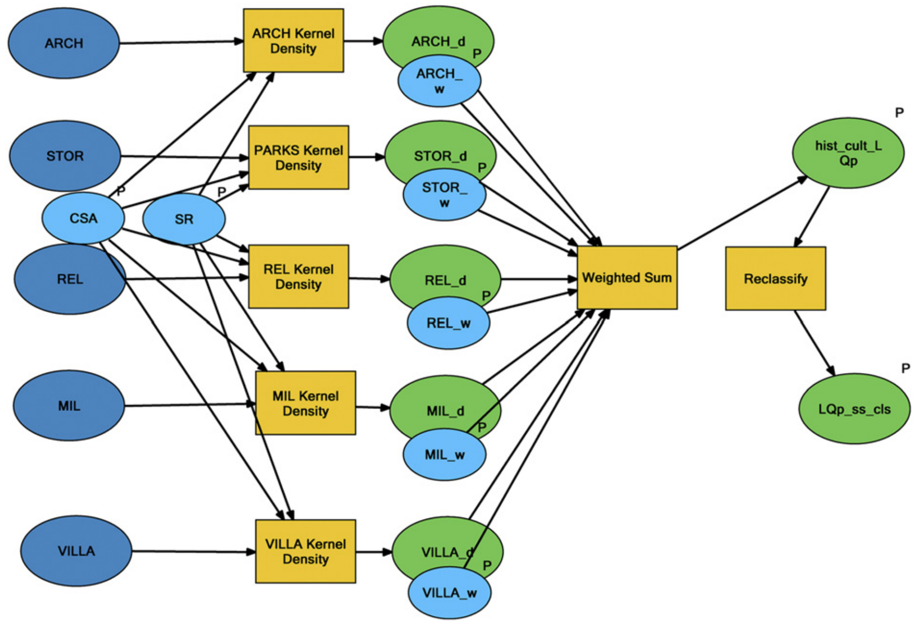


Fig. 4. GIS model applied for spatial analysis of historical-cultural quality indices.

quality components existing within a specific landscape context. Using AHP, a multilevel analysis process is developed, aimed at the decomposition of the landscape palimpsest and the progressive aggregation of the information pertaining to the landscape components. The first classification is based on the three landscape component groups proposed by Clementi (2002): physical-naturalistic, historical-cultural and socio-symbolic (Fig. 1). The former refers to the geo-physical (composition and configuration of the terrestrial surface) and ecological systems. The historical-cultural components include signs and consistencies documenting the history of a location and its transformations, and can be the subject of knowledge, study, literary and figurative representation (Clementi, 2002). Social components refer to social values and to the local population's attitudes and knowledge, while symbolic factors relate to aesthetic values and the different forms of landscape perception. In particular, symbolic and cognitive values pass through aesthetically perceived scenery, since they contain much information concerning the still poorly-known history of ordinary people and land management traditions (Antrop, 2005). The identification and evaluation of social components (and their contribution to landscape quality) can present several difficulties. Indeed, the majority of social indicators are rather difficult to express since they are non-visual and not spatially explicit (Wissen, Schroth, Schmid, & Lange, 2005).

The interpretative scheme described earlier, starting from a preliminary structure defined by experts at the beginning of the landscape analysis process, is progressively updated and developed by means of the information that becomes available during the study. A GIS system, optionally linked to an RDBMS (Relational Database Management System), is implemented, progressively introducing all the landscape data collected. Development of the interpretative scheme and the relevant GIS database can be supported by surveys of opinions from the local population.

Evaluation of the quality of individual landscape elements

In order to apply the interpretative scheme and proceed to evaluation, it is necessary to evaluate the quality of the individual landscape elements using specific information regarding said integrity and importance criteria. In this phase, it is possible to use a simple multicriteria model, already applied and validated in a landscape scenario in Umbria (Italy), whose basic formula is as follows (Vizzari & Mennella, 2009):

$$Q = I \times R \tag{1}$$

where Q is the quality of the landscape element under consideration, I is the integrity and R is the importance. Integrity (I) can be determined with the aid of experts through the assignment of a numerical indicator between 1 and 10. In this phase, pairwise comparison techniques may be useful for hierarchical organisation of the available alternatives, and for reducing subjectivity in the scores assigned (Saaty, 1990). Importance (R) is calculated through a WLC of the aforementioned categories: witness and documentary value, peculiarity, recognisability:

$$R = aD + bP + cK \tag{2}$$

where R is the importance, D is the witness and documentary value, P is the peculiarity, K is the recognisability, while a, b and c are three weighting coefficients. The three parameters D, P and K, necessary

Table 4
Weighting calculation for physical-naturalistic components (CI: 0.05; CR: 4.17%).

LAYER	GEO	RIV	pSCIs	PARKS	ECONET	Weights
GEO	1	1/5	1/7	1/8	1/7	0.034
RIV	5	1	1/2	3	1	0.231
pSCIs	7	2	1	3	2	0.375
PARKS	8	1/3	1/3	1	1/2	0.131
ECONET	7	1	1/2	2	1	0.228

Table 5
Weighting calculation for historical-cultural components (CI: 0.00; CR: 0.44%).

LAYER	ARCH	STOR	REL	MIL	VILLA	Weights
ARCH	1	1/3	1/2	1/2	1	0.114
STOR	3	1	1	1	2	0.268
REL	2	1	1	1	2	0.247
MIL	2	1	1	1	2	0.247
VILLA	1	1/2	1/2	1/2	1	0.124

Table 6
Weighting calculation for social-symbolic components (CI: 0.00; CR: 0.35%).

LAYER	TYP	TRAD	PAN	SYMB	Weights
TYP	1	1/2	1/3	1/3	0.109
TRAD	2	1	1/2	1/2	0.189
PAN	3	2	1	1	0.351
SYMB	3	2	1	1	0.351

for the calculation of relevance (R), are also determined with the aid of experts, and assigned numerical values within the range 1–10. This phase and the subsequent determination of the parameter weights (the sum of which equal 1) can be supported by pairwise comparison matrices. As a consequence of the procedure described, the parameter R will be expressed as a value within the range 1–10, while Q will be a value between 1 and 100.

Within GIS, the various parameters and weights are included in the feature tables linked to landscape component layers. Model equations are implemented and developed in order to calculate a Q value for each landscape element. Feature table construction and model development can be supported by the RDBMS linked to GIS. Thus, different thematic GIS level typologies are constructed where each georeferenced landscape feature (point, line or polygon) is linked not only to the general and descriptive information, but also to the integrity and importance parameters and to the landscape quality index (Q), calculated using the model.

Spatial analysis of landscape quality elements

Using GIS gridding techniques, it is possible to spatialise landscape quality indices calculated before generating a continuous landscape quality surface for each landscape component. Among the available gridding techniques, density analysis shows the best functionality in modelling landscape quality gradients in accordance with the above-described conceptualization. In fact, density analysis takes known quantities of certain phenomena and spreads them across the landscape based on the quantity measured at each location and the spatial relationship of the locations of the quantities measured (ESRI, 2007). Unlike simple density, kernel density estimation (KDE) produces smoother surfaces, better representing landscape quality gradients, since the resulting surfaces surrounding each point are based on a quadratic formula with the highest value at the centre of the surface (the point location) tapering towards zero at the search radius distance (Fig. 2). In GIS-based KDE functions, varying output raster resolutions and search radii can be defined (Smith, Goodchild, & Longley, 2007). Cell resolution can be defined according to the analysis scale (Hengl, 2006). Different search radii allow analysis of the phenomena at different scales, since a wider radius shows a more general trend over the study area, smoothing the spatial variation of the phenomenon, while a narrower radius highlights more localized effects such as 'peaks and troughs' in the distribution (Borruso, 2008). For the application of KDE in landscape quality analysis, the search radius can be defined with the aid of experts according to a representative maximum perception distance for landscape elements. A good rule is to test different search radius values in order to examine variation in the function at different scales (Bailey & Gatrell, 1995). For subsequent data integration in the multicriteria process, it is essential the same search radius and cell resolution be used for density analysis of all landscape layers. Prior to calculating density, polygonal landscape elements are converted to a mesh of points spaced at intervals equal to the size of the cells used for density analysis. This allows a proper resolution to be set, maintaining adequate polygonal shape detail in accordance with the scale of the analysis.

Multicriteria aggregation of landscape quality components

The above-described spatialisation process generates single continuous representations of landscape quality, in raster format, with reference to the various landscape component typologies. In

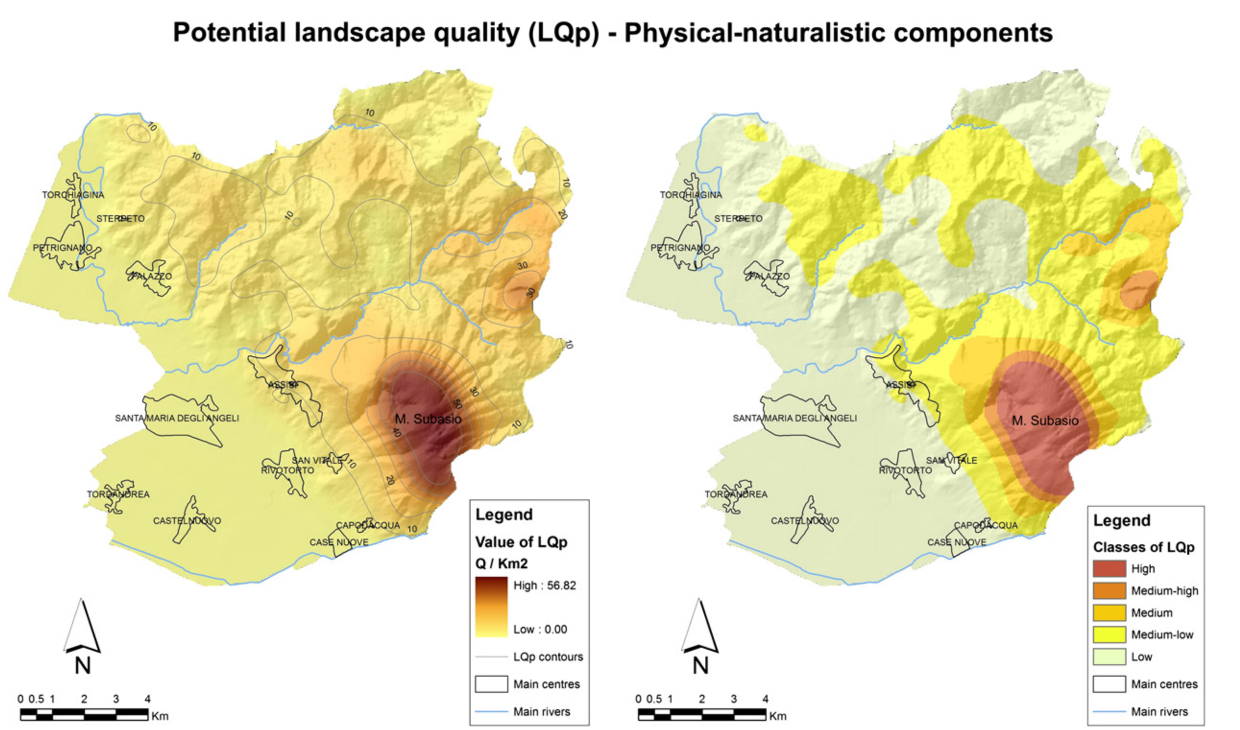


Fig. 5. Potential landscape quality index for physical-naturalistic components (left) and related classes (right).

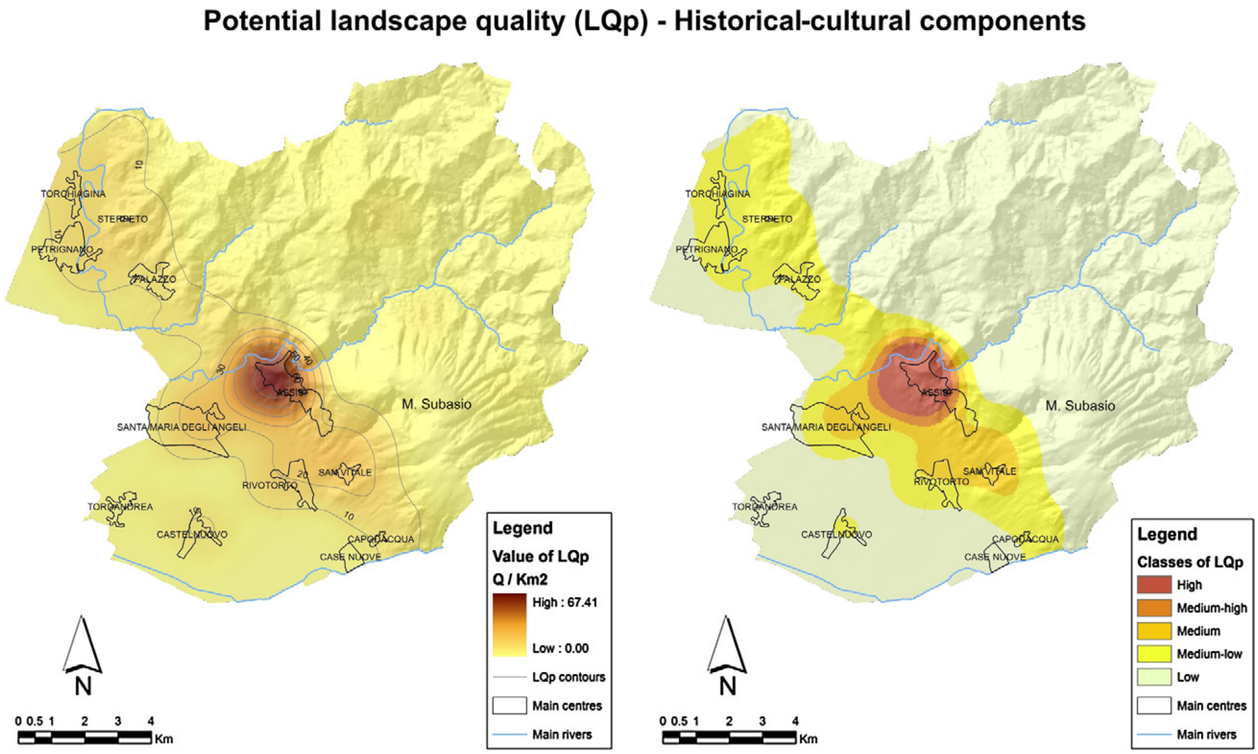


Fig. 6. Potential landscape quality index for historical-cultural components (left) and related classes (right).

accordance with the hierarchical scheme initially defined, raster layers can be progressively aggregated using the WLC technique. Accordingly, specific tools supporting the development of MCE–AHP procedures into the GIS environment may be used (e.g.: Boroushaki & Malczewski, 2008). The equation to be used for this is as follows:

$$LQp = \sum_{i=1}^{m} w_i Q_i \tag{3}$$

where LQp is the potential landscape quality index, w_i is the weight of the i component, Q_i is the landscape quality spatial indicator of

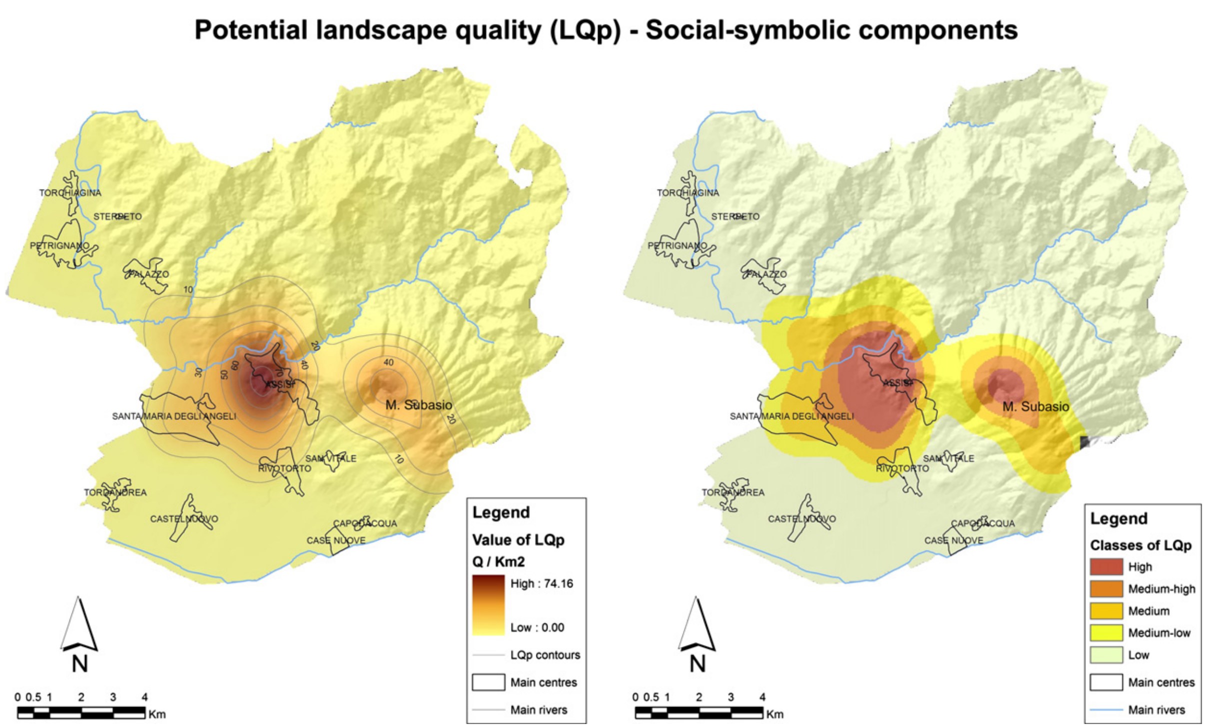


Fig. 7. Potential landscape quality index for social-symbolic components (left) and related classes (right).

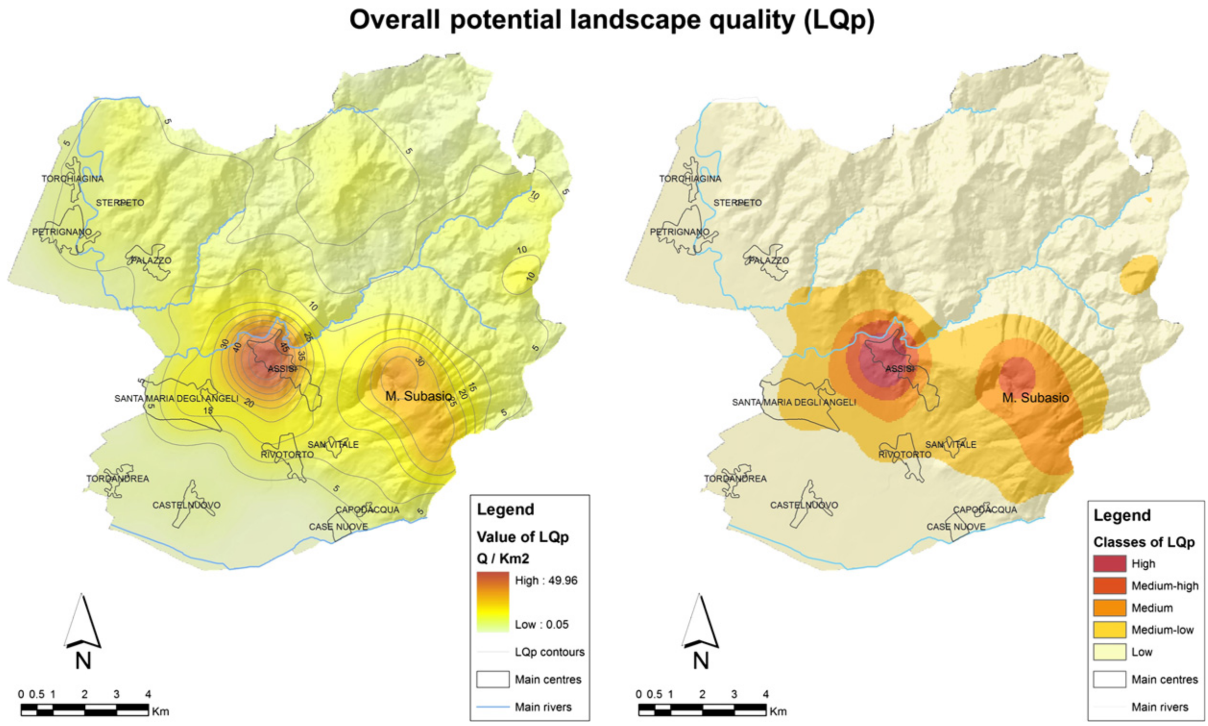


Fig. 8. Potential landscape quality index for all landscape components (left) and related classes (right).

the i component. Standardization of Q_i values, normally performed in WLC, is not required as a result of the above-described Q calculation procedure adopted. Weights (w_i), whose sum is equal to 1, allow the relative importance each component assumes in the landscape quality index calculation to be defined. Again in this case, a pairwise comparison technique seems to be the most reliable for the weights calculation. Using GIS map algebra, Eq. (3) can be applied in order to obtain progressive aggregation of the various landscape quality layers, according to the levels defined in the hierarchical scheme. The purpose is to obtain three intermediate indices relating to the physical-naturalistic, historical-cultural and socio-symbolic components. The subsequent aggregation of these three indices, using an additional WLC, produces an overall index of potential landscape quality.

Results

The methodology has been applied to an internationally recognised historical-cultural area in the territory of Assisi (Umbria, Italy) (Fig. 3). This case study has been developed in order to demonstrate the potential application of the proposed methodology in a complex landscape context.

The landscape components considered in this evaluation have been identified by three experts selecting the major physical-naturalistic, historical-cultural and social-symbolic components characterising landscape quality in Assisi and its surrounding area (Tables 1–3). Besides the famous historical-cultural landscape value of this area in relation to the extensive presence of medieval architecture (particularly religious and military), the study has also permitted investigation of the role of the lesser known physical-naturalistic and socio-symbolic components. The former is associated with the presence of significant landscape elements such as: Natura 2000 sites, regional parks, elements of the regional ecological network, geo-sites, and rivers. The latter is related to other specific elements such as: typical production activities, traditional events, panoramic viewpoints and other important symbolic elements. In this particular case study, a detailed hierarchical scheme of landscape quality components has not been developed due to the restricted number of selected thematic layers.

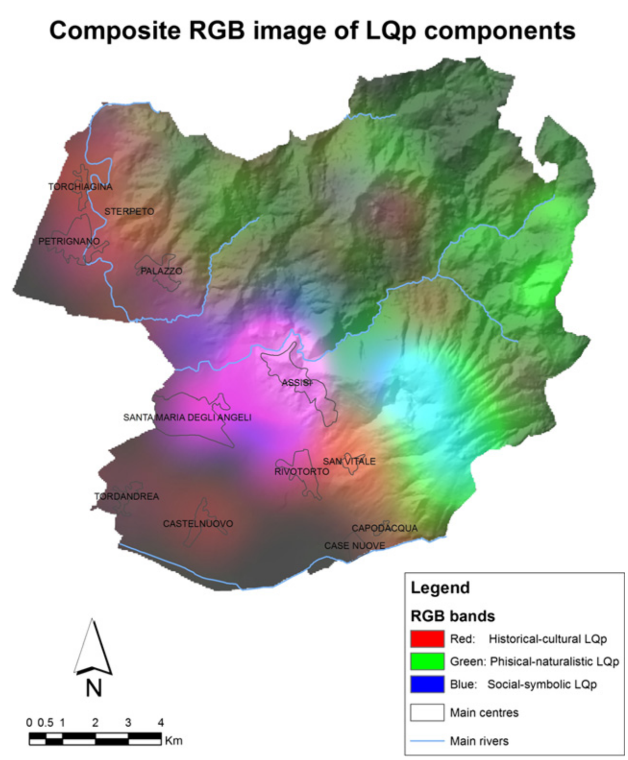


Fig. 9. RGB composite image of the three LQp indices.

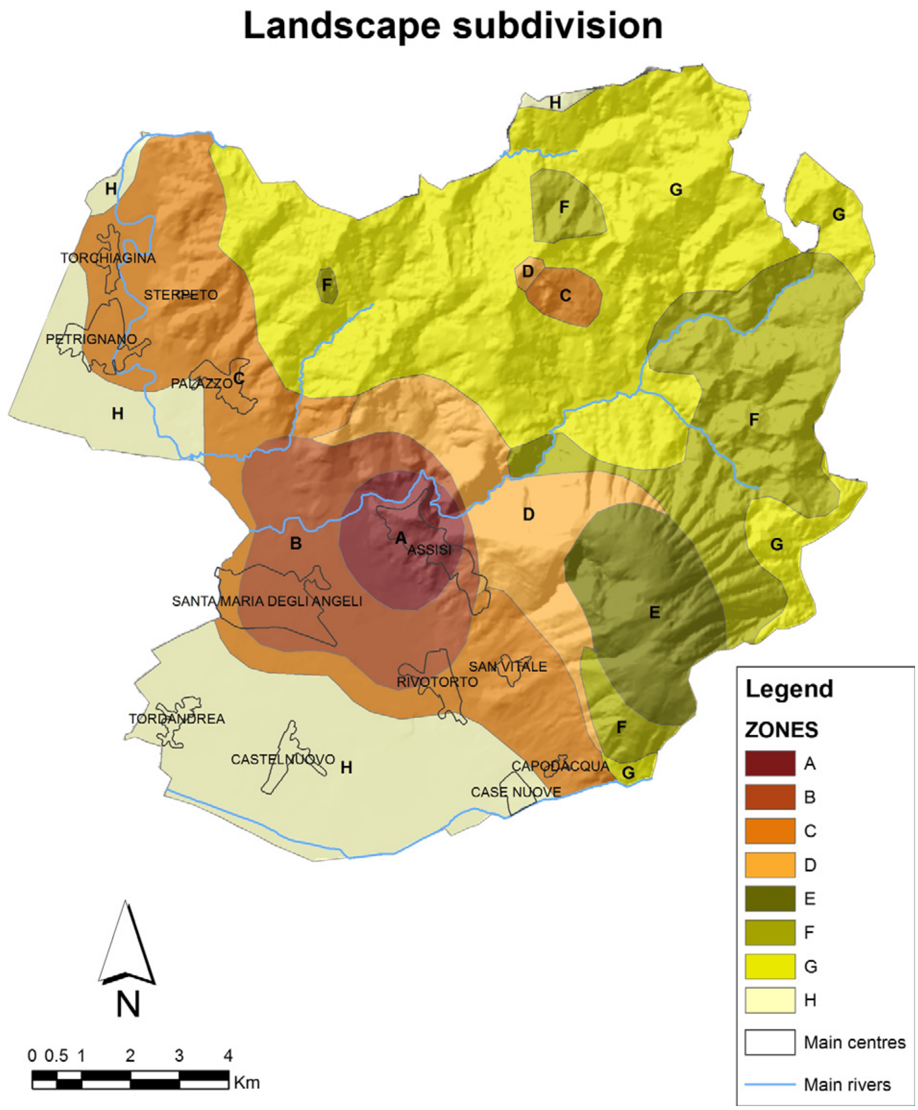


Fig. 10. Landscape subdivision produced by multivariate classification.

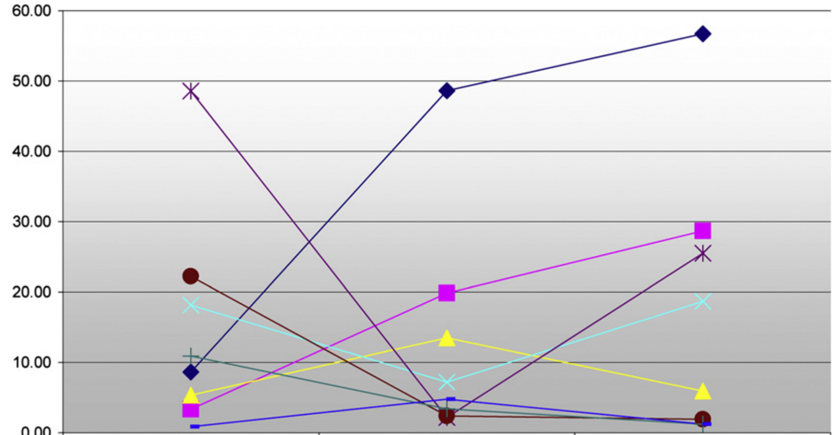
A GIS system containing the landscape information of interest has been implemented and developed throughout the study. For each landscape element, integrity (*I*) and the three parameters *D*, *P* and *K* required for the calculation of importance (*R*) were determined with the aid of the experts. All parameters have been calculated promptly thanks to the various experts' extensive knowledge of the landscape components within the territory. In certain cases, this phase has been supported by information from local surveys and interviews of the resident population. Parameters *D*, *P* and *K* were assigned the same relative weighting in the calculation of the importance of landscape elements (*R*). Again, this choice can often be considered rational since the development of a specific pairwise comparison matrix can allow accurate weighting of the three evaluation categories, even within a participated process. The landscape quality (*Q*) for each landscape element has been calculated using Eq. (1) as discussed in the methods section.

Four different models have been implemented using GIS python tools in order to automate the density analyses and the subsequent WLCs (Fig. 4). The effects of four different search radii (1, 1.5, 2, 2.5 km) on density analysis of the landscape quality indices have been explored through a wide number of iterations. The 2 km radius has proved to be the most reliable in the spatial analysis of landscape quality for the area under investigation.

With the aid of experts, layer weightings were determined using three different pairwise comparison matrices (Tables 4–6). Concordance indices (CI) and consistency ratios (CR) calculated for all matrices, as reported in the caption to the tables, were below the tolerance threshold.

Raster formatting of the data allowed landscape quality indices to be expressed as continuous surfaces, avoiding the spatial discontinuities typical of vector format data. Application of the model, followed by analysis of the data and subdivision of the values in accordance with consistent intervals ($\leq$10, 10–20, 20–30, 30–40, >40), has allowed the definition of five classes. Thus, for each landscape cell, it is always possible to deduce the original quality index value.

The LQp index for physico-naturalistic components appears greater in the vicinity of Mount Subasio, to the west of Assisi, where there is the simultaneous presence or proximity of protected areas characterized by high naturalistic-environmental value (geological sites, pSCIs, regional parks) (Fig. 5). At further distances from Subasio, the landscape quality tends to decrease due to the reduced presence of elements with naturalistic value. This reduction is less



	PN	HC	SS
A	8.62	48.63	56.74
B	3.36	19.83	28.67
C	5.35	13.52	5.92
D	18.13	7.18	18.67
E	48.60	2.19	25.49
F	22.23	2.40	1.93
G	10.91	3.38	1.20
H	0.82	4.78	1.22

Fig. 11. Signatures of LQp indices associated to zones and related mean values (PN: physical-naturalistic, HC: historical-cultural, SS: social-symbolic).

in the north-west of the area due to the presence of a pSCI area and green corridors representing important functional elements for the regional ecological network.

With regard to historical-cultural components, the LQp index assumes a different spatial configuration. The highest quality areas are located in and around Assisi, a medieval centre of great historical-cultural prestige (Fig. 6). Medium-low quality areas develop in a NW–SE direction around said centre with regard to the distribution and density of the landscape elements under consideration. At greater distances from Assisi, landscape quality decreases as a result of the lower density and value of historical and cultural elements.

The LQp index in relation to social-symbolic elements appears greater in and around the historical centre of Assisi and on the northern part of Mount Subasio, where there is a high concentration of symbolic elements, primarily, but also panoramic points and the locations of traditional events (Fig. 7). At greater distances from these areas, the index decreases almost linearly as a consequence of the reduced density of social-symbolic elements.

With the aim of constructing an overall potential landscape index, the three categories of landscape components have been aggregated by means of a subsequent WLC, where the three component groups were attributed the same relative weighting. The overall LQp index assumes a distribution that effectively interprets the potential landscape quality of the Assisi territory (Fig. 8). Higher LQp values may be observed in the historical area of Assisi as a result of the increased concentration of historical-cultural and socio-symbolic elements of high landscape value, considerably enhancing the landscape quality of this area. Medium LQp levels may be observed on Mount Subasio resulting from the great physical-naturalistic quality of this area. As may be observed in reality, at greater distances from Assisi and from Mount Subasio, potential landscape quality decreases as a result of the lower density and value of the landscape elements.

The spatial relationship between the three landscape component groups may be also analyzed visually by combining the three intermediate LQp indices in an RGB image (Fig. 9). The colour variations within the image make it possible to interpret how the three component groups interrelate and influence the landscape quality of the area. The intensity of the colour shows the overall LQp level, while the hue gives information on the dominance level of the various landscape components according to the attribution of RGB bands. First of all, two peaks of colour intensity, localized around Assisi and Mount Subasio, corresponding to the higher LQp values, may be observed. The former has a pink colour resulting from the dominance of red and blue due to said high concentration of historical-cultural and social-symbolic elements respectively. This pink area extends towards Santa Maria degli Angeli, with reduced landscape quality value intensity. A violet halo may be observed surrounding the pink area denoting the geographically wider influence of the socio-symbolic components around Assisi. The peak of intensity at Mount Subasio, on the northern side, is characterized by a cyan-green colour, due to the high LQp value in relation to both physical-naturalistic and socio-symbolic elements. The green hue turns more intense on the opposite side of the mountain due to the progressive dominance of physical-naturalistic components. Besides these two peaks of intensity, the image shows linear separation of colour in the NW–SE direction dividing the area in two main parts, a greener area on the NE side, with a dominance of physical-naturalistic components, and a redder area on the SW side, with a higher presence of historical-cultural components. The variations of colour intensity within these two areas are related to the presence and density of landscape elements of value.

With the aim of subdividing the area under investigation, a multivariate classification based on iso-cluster algorithms has also been performed on the three LQp spatial indices (Fig. 10). This iterative procedure has generated a land classification, based on potential landscape quality, effectively identifying the local landscape contexts of the Assisi territory. Each class is characterized by a specific signature, based on the mean values of the three indices, aiding interpretation of the final classification (Fig. 11). Eight zones may be distinguished with regard to the different levels of the LQp indices:

A. Core area of Assisi: high social-symbolic and high historical-cultural LQp;
B. Area around Assisi: medium social-symbolic and historical-cultural LQp;
C. Foothills: medium-low historical-cultural LQp;
D. Transition area: medium-low physical-naturalistic and social-symbolic LQp;
E. Summit of Mount Subasio: high physical-naturalistic LQp and medium social-symbolic LQp;
F. Area around Mount Subasio: medium-low physical-naturalistic LQp;
G. North-western hilly area: Low physical-naturalistic LQp area;
H. South-western plane area: Low historical-cultural LQp area.

Discussion and conclusions

Examination of the final and intermediate results relating to the physical-naturalistic, historical-cultural and social-symbolic components, confirmed the expert's knowledge on spatial configuration of potential landscape quality for the Assisi area. Even though a simplified application of the methodology was applied, the case study has successfully confirmed the consistency of GIS-based MCE methods for modelling landscape quality complexity. Spatial indicators optimally interpret not only the landscape value of individual elements and their contribution to the quality of surroundings, but also their density and variety. Mapping of landscape values provides reasonable measures of the level of attachment residents and visitors have for a location, while simultaneously providing a richer set of analytical tools for assessing the consequences of potential land-use change (Brown & Raymond, 2007).

The visual analysis performed on the three intermediate indices, based on the RGB composite image, improves understanding of the spatial gradients and interrelationships existing between physical-naturalistic, historical-cultural and social-symbolic components. The landscape zoning produced by the multivariate classification procedure optimally interprets the various combinations of quality elements that may be observed in the area under investigation. This information can effectively support land-use decision-making processes aimed at landscape conservation and enhancement.

The use of GIS introduces assumptions and methodological constraints that inevitably influence modelling outcomes; thus, it is important that the landscape interpretations drawn from such applications must be viewed with regard to spatial resolution and scale (Higgs & Langford, 2009). The GIS–MCA system constructed during the case study may be considered as a basis for a future project aimed at a more accurate landscape quality evaluation of the territory of Assisi. In the future it will be important to increase the level of integration of local and expert knowledge. For this purpose, the selection of landscape quality components can be supported by the DELPHI technique (Brown, 1968), a popular participative method that can be applied for the definition of evaluation criteria in MCE methods (Malczewski, 1999). A more extensive participatory GIS process oriented to more thorough involvement of local communities can improve the completeness of landscape data and the consistency of the whole evaluation (Cinderby & Forrester, 2005; Gonzalez, 2002; King, 2002; Vajjhala, 2006; Wang, Yu, Cinderby, & Forrester, 2008). By means of this process, local communities can contribute actively to the implementation and updating of GIS data and improving evaluation of integrity and relevance of landscape elements. Thus, in addition to supplying the experts with valuable information for improved landscape understanding, they are also made much more aware of the characteristics and values of their own landscapes.

The AHP has demonstrated good efficiency during the hierarchisation and landscape component weighting phases. Therefore, in the future, it may be of interest to verify the applicability of other more advanced methods used in the field of decision support such as, for example, the ELECTRE technique (Roy, 1968, 1996). Also, the GIS-based MCA procedure should be tested by means of a sensitivity analysis in order to determine the robustness of the model and to explore, also visually, how output changes with appropriate variations in the input criteria parameters (Crosetto, Tarantola, & Saltelli, 2000; Malczewski, 1999; Robert & Hall, 2004).

As indicated, potential landscape quality only represents the contribution of components of value. It will be fundamentally important to implement the subsequent methodological application aimed at the evaluation of actual and tendential landscape quality. The former may be quantified by analysing the interaction between the elements of value and critical landscape factors actually present producing pressures and resulting in deterioration in the qualitative characteristics of landscape environments. The latter may be assessed by analysing transformation trends and dynamics resulting from ongoing territorial plans and programs in addition to new landscaping projects. The three indicators may be interpreted jointly in order to quantify variability of landscape quality in space and time, and understand the spatial relationships existing between elements of quality, actual critical factors and transformation dynamics. Within the framework of landscape analysis and planning processes, this information will effectively support a more accurate quantification of landscape quality, allowing proper identification of not only valuable landscapes, but also degraded landscapes to be recovered.

Acknowledgements

The author wishes to thank all those who helped in the multi-criteria evaluation process developed for the case study area. Special thanks go to the experts who assisted with calculation of the quality indices for the landscape elements: Dr. Francesco Vale for physical-naturalistic components, Dr. Francesco Marcattili for historical-cultural components and Dr. Massimiliano Segoloni for social-symbolic aspects. The author would like also to thank anonymous reviewers for their constructive comments on an earlier version of this paper.

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