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Classification of Landscape Sensitivity in the Territory of Cremona: Finalization of Indicators and Thematic Maps in GIS Environment

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ABSTRACT

Centrality of landscape, in territorial planning, has been influencing for years, the testing of innovative analytical techniques aimed to gather peculiarities of urban and suburban context. The advent of Spatial Information System created the possibility to produce more detailed studies analyzing a lot of information dealing with territorial phenomena of crucial importance in spatial planning. The development of analytical systems based on multidimensional analysis may represent the right way to synthesize different phenomena that interact locally, in order to obtain the intrinsic sensitivity of a specific landscape as a result. In the case of Cremona Urban Variant, the production of thematic maps has allowed the construction of six synthetic indicators, dealing with specific aspects of Cremona landscape. The indicators are: i) insularisation of non-built spaces, ii) morphological/structural values, iii) perceptual landscape aspects, iv) permanence of urban system, v) degree of imperativeness of environmental constraints, vi) integrity of land use.

Keywords: Data Mining, Geostatistics and Spatial Simulation, Spatial Data Analysis, Spatial Data Mining, Spatial Statistical Models, Urban Modeling

DOI: 10.4018/ijaeis.2013070104
1. KNOWLEDGE ORGANIZATION TO CARRY OUT THE ANALYSIS WITHIN A GEOGRAPHICAL INFORMATION SYSTEM ENVIRONMENT

1.1. Methodology and Operating Basis

In recent times the concept of landscape has been considered not only in the simple natural/environmental way. Both international and Italian national and regional laws have identified, over time, a number of complex factors to be considered for the identification of landscape structural elements.

According to such ideas, preliminary steps to achieve a landscape sensitivity map for Cremona, have been focused on:

1. Understanding the peculiarity of settlement and environmental contexts, analyzing planning documents at local and regional scale;
2. Collecting and preparing the corresponding GIS map layers.

After the formalization of knowledge kept, a methodological/procedural scheme has been developed for highlighting the symbiosis between spatial information used to build thematic indicators, and the subsequent production of homogeneous areas for events thematic characterization and entity (Figure 1).

1.2. Building Survey Statistical Units

During the preliminary operations of thematic indicators assessment, it turned out to be crucial to build survey units (Fabbris, 1997) to which connecting the information collected, depending on the subsequent treatment with dedicated GIS software and, later on, with geostatistical applications in AddaWin environment. Con-

---

Figure 1. Methodological/procedural scheme
cerning different analyses, it was considered appropriate to operate at two different scales: in order to investigate exclusive events of suburban areas, continuous dimension survey units were considered, identifying, by processes resulting from landscape ecology, landscape units (UDP) generated by the conformation of natural and anthropic elements, setting barriers of different degree of intensity; vice versa, all other events in the study area were analyzed adopting a grid of cells of 25 m side, assigning to each of them the information derived from both complex analysis made in continuous geometries, and other analyses.

2. CALCULATION OF THEMATIC INDICATORS TO RECOGNIZE SPECIFIC CHARACTERISTICS OF CREMONA AREA

2.1. Insularization Degree of Un-Built Areas

The preliminary steps were based on the investigation of un-built areas features, analyzing which ones are most intact and have the most probability to remain unaltered by anthropic use and separating them from those compromised by human transformation (Debinski & Holt, 2000), for which specific recommendations need to be suggested, to prevent further degradation, by an index expressed as:

\[ Ins = f^I \left( A_{Udp} \right) \cdot \left[ 1 + f^{II} \left( P_{Udp} \cdot F_{Udp} \right) \right] \]

where:

- \( Ins \) = insularization index (significant measure of integrity of \( Udp \))
- \( A_{Udp} \) = extension factor of \( Udp \)
- \( P_{Udp} \) = permeability degree of \( Udp \)’s perimeter
- \( F_{Udp} \) = shape factor of \( Udp \) (\( Udp \): landscape unit)

The area factor is involved in the analysis of insularization index for its influence over the extension of UDP (Haila, 2002). In fact, it reaches maximum values at \( Udp > 350 \) ha and smaller values, where the surface is affected by insularization consequences. The permeability factor expresses the impact of anthropogenic pressures on the relationship between UDP and its context, producing an index of a trend to go through, outside to inside, the perimeter of UDP (Figure 2). Its area represents a significant element since UDP extension > 350 has reached the maximum value of the index, also considering that these cases have permeability values conditioned by the ratio of the area and perimeter of each field; beyond a distance of 150 m from the perimeter edge, it does not happen to suffer any negative effect (Duchateau, 2002).

The index of insularization (Figure 3) identifies the state of structural integrity of landscape systems, in which UDPs having a low or low–medium value, have to be considered integrated (or to be integrated) with anthropic areas because they lost their landscape identity (Ingegnoli, 2002).

Nevertheless, landscape units, characterized by high values of structural integrity, correspond to portions of territory that, over time, were not involved by disturbing factors, presenting good chances of developing relations between existing natural systems/structures. This suggests greater protection and preservation for these UDPs (Duelli, 1997).

Particular attention should be paid to UDPs having medium and low values of the indicator, because they reveal higher risk areas of degradation due to human contingencies. Here unstable situations can be found, requiring aggressive actions to prevent the progressive decline from the original integrity condition (Hoffman & Greef, 2003). Compared to the global scenario represented by the structural
Figure 2. Representation of area factor (1) and of permeability (2), for each landscape unit

Figure 3. Insularization index representation
integrity index, particular attention should be paid to landscape units in medium and low range that will be discussed below. While preserving natural characteristics, they are in some parts surrounded by urban areas and infrastructures of different impact, and are also interested in impacts produced by spread and spot settlements (McAlpine & Eyre, 2002).

2.2. Disposition of Morphological/Structural Values

Primary importance must be given, also, to the topic of morphological/structural landscape evaluation, in the awareness that any area of analysis is affected by multiple characteristics of this type, and it is their special integration that helps to determine landscape quality of the sites (Paolillo, 2005). Very important is, therefore, the research of distinguishing characteristics of an area, identified as follows for Cremona (Paolillo et al., 2001), at both regional and local scale levels (Malcevschi & Poli, 2008).

At regional scale we distinguished:

1. Morphological structures of particular importance in the configuration of landscape contexts (ridges, edges of terraces, river banks);
2. Areas or elements of environmental significance having relationships with other relational elements in the composition of systems of greater wideness (components of natural water, green corridors, protected areas, wooded areas and shrubs);
3. Key elements of historical settlement pattern (paths, channels, artifacts and art works, historical centers, important buildings such as villas, abbeys, castles, fortifications);
4. Evidence of formal and material culture of a historical/geographical area (e.g. “that” terrace morphology, or “that portion” of terrace morphology), with stylistic solutions or typical use of specific materials and techniques (building stone or wood, dry-wall, etc.), together with the treatment of public spaces (Cataldo, 2006).

At local scale (Bertinelli Spotti & Mantovani, 1996) we identified:

1. Signs of space morphology (gradients of altitude, slope morphology, minor elements of surface hydrography);
2. Natural/environmental significant elements (trees, natural monuments, springs or wetlands not connected to larger systems, green spaces with nodal role in the local frame of green areas);
3. Components of historical–agricultural landscape (rows, elements of the irrigation network and artifacts such as sluices, bridges, etc., paths tracks, historical centers and rural buildings);
4. Elements of historical/artistic interest (centers and historical centers, monuments, churches and chapels, historic walls);
5. Basic elements of relational importance at local level (urban parks, linear elements of green or water, “doors” of the center or town center, railway stations);
6. Proximity or belonging to a distinct place with high levels of linguistic, typological and iconographic consistency (Cosgrove, 1990).

All these factors were accounted to produce two synthetic analysis blocks, synthesized by pairwise comparison. In this way values given to each element were georeferenced, giving to each cell, characterized by the presence of a specific element, the value corresponding to the obtained weight. Once the sum of all values associated with the individual element in the cell was calculated, the morphological/structural value of the sites was determined considering five classes of intensity.

The function of normalized values, expressed by the coefficients (weighted factors) related to each element of investigation to measure the synthetic index, was calculated by means of both a matrix A, composed by pairwise comparisons related to 100 elements (with $\alpha_{ij} + \alpha_{ji} = 100$), and a matrix B where the single elements were obtained from the relationship
with their complementary to 100 ($\beta_{ij} = \alpha_{ij}/\alpha_{ji}$) (see Box 1). The function was calculated using many column vectors ($V_j$) equal in number to the n elements, corresponding to the sum of the values of the analyzed column, with:

$$V_j = \sum_{j=1}^{n} \beta_{ij}$$

and then normalizing elements of matrix B with the corresponding column vectors $V_j$, thus obtaining the normalized matrix C.

Coefficients of value function were obtained as standardized average values on the maximum value (Best Positioned One) of the elements sum of each row of matrix C, normalized as follows:

$$E_j = \frac{\sum C_{ij}}{n}$$

with:

$$\sum_{j=1}^{n} E_j$$

In summary, evaluating morphological characteristics sensitivity, physical/geological parts were examined with hydrographic elements, parks and gardens, vegetation cover, ecological networks, agricultural landscape, infrastructural and historical dimensions of mobility, attributing to each layer the value resulting by pairs comparisons, starting from the consideration that the more morphological/structural elements match and interact, the more a site is unique and sensitive (Figures 4 and 5). Therefore, for each cell, Σ of values assigned to the different included elements was determined, to take into account both the greater importance of some of them, and the added value of the co-presence of elements.

2.3. Investigation of Landscape Perceptual Aspects

The first step in landscape analysis was the creation of a DEM (Digital Elevation Model), able to account for the morphology of Cremona area; in this phase the presence of perceptual disturbance elements has been considered, too (Simmel, 2006; Socco, 2000).

The second step was a Viewshed analysis able to identify, after defining both observation and target points, which cell was visible or not visible.

In this analysis the following elements (Duhme & Pauleit, 1998; Loreau et al., 2003) have been considered: i) historical and scenic trails; ii) viewpoints; iii) architectural and religious sites of historical – landscape interest; iv) defensive artifacts and ruins of historical – landscape interest; v) buildings and rural artifacts of historical – landscape interest; vi) architectures and historical – industrial artifacts; vii) places, buildings and civil artifacts, residential and military of historical – landscape

Box 1.

Matrix A of the pairwise comparisons, where $a_{ij} + a_{ji} = 100$

$$A = \begin{bmatrix}
\alpha_{11} & \alpha_{12} & \alpha_{13} & \ldots & \alpha_{1n} \\
\alpha_{21} & \alpha_{22} & \alpha_{23} & \ldots & \alpha_{2n} \\
\alpha_{31} & \alpha_{32} & \alpha_{33} & \ldots & \alpha_{3n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
\alpha_{n1} & \alpha_{n2} & \alpha_{n3} & \ldots & \alpha_{nn}
\end{bmatrix}$$

Transposed Matrix B, where $\beta_{ij} = a_{ij}/a_{ji}$

$$B = \begin{bmatrix}
\alpha_{11}/\alpha_{11} & \alpha_{12}/\alpha_{12} & \alpha_{13}/\alpha_{13} & \ldots & \alpha_{1n}/\alpha_{1n} \\
\alpha_{21}/\alpha_{21} & \alpha_{22}/\alpha_{22} & \alpha_{23}/\alpha_{23} & \ldots & \alpha_{2n}/\alpha_{2n} \\
\alpha_{31}/\alpha_{31} & \alpha_{32}/\alpha_{32} & \alpha_{33}/\alpha_{33} & \ldots & \alpha_{3n}/\alpha_{3n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
\alpha_{n1}/\alpha_{n1} & \alpha_{n2}/\alpha_{n2} & \alpha_{n3}/\alpha_{n3} & \ldots & \alpha_{nn}/\alpha_{nn}
\end{bmatrix}$$
Figure 4. Coefficients of the function value chart resulting from pairwise comparisons

Figure 5. Representation of morphological/structural index of local landscape
interest; viii) elements of the natural landscape of scenic interest; ix) water surface items and connected artifacts of scenic interest (Figure 6).

The nine grids for each category, obtained by viewshed analysis, were subsequently combined into a single information layer, producing a cumulated value with:

\[ V_v = \sum_{i=1}^{n} \left( A_{(a_1, a_2)} + B_{(b_1, b_2, b_3, b_4, b_5)} \right) \]

### 2.4. Permanence Differentials of Urban Settlement

Another fundamental indicator is the degree of transformation or, reciprocally, landscape integrity between natural and anthropogenic historical forms. In this way, we examined the historical evolution since 1793 grouping buildings by age, identifying hold settlements and their corresponding expansions (Figure 7).

This classification allowed to calculate the degree of permanence of urban areas over the years (Brenna et al., 2004). Considering the occurrence at eight historical thresholds, total frequency per cell has been calculated defining the degree of permanence in five classes, excluding value 0, corresponding to absence of urbanization. This analysis shows that 66% of municipalities are not urbanized and that a considerable part of built areas has a medium/high degree of permanence indicating a good compactness of historical settlements. Several critical situations must be considered: Tamoil refinery area and new isolated villages.

*Figure 6. Representation of landscape intensity value*
2.5. Restrictions Due to Constraints System

Constraints system undoubtedly has a great relevance. In order to highlight this aspect, a constraints map was built considering the collection of invariants identified at different spatial scales (Figure 8). Three main categories can be considered:

1. Areas with restrictions due to proximity to railway and road network, cemetery, power lines, etc.;
2. Areas with constraints due to the presence of historical – artistic and landscape – environmental elements, and the proximity to the water system;
3. Areas with restrictions defined in planning documents: Po and Morbasco Parks, Spinadesco – Cremona Special Protection Zone (ZPS), oasis of forest protection.

Risk factors due to human activities or natural events have also been considered in this experience. Disaggregated groups of constraints have been synthesized in a Total Synthetic Index of constraints obtained considering the different peculiarities expressed by remaining planning prescriptions, with $E_n = [(+A_{IVA} + A_{Ibc} + A_{ili}) / A_{iota}] / A_{imax}$.

The final synthesis of constraints at municipality scale has been achieved considering cumulative effects, within each cell of a 25 m grid.

Figure 7. Representation of historical permanence of urban settlement
2.6. Geography of Land Use Integrity

The production of land use (Bartel, 2000) multitemporal archive found the analytical basis with Dusaf database, updated to 2009 and compared to the seven other time thresholds 1994, 1981, 1967, 1925, 1890, 1805, 1723. Data sources that needed to be examined were selected from those available, primarily based on three criteria:

1. We preferred the one with the most detailed scale;
2. We wanted to create a temporal scan being able to represent speed of changes succession, identifying thresholds, little by little getting closer until they reached the current one;
3. Historic thresholds with sufficiently detailed available material to face a deep analysis were preferred (Paolillo, 2009).

A grid of 25 m steps was overlaid to the different types of land use destination, assigning identifiers of each cell uses, calculating the area under each use (and choosing not to identify the prevalent use of the unit, but to consider the possible coexistence of different land uses for each of the six historical thresholds considered), deriving a data matrix of 64 variables: variance was recognized (degree of mutation of each cell compared to land use variation during the time range considered), by means of AddaWin software analysis, thus resulting in the municipality space shown in Figure 9 (Paolillo et al., 2009).

Large portion of territory is characterized by high and medium/high land use integrity.
classes, confirming the maintenance of traditional agricultural use (Figure 9). It should be underlined, how a good quantity of cells, with medium and medium/low integrity, came out from progressive substitutions in agricultural assets; meanwhile we detected low – and medium – low degree of integrity in south/west portions of the area and along main routes against the main alteration given by the strategic role of these areas.

3. MULTIDIMENSIONAL ANALYSIS, THE FINAL SUMMARY OF INVESTIGATED VECTORS TO IDENTIFY LANDSCAPE SENSITIVITY AREAS

Landscape sensitivity classes were built with the intensity of landscape values (Paolillo et al., 2012), estimated and synthesized through a multivariate geostatistical method, the use of which has permitted to interpret events that determine the complex municipality landscape structure (Borachia & Paolillo, 1993), through observation of a set of k variables on n statistical units (cells).

In this case exploration of matrices produced was made by the classification of data into ordinal categorical variables, none (N), low (B), medium (M), high (A) and matrices treated in AddaWin (Griguolo, 2008) environment were related to the outcome of the investigation for:

1. Insularization degree of unbuilt spaces (INS);
2. Morphological /structural values (IMS);
3. Landscape perception aspects (landscape survey) (VIS);
4. Degree of permanence of urban settlement (PER);
5. Constraints degree of application (COG);
6. Integrity factors of land use (IUS).
After identifying a group of twenty variables, we proceeded to Principal Component Analysis; for each one, absolute magnitude of eigen values was provided (Eigen Value, inertia explained for each component), and the proportion (i.e. the portion of variance explained by each component relative to the total), accumulated from previous reports (sum of eigen values), to assess from how many main component results, a specific portion of variance was explained.

In usual applications, rarely all n principal components are considered (CP) and, therefore, you must select the number of components to be considered in the analysis according to criteria of optimality, consisting of:

1. Parsimony (minimum possible number of principal components);
2. Minimum loss of information; iii) minimum deformation of representation quality.

Aiming to what written above, we need to set a percentage of total variance explained (which satisfies the three criteria mentioned above) and, under the assumed type of matrix (cells of 25 m side), it was not necessary to assume greater cumulative inertia, higher than the range of 65 to 70%, since the first 7 principal components explain about 69% of the model. Such a percentage (for this analysis) was more than sufficient for the subsequent identification of iso–events characterization clusters.

In order to obtain basins of propensity to urban transformation and/or environmental conservation, we considered important to use a non–hierarchical cluster analysis, to be performed on the results of main components analysis, carried out earlier. The application tests the variables chosen, deriving a target, able to synthetically describe the whole area considered, and shows how the value of the target function decreases following the classes number, lowering through mergers and optimizations.

Consequently, after non–hierarchical classification, portions of the territory (cells 25 m) have been grouped in “equal areas” with similar behaviour. In this way, a further reduction of complexity has taken place in order to generate the following situation:

1. Number of classes identified = 14;
2. Degree of inertia explained = 76% (target curve, in fact, tends to the maximum value of inertia for classes from 88 to 15, where it expresses a more linear trend) (Figure 10).

Knowing the number of classes to describe, which was 14, we obtained a process which indicates, for each identified class, which of the 20 active variables (above choices) more characterizes it. The subsequent description of the 14 stable classes identified, through the interpretation of reports provided by geostatistical AddaWin package, is made of a matrix with classes on the ordinate and variables in abscissa: for each junction, through (+) and (–) symbols the software achieves the degree of single variable characterization for each class.

The summary table of each class is derived by this analysis. Interpreting the table, classes with low and very low characterization came out. The first step of cartography elaboration started relatively to the 14 cluster iso–events, performing operations of table joining in GIS environment, between mother matrix of 25 m step and text file produced by AddaWin, as a result of non hierarchical analyses, properly treated and made compatible with the format required by GIS software.

The resulting matrix was then spatialized on an aerial photo, afterwards formulating a quality and similarity judgment of the “equal – areas” obtained, and so arising an appropriate classification by the adjustment of data outputs, their dismemberments and the resulting combinations of classes (Paolillo et al., 2011). In this way, from 14 original, 10 synthetic classes of multidimensional landscape value characterization were aggregated, whose further synthesis made us able to derive five landscape sensitivity classes:
Figure 10. Target function, with the intersection point identification (XIV class)
Figure 11. Representation of the iso-events landscape cluster recombined in 10 classes

Figure 12. Representation of the degree of landscape sensitivity
1. Very high (areas that have boundary conditions simultaneously at a high protection for landscape safeguard and mitigation);
2. High (areas that have more than one boundary condition, not to be exceeded, with high landscape protection and maintenance of existing original features);
3. Medium (areas with landscape protection conditions, with a limit determined by landscape relevance);
4. Low (areas that have landscape “edge conditions”, with protections related to residual values of permanence and importance of landscape agricultural matrix);
5. Very low (areas that have only “edge conditions”, with no landscape qualification) (see Figures 11 and 12).

REFERENCES


Pier Luigi Paolillo is a professor of Urban Planning, president of the graduate program in urban planning and director of the graduate program in Geographic information systems and integrated governance of the territory in the Politecnico di Milano, is the author of multiple instruments at different scales including: the general version of the inter-communal Plan of the Savona area; the strategic guides for agro-forestry areas of the territorial plan of the autonomous region Friuli-Venezia Giulia; the framework of the Spatial Plan of the Marche region, the prototype of the ecological environmental program of Lombardy Region; the project for the productive activities of the Consortium “AreaAltoMilanese”, the environmental report of the Vas for the Territorial Plan of the Lombardy Park “Valle del Lambro”. Curator for Enea of the chapter “Soil” in the fourth edition of the Report to Parliament on the state of the environment, has been a member of the Scientific Committee of ARPA Lombardia for the Report on the state of the Lombardy environment. Recently involved with: the Environmental Report of Vas for the Territorial Plan of the city of Sondrio; the general variant of Territorial Plan of the Lombardy Park “Groane”; the Territorial Plan of city of Como; he also directed from 1993 to 1996 the bimonthly INU Planning information and, from 1988 to 1994, he was editor in chief of Territorio (quarterly of the Department of the territory of the Politecnico di Milano).

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