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Analysis of Correlation between Anthropization Phenomena and Landscape Values of the Territory: A GIS Framework Based on Spatial Statistics

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Abstract: The evaluation of anthropogenic impacts on the landscape is an issue that has traditionally been carried out from a descriptive or at least somewhat qualitative perspective. However, in recent years, the technological improvements provided by geographic information systems (GIS) and spatial statistics have led to more objective methodological frameworks for analysis based on quantitative approaches. This study proposes an innovative methodological framework for the evaluation of landscape impacts of the usual anthropization phenomena, using a retrospective spatiotemporal analysis based on geostatistical indicators. Various territorial indices have been used to assess the spatiotemporal evolution of fragmentation of the built-up urban fabric, the construction of roads or linear communication works and the changes in land use. These phenomena have been statistically correlated with objective indicators of the landscape's intrinsic value. The analysis of said spatial statistical correlation has been applied to three different but neighboring environments in the region of Murcia, located in the southeast of Mediterranean Spain, providing interesting results on the objective impact of each of these phenomena on the landscape and depending on the boundary conditions.

Keywords: anthropization impacts; landscape alteration; spatiotemporal analysis; geostatistics; GIS retrospective indicators

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1. Introduction

The valuation of landscapes is an increasingly studied issue due to its growing importance in very diverse fields of knowledge, such as urban planning [1,2], real estate market analysis [3], environmental management [4] or the implementation of communication infrastructure [5]. Additionally, in recent years, the analysis of anthropogenic impacts on the landscape has become a determinant parameter for decision making in the evaluation of alternatives of very thriving sectors, such as renewable energy [6] or P2P tourism [7,8]. However, this discipline still often suffers from the absence of rigorous methodological frameworks to assess said impacts in an objective way, both quantitatively and objectively.

Important advances have been made from a scientific point of view in areas such as visual impacts on landscapes [9] from the installation of wind turbines or the quality of landscapes from the point of view of territorial planning in some regions [10]. However, these advances have been focused from a numerical point of view on the implementation of specialized software for the visual analysis of isolated perceived impacts [11,12] or on the territorial analysis of the transformation of land from a somewhat qualitative point of view. Important innovations have also been made in terms of landscape impact analysis using sociological approaches by conducting surveys subsequently treated with statistical evaluation [13]. The use of spatial indicators, such as the evaluation of the compactness of the urban fabric, has also been consolidated as a common methodological framework for evaluating the impact of the landscape on the territory [14]. We can find interesting contributions on the matter within the framework of landscape pattern indices for evaluating urban

spatial morphology in cities of China [15,16], the U.S. [17] or Europe [18]. There are also approaches that are more oriented towards an environmental perspective which mainly focus on issues such as ecosystem values [19], ecosystem services [20], natural hazards [21] or ecological risks [22]. In this sense, spatial analysis through GIS land transformation indicators derived from anthropogenic phenomena can contribute a higher level of scientific scholarship to this field of knowledge [23], incorporating a quantitative vision and, thus, be more objective, focusing on the evaluation of the landscape on anthropic impacts.

The analysis of increasingly complex anthropic phenomena, such as the fragmentation of the territory, the construction of linear communication infrastructures or changes in land use from a statistical perspective using GIS tools, represents an important advancement towards the creation of more rigorous and sophisticated methodological frameworks for assessing impacts on the landscape. Some recent studies have begun to address this problem from the perspective of GIS participatory landscape planning [24,25] or combined with multi-criteria decision analysis (MCDA) [26].

However, it is still necessary to implement holistic methodologies that contribute solutions to the current problems associated with the anthropic processes of territorial transformation from a comprehensive and multidisciplinary vision [27]. Traditional methods, even when based on spatial analysis, generally fail to establish numerical correlations between the transformation of the territory and the level of impact on the landscape [23,28]. In addition, it is still not easy to discretize which parameters govern these transformation processes, since they are generally anthropic processes made up of multiple different variables. These processes develop over time in a diffuse manner, rendering the analysis of their impacts more complex for numerical evaluation. In this sense, GIS analysis based on space–time indicators of a retrospective nature and supported by spatial statistical analysis methodologies can represent an important advance from a methodological point of view.

In that context, the following study is proposed, where an analysis of the existing geostatistical correlation between the processes of land transformation of the territory in a region of the Mediterranean southeast of Spain and the current assessment of the resulting landscape is implemented through data from official sources of regional administrative authorities. The way in which anthropic phenomena, such as the jeopardies of urban sprawl, the fragmentation caused by the construction of linear infrastructure and the identity alterations caused by land use change impacts on the valuation of the landscape from the point of view of spatial analysis, will be evaluated through the implementation of a methodological framework based on GIS indicators.

Different scenarios with different boundary conditions will be addressed for the analysis of landscape impacts of anthropic effects derived from land transformations. Three different study areas will be comparatively evaluated; broadly speaking, they provide a clear example of the most common causes behind landscape deterioration as a consequence of anthropic actions to transform the territory. These case studies will correspond, in the first place, to the periurban environment of a regional capital city whose urban growth transforms transition areas that were formerly dedicated to agriculture. Second, the phenomenon of the replacement of traditional agricultural land in the countryside with golf resort-type residential developments or irrigated intensive agricultural uses will be addressed. Finally, there will be a focus on the issue of mass sun-and-beach tourism that traditionally takes place in Spanish Mediterranean coastal areas.

We will explain the study areas and the methodological framework of analysis in the following section. Subsequently, the results for said study areas applying this methodological framework will be presented based on the indicators developed and the proposed spatial statistical analysis. These results will be scientifically discussed in the fourth section from a comparative perspective of scenarios and variables. Finally, the conclusions will be presented in the final section.

2. Study Areas

To carry out the research, a comparative analysis of three study areas that are geographically close together, but which present very different boundary conditions in their territorial configurations, is proposed. Three samples of relatively similar sizes located in the region of Murcia (southeastern Spanish Mediterranean region) were chosen. The samples for the analysis were the metropolitan area of the city of Murcia, called the Huerta de Murcia, the coastal perimeter of the Mar Menor lagoon and the agricultural area called the Campo de Cartagena (Figure 1).

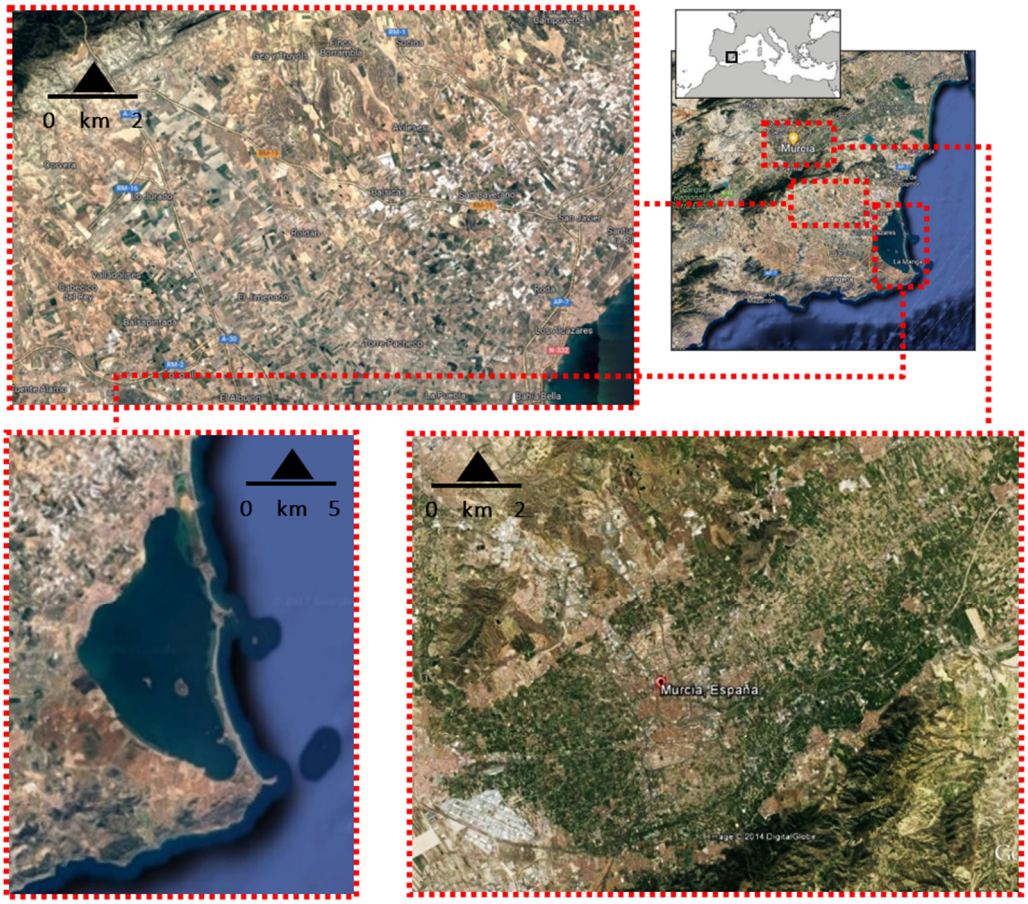


Figure 1. Metropolitan area of the Huerta de Murcia (**bottom right**), Mar Menor lagoon coastal perimeter (**bottom left**) and Campo de Cartagena agricultural area (**upper left**) in the Region of Murcia in Mediterranean southeastern Spain.

2.1. Metropolitan Area of Murcia (Orchard of the Segura River)

The metropolitan area of the city of Murcia (capital of the region) is located in the area known as the Orchard of the Segura River. It covers an area of over 1000 km^2 and has around 600,000 inhabitants. However, the population is distributed in a heterogeneous way. On the one hand, 40% of said population is concentrated in the 25 km^2 of the urban fabric of the city of Murcia. On the other hand, the remaining 60% of the population is scattered in small satellite towns, gated communities and semi-rural dwellings linked to agriculture in an area called the Huerta de Murcia, with an area of 975 km^2.

This territory was formerly known as the "Orchard of Europe" due to its historically high capacity for agricultural production. The development of this agricultural space dates back to the time of the Moorish occupation of the Iberian Peninsula, whose influence over eight centuries has left its footprint on the current configuration of the territory. As a result, this area has important cultural values that are transmitted through the landscape, such as the existence of an extensive traditional irrigation hydraulic network that config-

ures the parcel structure of land through a complex hierarchical system of canals called ditches (Figure 2).

Figure 2. The Huerta de Murcia landscape: size of the area linked to the city of Murcia (**upper left**), example of its landscape values (**upper right**), schematic map of the ditch network that covers the entire territory of the orchard (**bottom right**) and traditional hydraulic infrastructure of the area (**bottom left**).

This area has seen its landscape configuration strongly altered in recent decades because of various anthropic processes associated with the strong urban growth that the entire area of the city of Murcia (the seventh most populous urban area in Spain) has experienced. The progressive urbanization of many periurban areas of this environment through the construction of small roads or urban paths to improve connectivity, changes in land use and the illegal construction of numerous houses scattered throughout the entire territory of the orchard (more than 10,000 houses in recent decades, theoretically for purposes linked to agricultural activities and finally destined for residential use) have transformed traditional agricultural areas into mixed environments more typical of a "garden city"-type landscape, in many places with a rather chaotic configuration (Figure 3).

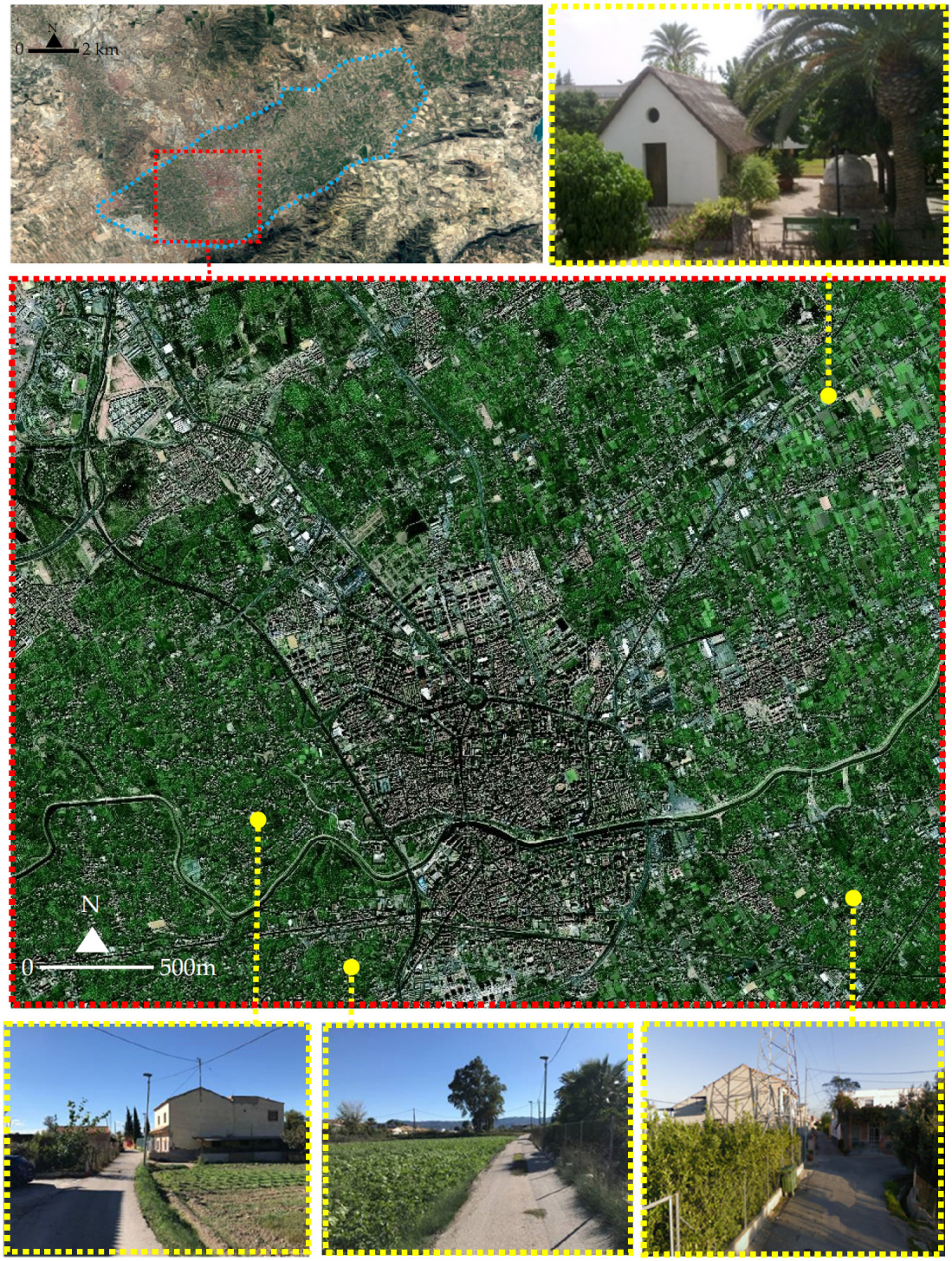


Figure 3. Metropolitan area of the 'Orchard of Murcia' (**upper left**), traditional construction typical of the Orchard of Murcia associated with agricultural activities (**upper right**), main urban area of the city (**middle**) and periurban anthropized areas with mixed uses (**bottom**). Source: Sentinel 2 satellite and own photos from authors.

2.2. Campo de Cartagena Area

The second study area corresponds to a group of municipalities that constitute what is called the Campo de Cartagena subregion. These are small populations which had traditional rainfed agriculture with a population of barely 30,000 inhabitants in more than 20,000 hectares. After the construction of the large hydraulic infrastructure for the transfer

between the Tagus and Segura rivers in the 1970s, this area progressively transformed its traditional dryland activity with trees and woody crops to intensive irrigated agriculture. In this way, the traditional landscapes of fruit trees were replaced by vegetable fields and greenhouses. At a business level, these now constitute the current real "Orchard of Europe" and are known from a visual point of view in several areas as the "sea of plastic" (Figure 4).

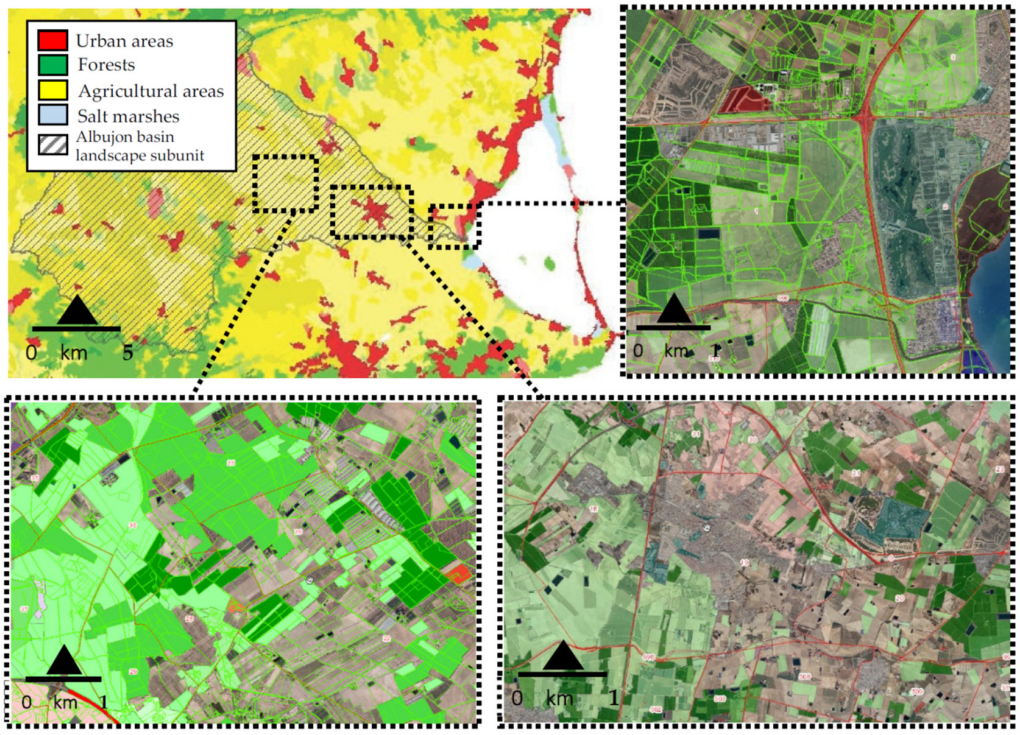


Figure 4. Characteristics of the study area of the Campo de Cartagena: global land uses according to SIOSE [29] (urban areas in red, agricultural areas in yellow and natural spaces in blue and green). In the rest of the figures, it can be seen how, within the same landscape subunit, there is a varied mix of uses that combine the anthropic phenomena of urbanization with anthropic phenomena of land transformation by agricultural activities (mainly plots transformed for irrigation by means of greenhouses, in green).

Subsequently, thanks to the growth of tourism in the area and the real estate boom that took place in Spain as a whole from the mid-1990s, several of such agricultural areas were also transformed into golf resort-type residential developments primarily for foreign tourists. The development of these residential projects has contributed to the construction of numerous roads in the area that break up the territory, configuring a heterogeneous landscape that combines agricultural crops with urbanization, golf courses, low population density and high surface occupancy (Figure 5).

Figure 5. Original and current landscapes in the Campo de Cartagena area (from left to right: original cultivation of dryland fruit trees, intensively irrigated fruit and vegetable crops, a sea of plastic made up of greenhouses and golf resort-type residential developments).

2.3. Mar Menor Lagoon Coastal Perimeter

The third case study is the coastal perimeter of the Mar Menor, a coastal lagoon with a surface area of 135 km^2 and an average depth of four meters. This hypersaline lagoon is separated from the Mediterranean Sea by an ancient 20 km long dune sand cord that, in its northern area, houses salt marshes and a protected natural park. Even so, the 50 km coastal perimeter of this body of water presents important contrasts in its landscape. On the one hand, we find valuable natural spaces both in its wetlands, which are home to numerous protected species, and in its marine environment, which has flora and fauna of high ecological value. It is also easy to find areas of high cultural value, such as the traditional salt flats or the old windmills. On the other hand, the important tourist attraction of the seaside area has generated a significant anthropic impact associated with mass tourism.

In the eastern part of the lagoon, the old dune cord that separates the two seas has been massively urbanized in recent decades and is currently a hypertrophied urban area with buildings for sun and beach tourism. Even so, we can still find small spaces in which the original dune ecosystems of the beach persist. On the interior coast of the lagoon, various heavily urbanized areas and several marinas, whose impact on sedimentary dynamics causes alterations in the beaches, intermingle with spaces of high ecological value, such as undeveloped salt marshes and crypto-wetlands along the coastal perimeter (Figure 6).

Figure 6. Various examples of landscape heterogeneity on the coastal perimeter of the Mar Menor (areas in a natural state or of high ecological value in blue compared to highly anthropized elements in red).

3. Methodological Framework Proposed

A methodological framework based on GIS analysis through territorial indicators and the use of geostatistical evaluation tools is proposed for the investigation of the landscape impacts of this varied catalog of anthropic effects. This methodological framework, the anthropization and landscape GIS indicators and the spatial geostatistical evaluation process are detailed below.

3.1. Analysis Framework

The methodological framework is configured into two blocks (integrated diagnosis and GIS evaluation) with four stages (prospective diagnosis, configuration of indicators, application of indicators and geostatistical evaluation) and two differentiated parallel paths for landscape analysis and analysis of anthropization phenomena. In the first stage, an approach to the case study is carried out, analyzing the usual phenomena described in the scientific literature and extracting feedback from the main stakeholders. In the second stage, the GIS indicators and the landscape analysis subunits of the study cases are designed for the spatial evaluation of diffuse territorial anthropization phenomena. In the third stage, said indicators are applied both to the landscape analysis as well as to the analysis of the anthropization phenomena in the different case studies to evaluate their behavioral patterns from a spatiotemporal point of view. Finally, in the fourth stage, the geostatistical analysis of the distributions of the indicators is carried out to assess the level of spatial statistical correlation existing between landscape values and the evolution of diffuse anthropization phenomena. This methodological framework has been summarized schematically in Figure 7. An analysis of these large-scale spatial correlation patterns will be further verified using contrast assessment at the local level with GIS high-resolution detailed mapping (see Appendix A).

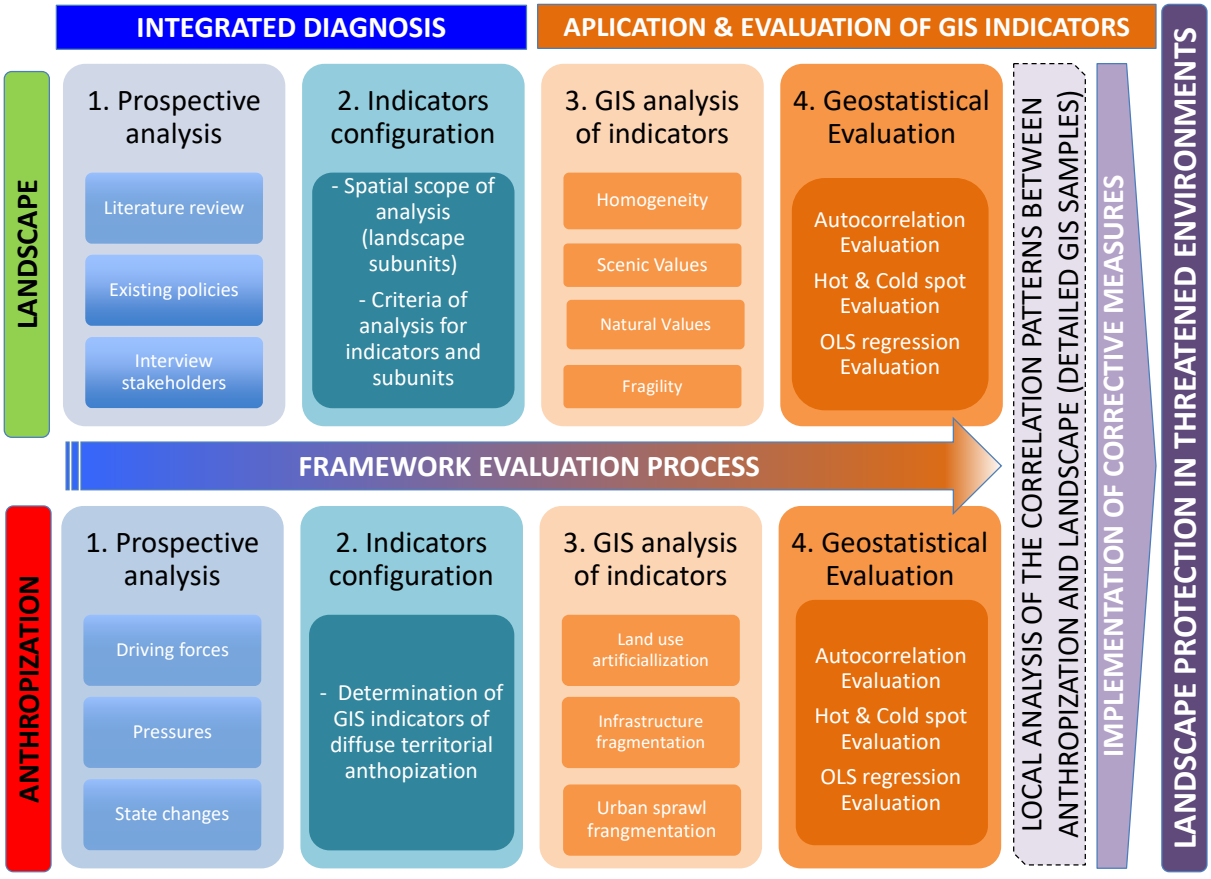


Figure 7. Schematic summary of the stages in the proposed methodological framework.

3.2. Prospective Analyses

In the first stage, a combination of technical data extracted from a review of the scientific and regulatory literature and feedback from various semi-structured interviews with local stakeholders will be used to determine the landscape values and the areas of analysis of a territory. These interviews must gather a representative sample of the different existing sensitivities and will therefore include 25% social and cultural, 25% technical and officials, 25% scientific and 25% business or political groups. The answers will be scored

on a scale of values from one to ten for the determination of quantitative elements as impact factors on the landscape and evaluated using a Likert scale for the establishment of qualitative hypotheses to formulate the delimitation criteria of the landscape subunits and their valuation.

These interviews will enable us not only to know the main landscape values and key criteria for the selection of landscape analysis but also to evaluate the possible impacts that are taking place to lay the foundations for the analysis of diffuse territorial anthropization phenomena. On the other hand, to determine these main diffuse territorial anthropization phenomena in the study cases, a prospective analysis will be carried out using a DPS (driving force, pressure, state) model combined with the hypotheses from the interviews. The results obtained in this first stage can be seen in the first section of the Results section and provide the justification for the adoption of the GIS indicators described in the following section.

3.3. Elaboration of GIS Indicators

3.3.1. Landscape Subunits

In the second stage, the indicators and analysis parameters to be applied were designed. In the field of landscape analysis, different analysis subunits were determined within the territory covered by the three case studies (GIS file included as supplementary material). Given that the territory is a continuous space, the entire surface analyzed was compartmentalized into a finite number of units that enable the subsequent analysis of the correlation between landscape values and the evolution of territorial anthropization phenomena. These units are spatial items that meet minimum uniformity and unitary coherence criteria in terms of multidisciplinary GIS analysis. The delimitation of these units was carried out based on a multivariate analysis taking the following territorial boundary conditions into account (Table 1).

Table 1. General and specific criteria applied for landscape subunit delimitation.

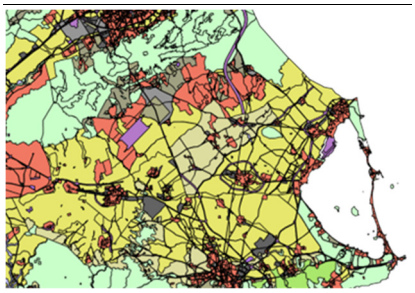
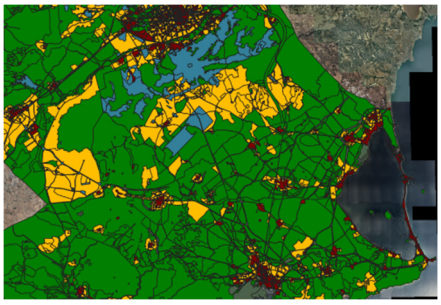
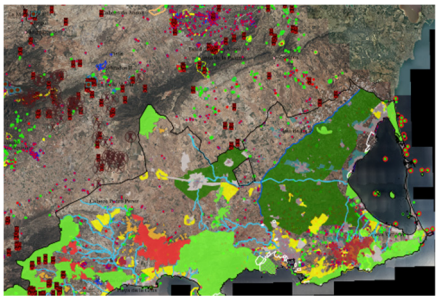
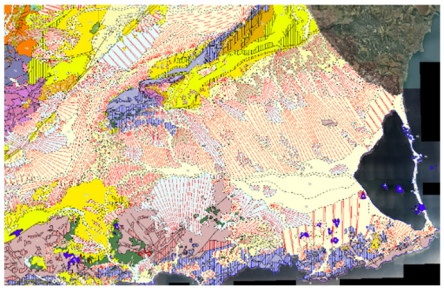
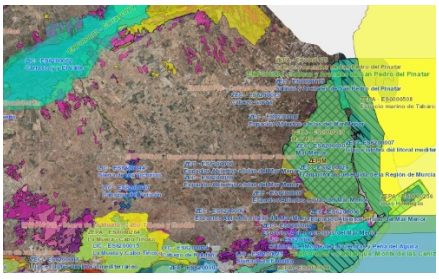
Criteria	General Parameters	Source	GIS Analysis Example
Land Use	Data from the Land Use Information System of Spain (SIOSE) integrated within the National Plan for Earth Observation (PNOT) according to European Directive INSPIRE. These data have been supplemented with local geolocated cartography from air flights.	[30]	
Current Land Cover	Current land cover according to the European Corine Land Cover (CLC) system. It consists of an inventory of land cover in 44 classes. CLC uses a minimum mapping unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. These data have been completed with local cartography from air flights.	[29]	

Table 1. *Cont.*

Criteria	General Parameters	Source	GIS Analysis Example
Land planning	The urban planning foreseen in the municipalities must be considered. Land that is already urban has been differentiated from land that cannot be developed or that can be developed as established by masterplans or regional planning tools.	[31]	
Sociology	Sociological issues, such as cultural elements, protected spaces for non-environmental issues (heritage, identity, etc.) or conformation of the territory for social issues, must be considered. This layer therefore brings together various sociological aspects of a heterogeneous nature.	[32–34]	
Geology	The geology of the land must be considered to assess those landscapes without vegetation cover or without transformation of the territory through urbanization processes. To do so, data from the Spanish National Geological Institute have been used.	[35]	
Environmental values	Another important issue is the natural values of the territory, both from an environmental point of view and from an ecosystem point of view. For this, the information of spaces with environmental protection or ecological values has been consulted.	[36–39]	

3.3.2. Spatial Landscape Values Database

In order to analyze the landscape values of the different landscape subunits generated, four parameters were established for evaluating the landscape value of each spatial delimitation. The evaluation parameters are as follows:

Landscape coherence and homogeneity: The degree of landscape homogeneity and coherence will be assessed using the Shannon diversity index. This index, based on the principle of entropy and more common in the field of ecology of species [40–43], was adapted for its application in the territorial analysis. Our adaptation to landscape analysis of the Shannon diversity index (SDI) provides information about area composition through the number of land cover types present in the Corine Land Cover [29]. It considers both the number of different land cover types (m) observed as well as their relative abundances (P_i). The results were formatted in a dimensionless way in an index that we have called the Shannon evenness index (SEI) to enable comparison of the three case studies. This new Shannon evenness index is obtained by dividing the Shannon diversity index by its

maximum (SDI_{MAX})) = ln(m). Therefore, it varies between 0 and 1, and its results are easier to interpret from a comparative point of view:

$$SEI = -\sum_i^m (P_i \times \ln(P_i))/\ln(m) \quad (1)$$

Scenic values: The density of the valuable scenic values of each unit will be evaluated through a self-elaborated landscape visual quality index (LVQI). This index will consider the level of density of specific elements cataloged by municipal, regional or national regulations as protected by cultural or historical plans, etc., (not including environmental protections) or with an officially established value of landscape interest of spatial characteristics (for example, land declared in urban planning as being undevelopable due to landscape justification). The weighting of each of the n specific elements will also be corrected with a parameter α that considers both the relevance of the element itself (differentiating relevant, very relevant or exceptional elements) and another β to address its affiliation surface (to differentiate elements insulated against large surface elements). To make this visual quality density parameter dimensionless, each sum of values will be divided by the surface area S of the analyzed landscape unit:

$$LVQI = \sum_i^n \alpha_i \beta_i P_i / S_i \quad (2)$$

Natural values: Natural values will be evaluated through an index of presence of natural values PNVI, which will analyze the existence of European, national or regional environmental protection figures in the different landscape subunits. Protection figures, such as the European Natura 2000 Network, the RAMSAR agreement, Spanish Law 42/2007 on natural heritage and biodiversity, the Protocol on Specially Protected Areas and Biological Diversity in the Mediterranean, regional regulations on natural parks and natural protected landscapes, etc., will be considered. These values will be evaluated in the different subunits designed in a specific or spatial manner. The characterization of the valuation of each analyzed landscape subunit will be made in the proportion γ of the surface area that corresponds to the protected space Z in its delimitation and considering its relevance δ from a regulatory point of view. In addition, the quantification of the valuation of the n protection figures will be carried out in a summative manner, so that the assignment of multiple environmental protection figures in the same area of land will entail a greater natural value of a protected space. To make this visual quality density parameter dimensionless, each unit will be divided by the surface area S of the analyzed landscape unit:

$$PNVI = \sum_i^n \gamma_i \delta_i Z_i / S_i \quad (3)$$

Landscape fragility: The concept of landscape fragility is an issue that does not have just one meaning in the scientific literature [44,45]. A common approach is the so-called visual fragility, which is usually defined as "the susceptibility of a landscape to change when a use is developed on it", that is, the expression of the degree of deterioration that the landscape would experience due to the incidence of certain actions. This is an approach with considerable complexity when modeling because it has significant subjective conditioning, as it is affected by variables such as the size or characteristics of the so-called "visual basins" of analysis with which it is measured. In this case, to parameterize this very abstract concept in a simplified way, the distribution of landscape fragility will be assessed based on the observation of the spatial potential risk of deterioration that a landscape unit may suffer. This will be completed through the evaluation of the coexistence of a set of valuable elements with its closer anthropized elements (for example, the presence of urbanized areas close to subunits of high ecological value). This analysis will be carried out through the dataset of the Landscape Atlas of the Region of Murcia [46]. This geoportal has a geolocated database of numerous locations with different landscapes established by the regional public administration as relevant or valuable landscapes, to which different quality values have been assigned (Figure 8). This source of information is of particular interest

as it consists of an extensive official database with a photographic catalog containing over 1000 photographs of different landscapes and points of interest from the last 60 years. A kernel density analysis geoprocess has been applied to this dataset, which results in the generation of a tessellated distribution of proximity valuation. Depending on the relative surface presence of said distribution in each of the landscape subunits, a value has been established for each of them. The geoprocess calculation formula for the analysis of the neighborhood distribution of the data is as follows:

$$LF = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \quad (4)$$

where K is the kernel function, h is the smoothing bandwidth parameter and $(x_1, x_2, \ldots, x_n)$ the independent distributed samples from the Landscape Atlas spatial data infrastructure of the Region of Murcia with fragility function LF at any given point x.

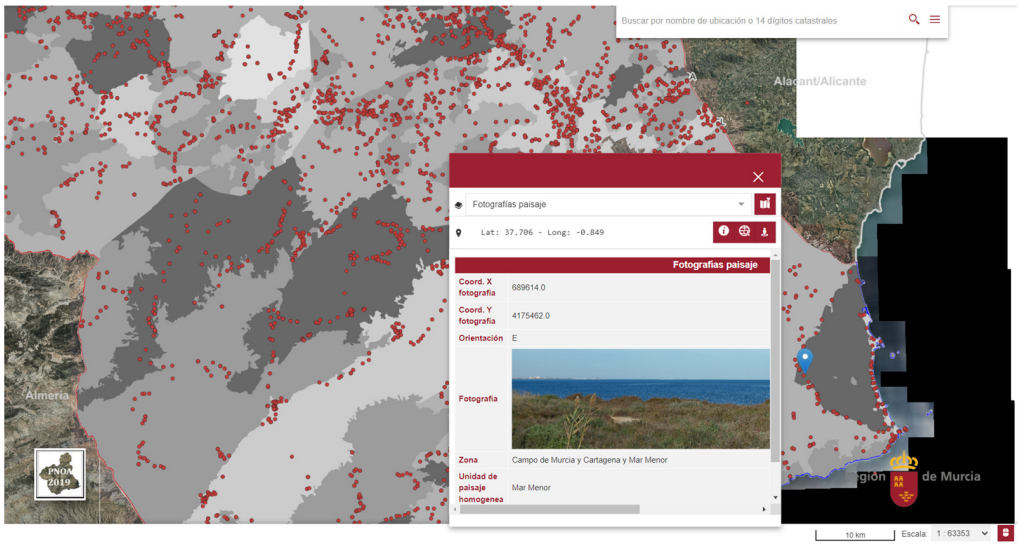


Figure 8. Sample of the geolocated dataset (red spots) of the Landscape Atlas SDI from the region of Murcia [46].

In this way, the level of fragility of the landscape has been evaluated by measuring the proximity (through buffering) of each of these dataset points to anthropized areas according to the Corine Land Cover criteria (assuming anthropized areas as land uses category 1, see Appendix B for detailed explanation)). The closer to anthropized elements, the higher the level of fragility.

The spatiotemporal analysis parameters will be assigned a category of relevance in the results section to homogenize the comparative assessment of all these values in the landscape in accordance with the criteria in Table 2.

Table 2. Criteria for the level of significance of the landscape indicators.

	Homogeneity	Scenic Values	Natural Values	Fragility
Very high	SEI > 0.8	LVQI > 2	PNVI > 3	LF > 50
High	0.6 < SEI < 0.8	1 < LVQI < 2	1 < PNVI < 3	20 < LF < 50
Average	0.4 < SEI < 0.6	1 < LVQI < 0.5	1 < PNVI < 0.5	5 < LF < 20
Low	0.2 < SEI < 0.4	0.5 < LVQI < 0.25	0.5 < PNVI < 0.2	2 < LF < 5
Very low	SEI < 0.2	LVQI < 0.25	PNVI < 0.2	LF < 2

3.3.3. GIS Indicators of Anthropization

Diffuse territorial anthropization is a complex phenomenon to analyze both from a qualitative and quantitative point of view. In addition, there is little methodological background in the scientific literature regarding its impacts on the landscape. These are atomized land transformations that may not follow a specific pattern of behavior and, thus, require spatial evaluation indicators that are raised ad hoc. The following three GIS indicators have been designed in accordance with the results from the prospective analysis stage to analyze the most common diffuse territorial anthropization phenomena related to land transformation processes that affect the landscape.

Index of Landscape "Artificialization" (ILA)

The transformation of land use is usually the main cause of landscape deterioration. However, the transformation can be of very different types, and it does not always unequivocally entail the loss of value of the landscape. It is particularly interesting above all to know the levels of transformation associated with the loss of natural values of the landscape [47,48]. In this context, the analysis will focus on situations when the land transformation processes entail the replacement of spaces in their natural state by artificial non-agricultural land uses, excluding those destined for greenhouses.

For this, a spatiotemporal evaluation of land use changes according to the European Corine Land Cover and the Inspire Directive criteria [49] will be carried out for each landscape subunit. For the determination of this parameter, all the surfaces established as being artificial by the Information System on Land Occupation of Corine Land Cover 2018 (category 1 uses and agricultural areas established as greenhouses) have been considered. The higher the index value, the more "artificialized" the landscape of the subunit:

$$ILA = \frac{S_n}{S_{tr}} \quad (5)$$

where S_n = Land use changed between 1956 and 2020 to artificial surfaces from category 1 uses Corine Land Cover 2018 [23] or greenhouse use (Ha) with crops identified using criteria based on Van Vliet et al. [50] and la Cecilia [51];
S_{tr} = surface of the landscape subunit (m^2).

Indicator of Infrastructural Anthropization (IFA)

There are various categories of partial diffuse territorial anthropization causal factors that respond to the phenomena of smooth alteration of the landscape by linear spatial transformations. These transformations, although they do not imply a great distortion at the spatial level, are sometimes the seed of greater inertia for global alteration of the landscape. One of the characteristics of soft anthropization in a territory is the development of fragmented configurations through linear paths that "unstructure" the natural landscape of a territory and fracture the homogeneity of plots [52]. At the spatial level, they are usually a propitious framework for the subsequent development of other anthropic activities with limited landscape impact (gas stations, small and isolated activities located on the edge of the road, etc.) or of greater impact because of their extensive land occupation, such as resort-type urbanizations, industrial estates or small urban settlements.

To analyze the density and behavioral patterns of this phenomenon, a weighted spatial evaluation of the fragmentation of the territory will be carried out through the density of paths and urban roads per square meter, also considering the intensity of crossovers occurring between these elements. The higher the index value the more important the fragmentation:

$$IFA = \frac{\sum h_i {L_i}^2}{S_{tr}} \cdot \frac{c_j}{l_k} \quad (6)$$

L_i = length of existing linear infrastructures (m);
h_i = weighting coefficient (highway = 1, normal road = 0.75, urban path = 0.5);

S_{tr} = landscape homogeneous subunit surface (m^2);
c_j = number of crossings generated by linear infrastructures in a reference sector;
l_k = number of sections generated by the crossings in a reference sector.

Indicator of Urban Fragmentation (UFI)

The phenomenon of urban fragmentation is also one of the traditional catalysts for processes of landscape deterioration. The unstructured construction or occurrence outside of ordered urban policies, houses, industrial buildings and warehouses is one of the usual issues in the periurban orchard areas of the Mediterranean regions. In this context, fragmented urban structures are usually associated with mixed areas with dysfunctional plots where urban sprawl grows anarchically [53]. This type of growth is usually linked to a high degree of fragmentation of urban development, jeopardizing traditional rural environments or agricultural landscapes of transition to the urban areas. Therefore, certain links can be determined between the behavior of this parameter and the existence of unbalanced urban sprawl patterns in a territory. This phenomenon usually results in the impoverishment of cultural, traditional agricultural or simply natural landscape values in periurban areas.

To analyze the behavioral patterns of this phenomenon, a spatial evaluation of the fragmentation rates due to the increase in dispersed built-up areas will be carried out. This dispersed growth will be measured through the perimeter (L)/area (S) ratio of periurban areas in each landscape subunit. The assessment of the fragmentation of urban sprawl phenomena within these periurban areas will raise built environment impacts in natural and traditional agricultural landscapes; the higher the percentage of the index, the more important the fragmentation:

$$UFI = \sum \frac{L_i}{L_{tr}} \times \sqrt{\sum \frac{Su_i}{S_{tr}}} \quad (7)$$

L_i = maximum dimension of urban boundary i (m);
L_{tr} = dimension of reference boundary analyzed (m);
Su_i = urbanized area i analyzed (m^2);
S_{tr} = landscape homogeneous periurban surface (m^2).

3.4. Geostatistical Evaluation

Geostatistical evaluation tools will be used to determine the landscape impact of the different anthropic processes in the territory. This type of analysis assesses the patterns of spatial behavior of a series of georeferenced data, enabling for instance the level of statistical correlation between the distributions of two phenomena of a different nature to be known from a spatial point of view. In this case, the objective is to know the level of correlation between the evolution in the study areas of the indicators of diffuse territorial anthropization described above and the landscape characterization values designed through the analysis parameters assigned to the different landscape subunits created in the territory.

In that way, we will be able to know how phenomena, such as the artificialization of the territory, land fragmentation generated by linear infrastructures or the development of dispersed periurban growth, affect the alteration of the landscape depending on the criteria of homogeneity, presence of scenic or natural values and fragility of the landscape. The behavior of these phenomena expressed spatially in the territory through the distribution patterns of the GIS indicators created will be subjected to an evaluation using spatial statistical autocorrelation indicators and the analysis of hot and cold spot models.

The relationship between the spatial distribution of the landscape and anthropization GIS indicators is addressed through a three-phased geostatistical evaluation using geoprocessing tools from GvSIG desktop 2.5.1 (GvSIG Association, Valencia, Spain) and the spatial statistical package from ArcGIS 10.5 (Esri, Redlands CA, USA).

The spatial statistical evaluation will enable us to numerically analyze the extent to which the human transformations of land over the last decades in the subunits generated have influenced their current landscape situation. The spatial linkage is parameterized and rated first through Global Moran's I [54] and then using Anselin Local Moran's I [55] bivariate statistics.

Bivariate global spatial autocorrelation is a tool that enables us to know whether the statistical correlation of a georeferenced dataset is negative or positive. Its bivariate Global Moran's I statistic is formulated as I:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \tag{8}$$

where z_i is the deviation of an attribute for feature i from its mean $\left(x_i - \overline{X}\right)$; $w_{i,j}$ is the spatial weight between features i and j; n is equal to the total number of features; and S_0 is the aggregate of all the spatial weights of (10):

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \tag{9}$$

This spatial statistical evaluation provides three values: Moran's I index, the z-score, and the p-value. If we have a series of spatial distribution features and an associated attribute, bivariate Global Moran's I statistic indicates whether the pattern expressed is clustered, dispersed or random as well as its degree of statistical correlation with some kind of phenomena. When the z-score or p-value indicates statistical significance, a positive Moran's I index value indicates a trend toward clustering, whilst a negative Moran's I index value indicates a trend toward dispersion. The z-score and p-value determine the statistical significance by indicating whether or not the null hypothesis is rejected (in our study, the null hypothesis states that the values associated with features have no statistical correlation).

Once the statistical significance is confirmed, we can elaborate a hot and cold point analysis using the local indicators of spatial association (LISA) from Anselin [55] from the Getis-Ord Gi * [56] tool by ArcGIS. The Anselin Local Moran's I statistic of spatial association I is formulated as follows:

$$I_i = \frac{x_i - \overline{X}}{S_i^2} \sum_{j=1, j=i}^{n} w_{i,j} \left(x_j - \overline{X}\right) \tag{10}$$

where x_i is an attribute for feature i; $\overline{X}$ is the mean of the corresponding attribute; $w_{i,j}$ is the spatial weight between features i and j; and

$$S_i^2 = \frac{\sum_{j=1, j=i}^{n} \left(x_j - \overline{X}\right)^2}{n - 1} \tag{11}$$

with n equating to the total number of features.

In this case, the null hypothesis states that the correlation values of two elements are randomly distributed. Accordingly, the higher (or lower) the z-score, the stronger the intensity of the clustering of these parameters. A z-score near zero indicates no apparent clustering within the area of analysis. A positive z-score indicates clustering of high values, while a negative z-score indicates clustering of low values. Consequently, the bivariate statistical correlation analysis between the distribution of proposed indicators helps to spatially understand the extent to which the diffuse anthropization phenomena associated to land transformation affect the current values of the landscape in the territory. This multidisciplinary approach will enable us to interpret complex phenomena of risks that impact the territory beyond the traditional qualitative assessments usually applied in this field of study.

4. Results

The methodological scheme described in the previous section will be followed when presenting the results. In the first place, the results of the prospective analysis carried out by selecting the criteria conforming the indicators and the landscape units through the realization of 20 semi-structured surveys with local stakeholders are presented. Second, the results of the spatiotemporal GIS analysis of the territorial indicators selected in the first phase are analyzed to describe the main qualitative spatiotemporal behavioral patterns in the processes of anthropization and transformation of the landscape. Third, the geostatistical evaluation of the existing spatial correlation between the distributions of the landscape valuation indicators and the territorial transformation indicators associated with diffuse anthropization phenomena is undertaken to address the analysis of interactive phenomena from a numerical point of view.

4.1. Prospective Analysis

As indicated in the Methodology section, 20 semi-structured surveys were carried out with local stakeholders from the scientific, social, political and business fields to determine the main interaction phenomena with the landscape in the study region and to establish the basic criteria for the delimitation of the different landscape units. The elements that obtained the highest score in the weighted evaluations were those associated with homogeneity, the existence of natural values, the presence of cultural scenic values and the need for protected spaces in the case of landscape quality values (see Appendix C for detailed explanation). Regarding the anthropization phenomena with the greatest impact on the landscape, the phenomena associated with artificialization of the territory, fragmentation due to road construction and the loss of identity due to dispersed urbanization were highlighted. Below we can see the questions that obtained the highest scores (Figure 9).

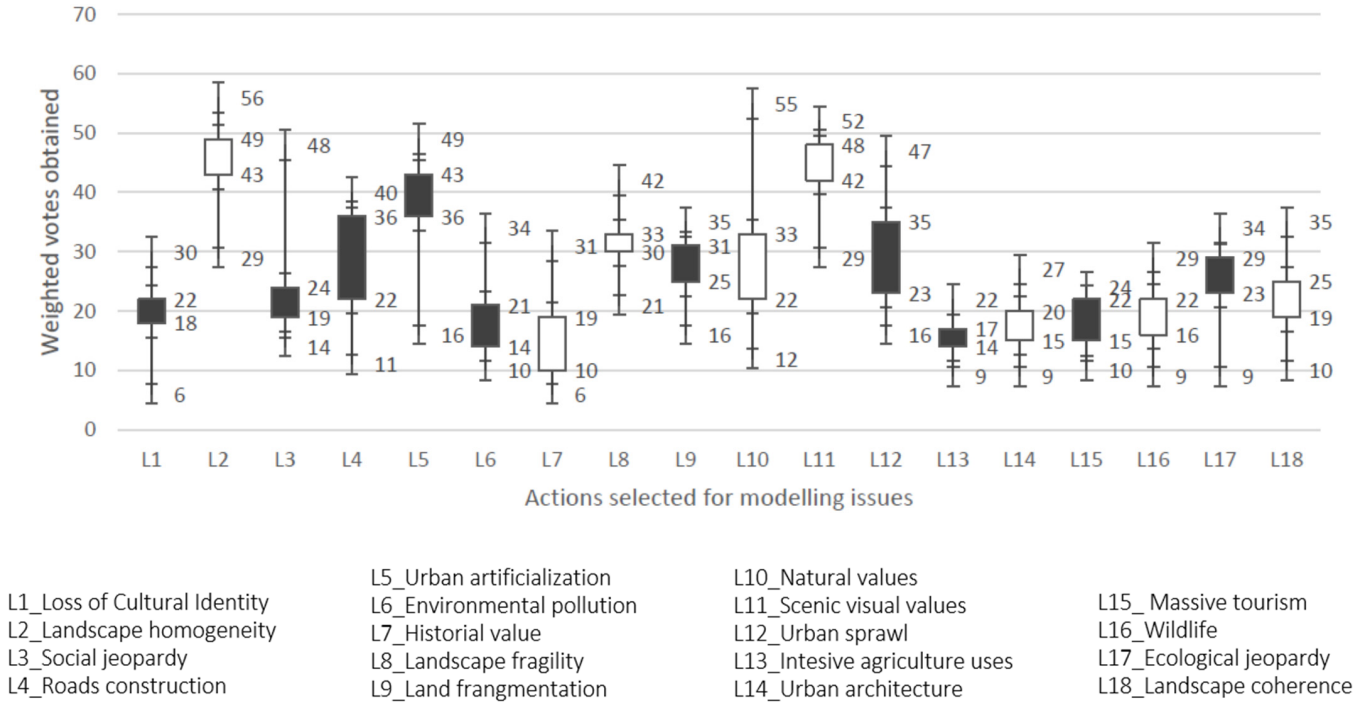


Figure 9. Main anthropization phenomena and landscape quality values extracted from the surveys.

On the other hand, by applying the spatial analysis criteria in relation to the land use, current land cover, land planning, sociology, geology and environmental values established in the Methodology section and combining these criteria with the qualitative feedback extracted from the surveys, the following 216 landscape units were delimited for the analysis of the proposed study areas (Figure 10).

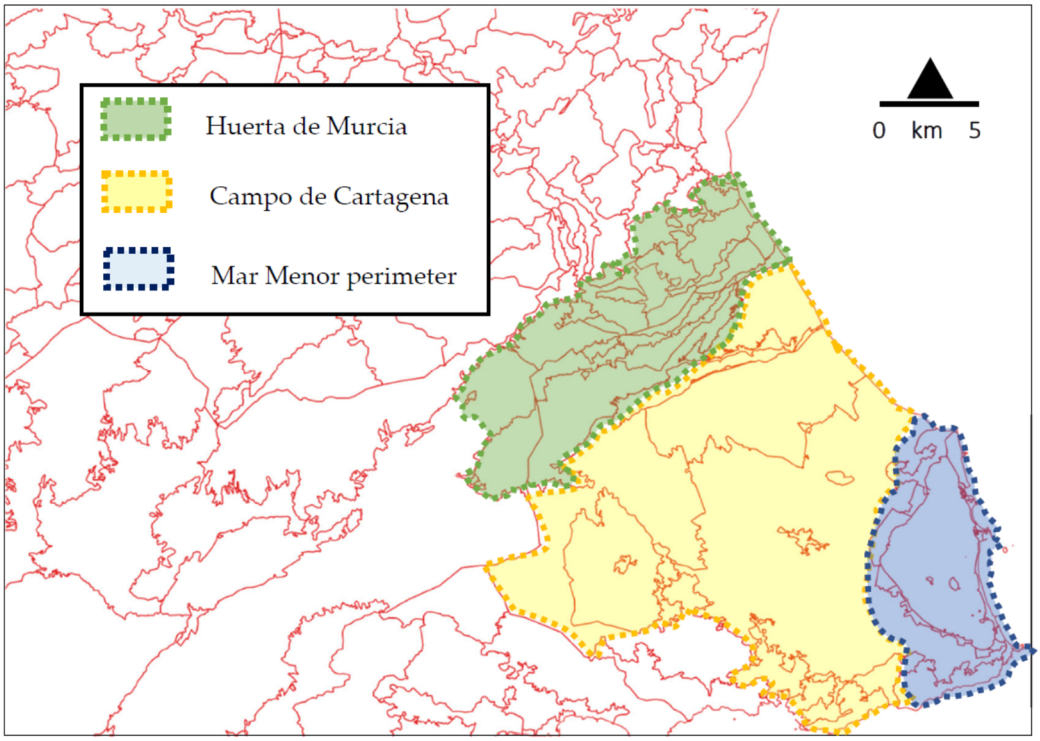


Figure 10. Distribution of the landscape subunits generated in the territory corresponding to the three study areas.

4.2. Spatiotemporal Analysis of GIS Indicators

Next, the evolution of the different GIS indicators proposed in the Methodology section was analyzed from a spatiotemporal perspective. In the first place, the evolution of diffuse territorial anthropization indicators was analyzed from a spatial perspective in a differentiated way in the three study areas. Second, the evolution of the landscape quality indicators was analyzed in an aggregate manner for the entire territory covered by the three study areas. Finally, the summary of the average values of the indicators of diffuse territorial anthropization and landscape quality is presented in aggregate for each of the case studies to observe their evolution from a comparative perspective.

4.2.1. GIS Indicators of Anthropization

The indicators of diffuse territorial anthropization were analyzed quantitatively and qualitatively. The configuration of the evaluated areas, the numerical evolution of the indicators over time and their maximum, minimum and average values in the set of landscape subunits analyzed are given in Table 3. In the case of the Huerta de Murcia area, upon analyzing the spatiotemporal evolution of the anthropization indicators proposed, we observe from a quantitative point of view how these indicators have all grown in the last decades. The increase in the level of artificialization of the ILA territory is rather moderate because agricultural uses are maintained globally, although more and more oriented to complement residential uses. On the contrary, we can see how there is a notable increase in the UFI indicator for the analysis of the urban sprawl phenomenon, whose spatiotemporal evolution data have been analyzed through the cadastral layer. Even so, apart from the numerical analysis, from the spatial and qualitative points of view, we can also observe a certain importance of the IFA indicator in the conformation patterns of this global phenomenon of anthropization (Figure 11). Dispersed urban growth in the orchard territory fundamentally follows the road structure, sometimes forming small population centers concentrated at the points of confluence of various paths.

Table 3. Summary of results of the anthropization indicators for the three cases.

	Huerta de Murcia			Campo de Cartagena			Mar Menor Coastal Perimeter		
Analyzed surface (Ha)	38,376			80,831			33,908		
Landscape subunits (Ha)	67 subunits	**Min.**	335	48 subunits	**Min.**	456	37 subunits	**Min.**	285
		Average	573		**Average**	1683		**Average**	916
		Max.	2765		**Max.**	5246		**Max.**	3549
Antropization indicators (1956)									
ILA	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.102	0.137	0.145	0.078	0.081	0.097	0.003	0.054	0.088
IFA	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.098	0.117	0.135	0.056	0.061	0.066	0.002	0.032	0.090
UFI	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.107	0.113	0.151	0.068	0.110	0.132	0.007	0.038	0.089
Antropization indicators (1981)									
ILA	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.142	0.169	0.192	0.103	0.128	0.243	0.056	0.172	0.368
IFA	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.147	0.193	0.267	0.099	0.125	0.156	0.068	0.176	0.394
UFI	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.162	0.184	0.224	0.072	0.119	0.141	0.094	0.160	0.379
Antropization indicators (2007)									
ILA	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.246	0.367	0.685	0.143	0.185	0.210	0.065	0.364	0.660
IFA	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.251	0.463	0.677	0.158	0.203	0.216	0.079	0.331	0.494
UFI	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.257	0.404	0.620	0.168	0.183	0.275	0.099	0.346	0.499
Antropization indicators (2022)									
ILA	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.307	0.486	0.694	0.168	0.252	0.332	0.067	0.381	0.689
IFA	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.356	0.502	0.708	0.191	0.227	0.276	0.079	0.340	0.506
UFI	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**	**Bottom**	**Average**	**Top**
	0.354	0.535	0.732	0.179	0.188	0.292	0.099	0.348	0.509

If we analyze the landscape units corresponding to the Campo de Cartagena area, a very different behavior is observed (Figure 12). In this case, although there is some growth in the UFI urban sprawl and IFA indicators of fragmentation corresponding to the generation of linear infrastructure, the highest growth rate occurs mainly in global artificialization processes. This situation is nevertheless contradictory with respect to land uses, since most of them continue to be agricultural; it is therefore to be expected that the phenomena of landscape transformation associated with this issue are, for instance, due to changes in use such as the implementation of greenhouses (this issue will be further addressed in the scientific discussion section).

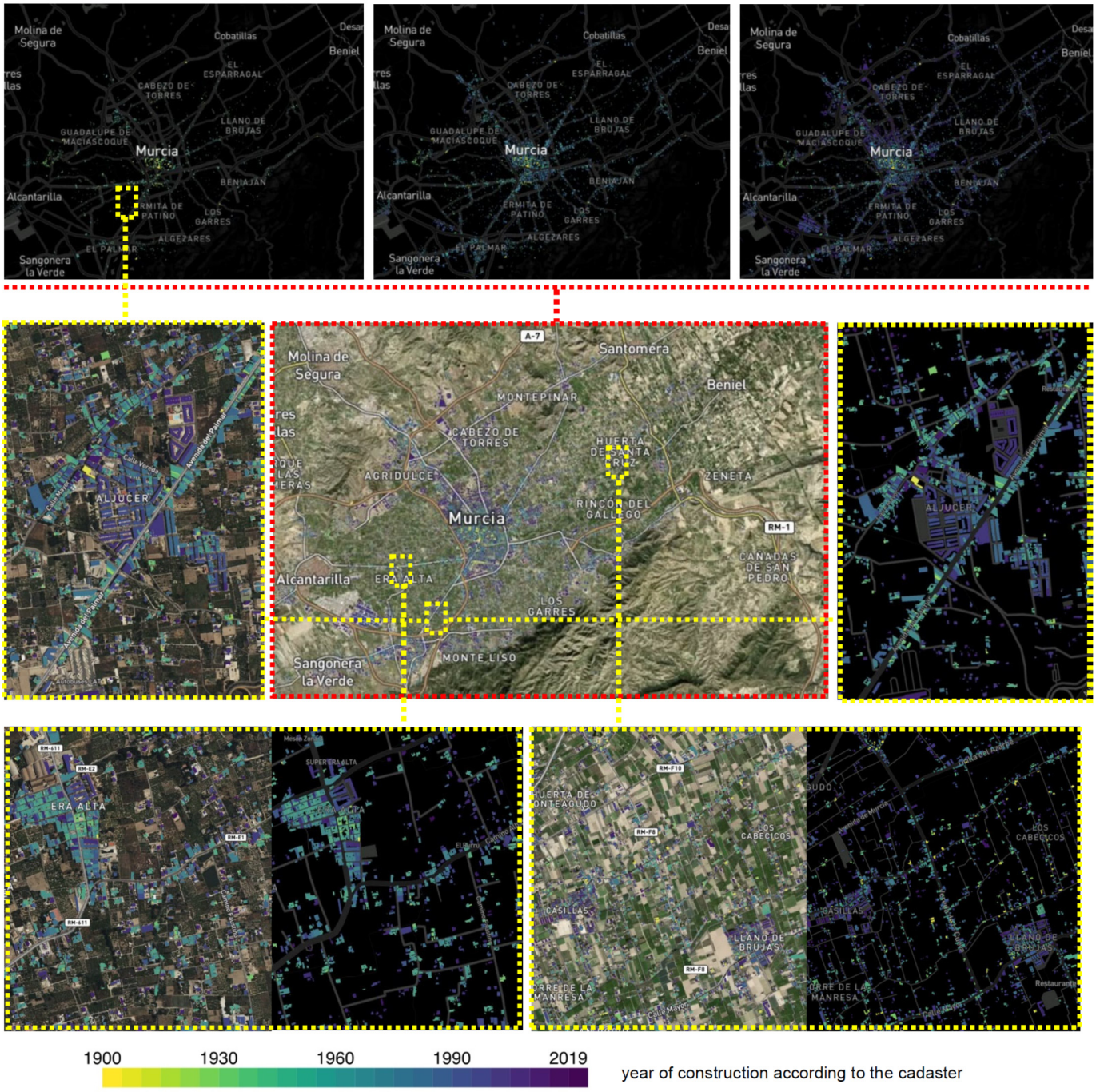


Figure 11. Evolution of the transformation process of the Orchard of Murcia between 1900 and 2019; some areas of interest are highlighted.

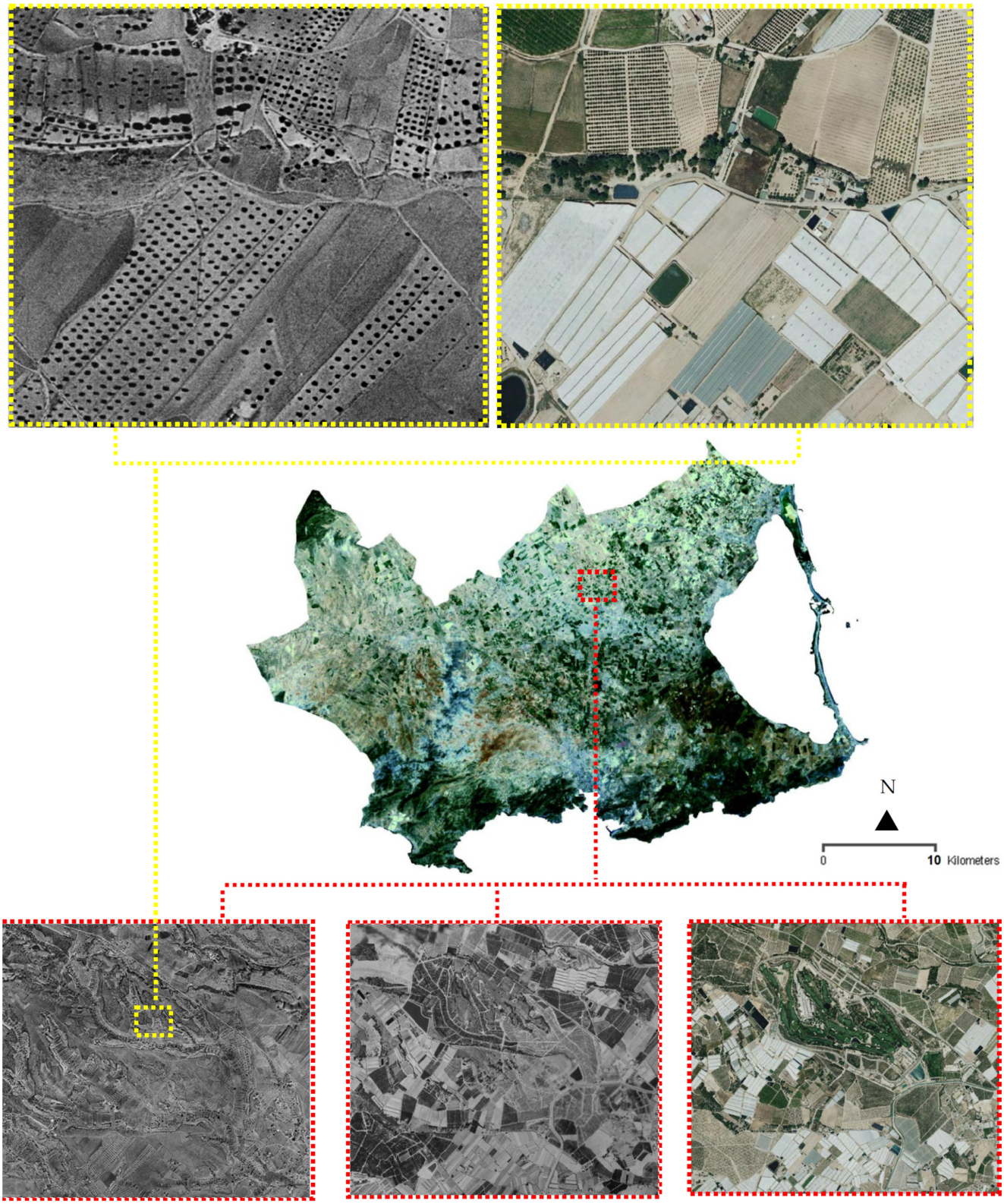


Figure 12. Evolution of the Campo de Cartagena cultivated area for 1956–1981–2022. In the upper part, we can observe in detail the comparison between an original rainfed area and the current agricultural configuration made up of irrigated crops and greenhouses. The lower part shows details of how the same area has evolved from a dryland landscape to one of irrigated land mixed with golf resort urbanized areas. Source: Sentinel 2 satellite.

The case of the Mar Menor harbors a different phenomenon. Over time, a concentrated process of urban saturation of the lagoon's coastal perimeter has been taking place since the 1950s because of the expansion of town settlements, but above all due to the new mass tourism activity. This process has stabilized in the last two decades and contrasts with the interspersed existence of protected areas of high ecological value, such as natural wetlands or salt marshes threatened by the expansive effects of tourism (Figure 13).

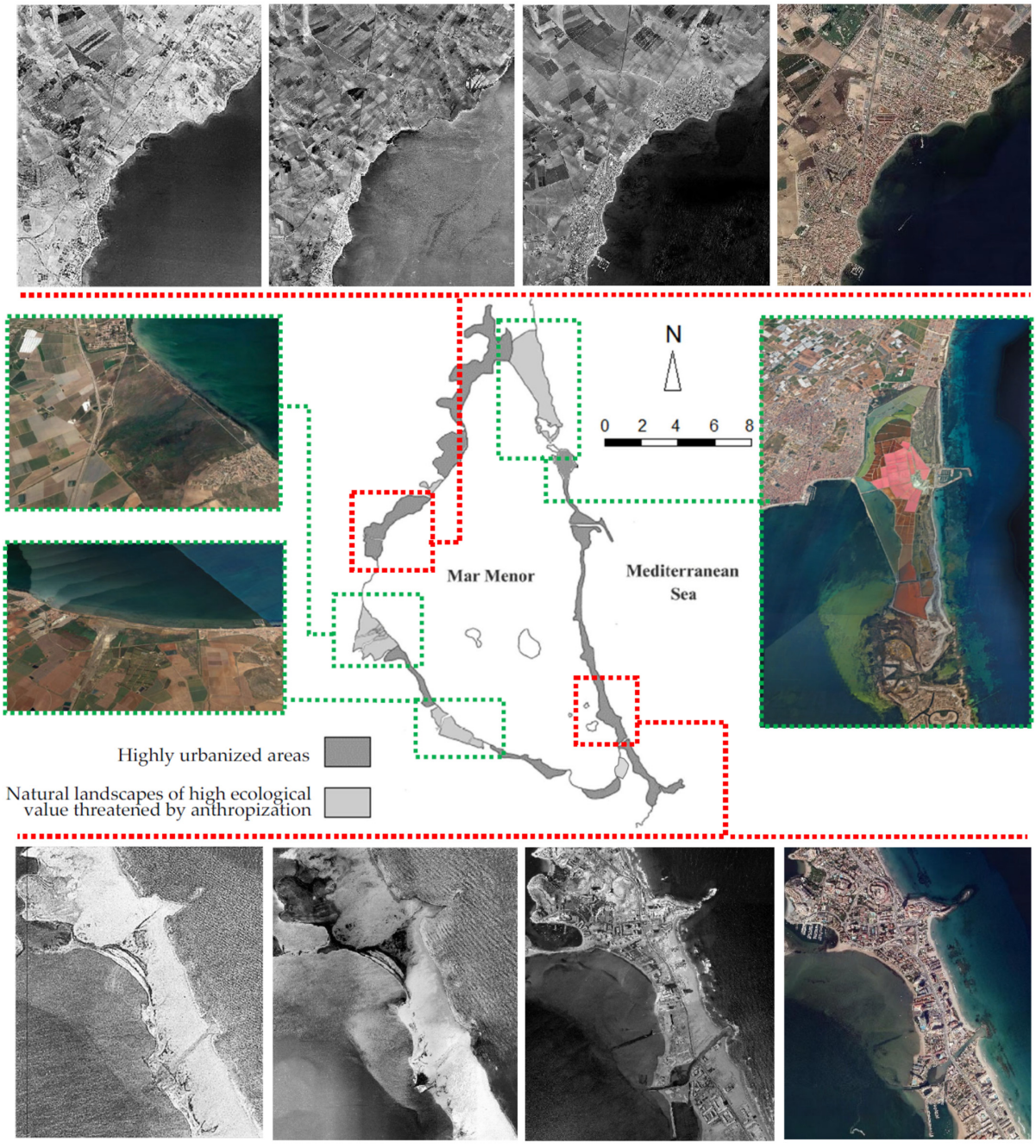


Figure 13. Samples of spatiotemporal evolution of urban areas from the coastal perimeter of the Mar Menor in 1929, 1956, 1981 and 2022 (in red) vs existence of neighboring threatened natural landscapes.

In fact, by jointly analyzing both case studies from a temporal perspective, we can observe that there is a certain interrelation between the problems of both cases regarding the transformation of the territory for tourism uses. In the first stage, from the 1950s, an important transformation of the coastal perimeter of the Mar Menor took place, associated

with the arrival of mass tourism. Once a certain clogging of that coastal perimeter had occurred by the 1990s, the phenomenon of land transformation associated with mass tourism began to mutate. A new growing tourism phenomenon started which was located several kilometers inland in the agricultural area of Campo de Cartagena, where several cultivated areas were being transformed into large, isolated, golf resort-type residential units (Table 4). At the same time, agricultural activity in the Cartagena countryside has not diminished; indeed, since the 1980s, with the water transfer between the Tagus and Segura rivers, agricultural activity has increased with a large part of the territory being transformed from dry land to irrigated land.

Table 4. Evolution of the Mar Menor perimeter and the Campo de Cartagena area for land transformation and population from 1950 to 2016.

	1950	1960	1970	1981	1991	2001	2011	2021
Land transformed (Ha,%)								
Irrigated areas (Ha)	0	22	436	2782	6388	15,874	25,556	26,854
Urban surface areas (Ha)	1036	1084	1517	1960	3006	3852	4673	4911
Coastal occupation [1] (%)	3.03	3.23	5.70	25.85	45.43	67.60	88.28	89.15
Resorts developed (Ha)	0	0	0	202	391	2674	5521	5714
Population (inhab.)								
Campo de Cartagena—Mar Menor area	184,855	179,847	204,671	238,138	251,837	301,256	402,278	462,867
Entire region of Murcia	755,850	803,086	832,047	955,487	1,045,601	1,190,379	1,335,792	1,498,065

[1] first 500 m. strip.

As a summary, the joint temporal evaluation of the indicators of diffuse territorial anthropization for the three case studies can be seen in an aggregated and summarized manner in Figure 14. It is interesting to observe that, despite the fact that it produces a general progression in all the parameters over time, this growth is, from the point of view of the mean values, more accentuated in the case of the Huerta de Murcia, with the case of Campo de Cartagena being the most limited. However, the one that presents (if we consider the maximum and minimum values of Table 3), the most extreme behavior is the case of the coastal perimeter of the Mar Menor. Finally, it is striking to observe how, if we analyze the temporal order of growth of the values, depending on the case and the time period, the process of anthropization due to the construction of roads or highways usually precedes the anthropic process of urban sprawl or vice versa (this issue will be analyzed in more detail in the scientific discussion section).

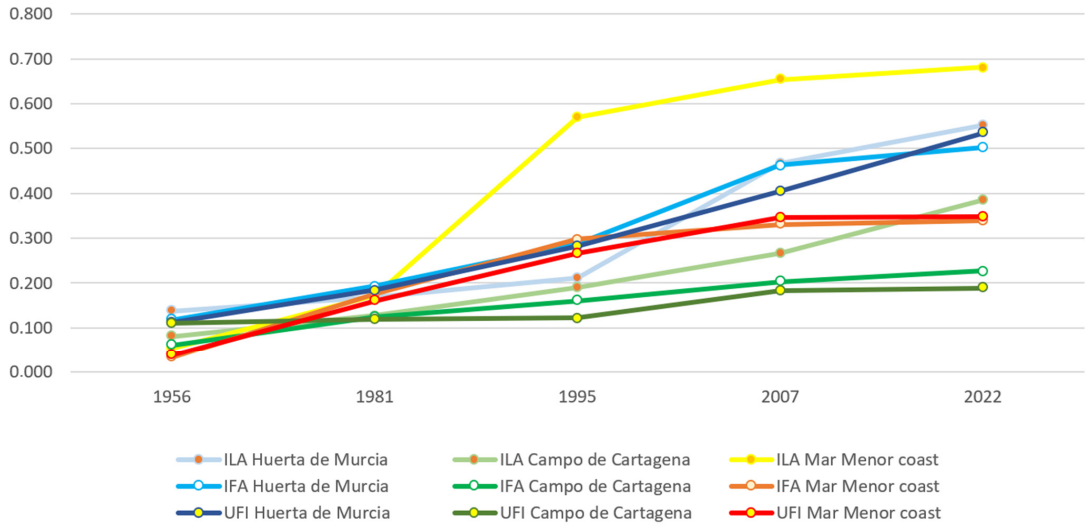


Figure 14. Evolution of aggregated values for anthropization GIS indicators in Huerta de Murcia, Campo de Cartagena and Mar Menor perimeter areas of study between 2000 and 2020.

4.2.2. GIS Indicators of Landscape Values

Subsequently, the indicators related to landscape quality were analyzed quantitatively and qualitatively. The values of the landscape quality indicators of each of the 216 delimited landscape units that affect the three study areas were calculated. To ensure the results are more easily understood, the spatial distribution of these values has been represented graphically in a simplified way, establishing five dimensionless ranges for each of the landscape valuation indicators following the criteria established in the Methodology section. These values have been compared and represented spatially over time in Figure 15.

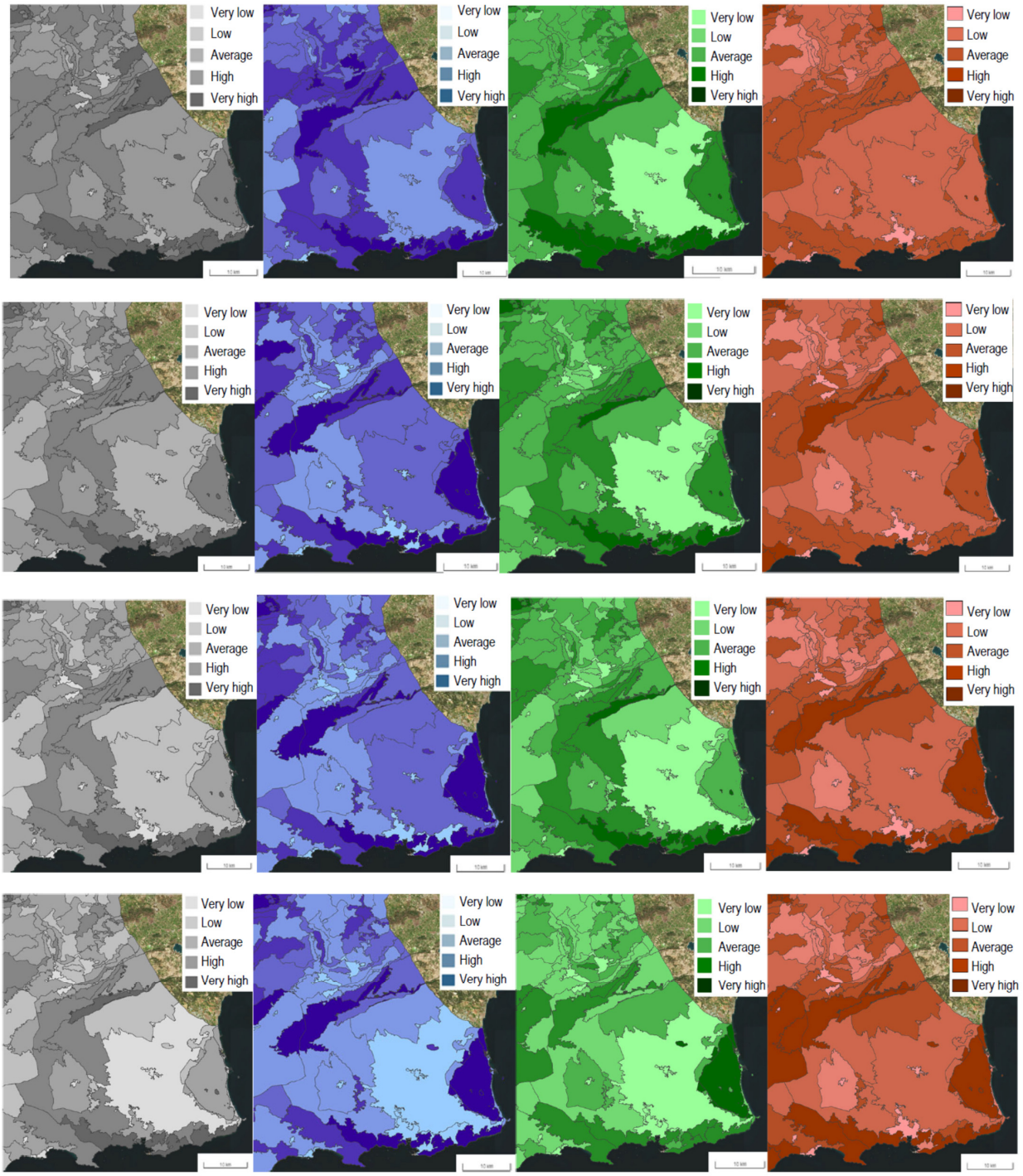


Figure 15. Spatial evolution of the landscape quality indicators in the landscape units affecting the study areas over time (years 1956, 1981, 2007 and 2022).

Analyzing the distribution patterns of the different results, we can observe an apparently heterogeneous behavior at the global level and differentiated in each of the three study areas. In the case of the Huerta de Murcia area, the stable maintenance of medium and high values can be seen for most of the indicators, fundamentally expressed in the high values of the LVQI scenic value indicator, with the SEI homogeneity indicator being the only one that shows a certain trend towards landscape deterioration. However, the existence of a certain differentiation in evolution between the eastern and western areas of the city is also observed (this will be discussed in detail in the scientific discussion section).

The case of the study area of the Campo de Cartagena generally presented medium or even low values in all the indicators, albeit interspersed with some isolated high value area for the PNVI natural value indicator since it corresponds to a protected natural space. It should also be noted that the trend towards a slow but widespread deterioration in that area can be seen in all the indicators from the point of view of the evolution over time. However, none of the indicators presented extreme behavior either, except in the case of the SEI homogeneity indicator, whose loss of value is somewhat relevant.

In the case of the coastal perimeter of the Mar Menor, we found very heterogeneous values, even in some extreme cases (often with very high or low values in neighboring landscape units). This characteristic of the area is corroborated by the presence of high values of the landscape fragility LF indicator, combined with high values of the SEI homogeneity parameter. However, the temporal evolution of the values shows some stability in the last decades due to the absence of recent land transformation phenomena (this issue will also be addressed in greater detail in the scientific discussion section).

An interesting issue to observe is that despite the higher values of anthropization progress in the case of the Huerta de Murcia and the coastal perimeter of the Mar Menor, the tendency toward landscape deterioration in the case of Campo de Cartagena seems more accentuated. The numerical representation of the temporal evolution of the main results of the four landscape valuation indicators in the three study areas has been summarized in an aggregated manner in Figure 16.

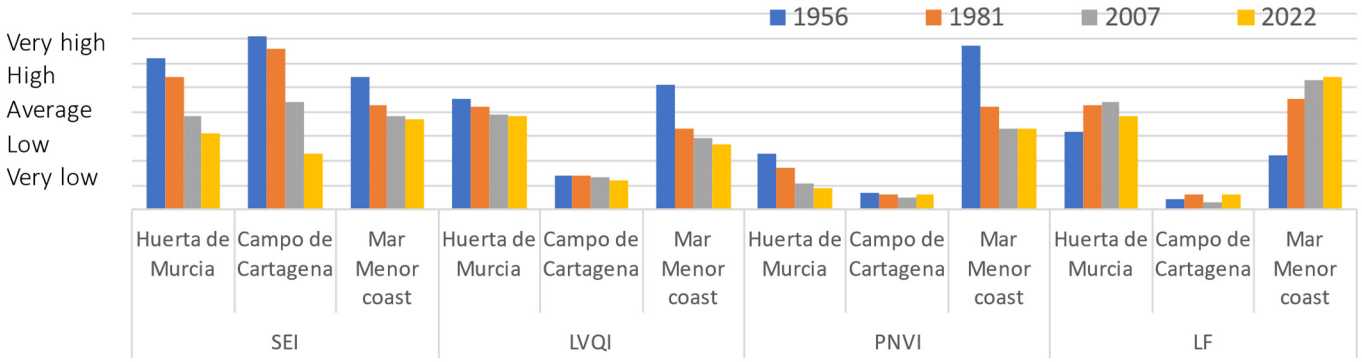


Figure 16. Evolution of aggregated average values for landscape indicators in the three case studies between 1956 and 2022.

4.3. Spatial Statistical Analysis of the Correlation between Indicators

To confirm that these were spatial pattern distributions derived from real physical phenomena and not the results of a set of mostly random events, the spatial autocorrelation based on feature locations and attribute values was measured using the Global Moran's I statistic with ArcGIS. The results obtained are summarized in Table 5.

The numerical results are not homogeneous for all the indicators and case studies, but it can be assumed that all of them presented enough statistical significance in their distribution so as to represent a real phenomenon. For this analysis, we have considered that low *p*-values and medium-high z-values verify the rejection of the null hypothesis (a statistically random distribution). In addition, the existence of positive values for the

statistic shows a global aggregative trend for all the indicators. Thus, we can confirm that these spatial distribution patterns are associated with verifiable physical phenomena.

Table 5. Global Moran's I statistic for the distribution of landscape and anthropization indicators in the three case studies (data order: Huerta de Murcia/Campo de Cartagena/Mar Menor lagoon perimeter).

Landscape Indicators	**SEI**	**LVQI**	**PNVI**	**LF**
Global Moran's index	0.36/0.16/0.42	0.35/0.12/0.29	0.17/0.21/0.62	0.39/0.10/0.51
z-score	29.3/11.1/37.5	30.0/14.8/22.4	14.6/19.3/53.5	24.7/12.2/48.4
p-value	0.01/0.01/0.01	0.01/0.01/0.01	0.01/0.01/0.01	0.01/0.01/0.01
Anthropization Indicators	**ILA**	**IFA**	**UFI**	
Global Moran's index	0.43/0.32/0.57	0.61/0.29/0.56	0.67/0.15/0.59	
z-score	40.2/22.8/53.9	53.2 /30.3/51.6	55.4/13.3/50.6	
p-value	0.01/0.01/0.01	0.01/0.01/0.01	0.01/0.01/0.01	

Apart from this verification, other relevant issues can also be detected. On the one hand, in the case of the anthropization indicators, more similarity is detected in the cases of the Huerta of Murcia and Campo de Cartagena than in relation to the coastal perimeter of the Mar Menor lagoon. This is possibly because in the third case the distribution patterns of the indicators are more concentrated compared to the first two, where phenomena of greater dispersion occur, both at the level of landscape configuration as well as at the level of anthropic impact (this issue will be further addressed in the scientific discussion section).

On the other hand, we generally observed higher levels of clustering in the case of the anthropization indicators than in the case of the landscape analysis indicators. This is also understandable because issues related to anthropogenic impacts can possibly be modeled more easily than those corresponding to the landscape configuration of a territory (this issue can be seen more clearly in the multiple OLS regression models based on a bivariate LISA analysis, see Table 6).

Table 6. Multiple regression assessment (OLS) obtained from LISA analysis of the spatial correlation between anthropization and landscape indicators for each case study.

Huerta de Murcia Area								
GIS Indicators	**Homogeneity (SEI)**				**Scenic Values (LVQI)**			
	B	**Std. Error**	***t***	**Sign.**	**B**	**Std. Error**	***t***	**Sign.**
ILA	−0.226	0.009	−2.128	0.000 *	−0.146	0.009	−2.113	0.000 *
IFA	−0.378	0.005	−2.904	0.000 *	−0.115	0.007	−1.837	0.000 *
UFI	−0.393	0.003	−3.515	0.000 *	−0.271	0.004	−3.180	0.000 *
Akaike's information criterion (AIC): 22,354.5 Multiple R-squared: 0.33 Adjusted R-squared: 0.32 F-statistic: 126.65 Prob (>F) (4,4) degrees of freedom: 0					AIC: 21,897.6 Multiple R-squared: 0.22 Adjusted R-squared: 0.22 F-statistic: 134.88 Prob (>F) (4,4) DF: 0			
GIS Indicators	**Natural Areas (PNVI)**				**Fragility (LF)**			
	B	**Std. Error**	***t***	**Sign.**	**B**	**Std. Error**	***t***	**Sign.**
ILA	−0.142	0.007	−1.823	0.000 *	0.233	0.009	2.201	0.000 *
IFA	−0.097	0.006	−1.243	0.000 *	0.098	0.011	1.325	0.000 *
UFI	−0.103	0.006	−1.712	0.000 *	0.156	0.006	2.004	0.000 *
Akaike's information criterion (AIC): 23,208.4 Multiple R-squared: 0.24 Adjusted R-squared: 0.24 F-statistic: 165.20 Prob (>F) (4,4) degrees of freedom: 0					AIC: 23,340.8 Multiple R-squared: 0.22 Adjusted R-squared: 0.21 F-statistic: 169.55 Prob (>F) (4,4) DF: 0			
* Significant at 0.01 level.								

Table 6. *Cont.*

Campo de Cartagena area								
GIS Indicators	**Homogeneity (SEI)**				**Scenic Values (LVQI)**			
	B	**Std. Error**	***t***	**Sign.**	**B**	**Std. Error**	***t***	**Sign.**
ILA	−0.364	0.006	−4.553	0.000 *	−0.136	0.013	−1.227	0.000 *
IFA	−0.349	0.005	−3.247	0.000 *	−0.095	0.009	−1.024	0.000 *
UFI	−0.132	0.006	−2.715	0.000 *	−0.112	0.009	−1.334	0.000 *
Akaike's information criterion (AIC): 25,785.4					AIC: 25,241.2			
Multiple R-squared: 0.26					Multiple R-squared: 0.19			
Adjusted R-squared: 0.26					Adjusted R-squared: 0.18			
F-statistic: 116.41 Prob (>F) (4,4) degrees of freedom: 0					F-statistic: 143.02 Prob (>F) (4,4) DF: 0			
GIS Indicators	**Natural Areas (PNVI)**				**Fragility (LF)**			
	B	**Std. Error**	***t***	**Sign.**	**B**	**Std. Error**	***t***	**Sign.**
ILA	−0.143	0.007	−1.826	0.000 *	0.056	0.013	1.220	0.000 *
IFA	−0.107	0.005	−1.643	0.000 *	0.071	0.009	1.524	0.000 *
UFI	−0.122	0.006	−1.712	0.000 *	0.067	0.011	1.144	0.000 *
Akaike's information criterion (AIC): 25,467.6					AIC: 26,188.3			
Multiple R-squared: 0.16					Multiple R-squared: 0.18			
Adjusted R-squared: 0.15					Adjusted R-squared: 0.17			
F-statistic: 131.42 Prob (>F) (4,4) degrees of freedom: 0					F-statistic: 122.76 Prob (>F) (4,4) DF: 0			
* Significant at 0.01 level.								
Mar Menor perimeter								
GIS Indicators	**Homogeneity (SEI)**				**Scenic Values (LVQI)**			
	B	**Std. Error**	***t***	**Sign.**	**B**	**Std. Error**	***t***	**Sign.**
ILA	−0.208	0.003	−3.681	0.000 *	−0.436	0.003	−4.027	0.000 *
IFA	−0.233	0.001	−3.270	0.000 *	−0.315	0.009	−2.960	0.000 *
UFI	−0.267	0.006	−2.999	0.000 *	−0.319	0.007	−2.205	0.000 *
Akaike's information criterion (AIC): 22,311.0					AIC: 23,012.1			
Multiple R-squared: 0.40					Multiple R-squared: 0.31			
Adjusted R-squared: 0.39					Adjusted R-squared: 0.31			
F-statistic: 194.63 Prob (>F) (3,3) degrees of freedom: 0					F-statistic: 143.87 Prob (>F) (3,3) DF: 0			
GIS Indicators	**Natural Areas (PNVI)**				**Fragility (LF)**			
	B	**Std. Error**	***t***	**Sign.**	**B**	**Std. Error**	***t***	**Sign.**
ILA	−0.317	0.004	−3.325	0.000 *	0.536	0.001	6.224	0.000 *
IFA	−0.412	0.005	−3.877	0.000 *	0.418	0.002	4.922	0.000 *
UFI	−0.398	0.004	−3.928	0.000 *	0.469	0.002	5.136	0.000 *
Akaike's information criterion (AIC): 21,289.5					AIC: 21,170.5			
Multiple R-squared: 0.34					Multiple R-squared: 0.40			
Adjusted R-squared: 0.33					Adjusted R-squared: 0.40			
F-statistic: 166.25 Prob (>F) (3,3) degrees of freedom: 0					F-statistic: 186.19 Prob (>F) (3,3) DF: 0			
* Significant at 0.01 level.								

Some interesting notes can be extracted from the results obtained. First, the analysis developed for the landscape indices indicates various common patterns of behavior for the three case studies. In general, the SEI index of homogeneity presents a much higher capacity for explanation (R2adj: 0.32/0.26/0.39) than those obtained for the LVQI index of scenic values (R2adj: 0.22/0.18/0.31), the PNVI index of natural area (R2adj: 0.24/0.15/0.33) and the LF index of fragility (R2adj: 0.21/0.17/0.40). As expected, we observe that the correlations are negative in the first three indicators (SEI, LVQI and PNVI) and positive in the last one (LF), given that only the phenomenon of fragility is associated with a growing phenomenon of anthropization.

On the other hand, a greater capacity to explain the model is obtained in the cases of Huerta de Murcia and the Mar Menor perimeter; the values for the case of the Campo de Cartagena are generally lower. This is probably because the Campo de Cartagena environment has suffered much more heterogeneous diffuse territorial anthropization phenomena related to urban sprawl and intensive agriculture than the other two, as confirmed by the low values of homogeneity. The cases of Huerta de Murcia and Mar Menor allow us to explain the phenomenon of landscape deterioration related to anthropization phenomena with simpler models based on fewer variables, as the lower values in the AIC evaluation for the landscape indices of these two case studies, i.e., (22,354.5/21,897.6/23,208.4/23,340.8) and (22,311.0/23,012.1/21,289.5/21,170.5) versus (25,785.4/25,241.2/25,467.6/26,188.3) of the Campo de Cartagena case study, confirm.

Finally, we can see that there is a greater general correlation in the case of the Mar Menor anthropization indices ILA, IFA and UFI than in the other two. This is surely due to spatial distribution patterns of the indicators that are much more clustered when compared to the two cases where the distribution is more dispersed. It is also interesting to observe cases in which the correlation is rather low, such as the scenic values LVQI and the fragility LF in the Campo de Cartagena case study.

5. Discussion

The work carried out leads us to interesting conclusions both from the general point of view of the methodological approach and the relevance of the specific results obtained. At a general level, the methodological proposal made represents a contribution that can be quite useful in the analysis of the impact patterns of the transformation of the territory in the landscape under certain boundary conditions. The proposal made raises alternative approaches to the traditional landscape indicators used to analyze the sub-phenomena of landscape anthropization linked to peri-urban growth structured around linear communication infrastructure.

On the other hand, the combined use of remote sensing and GIS local cartography supported by geostatistics may be of interest to reduce the need for resources and data within the framework of a comprehensive analysis of this type of phenomena from a spatiotemporal perspective. The spatial resolution of the Landsat images (30 m average) might not be sufficient to capture small-scale changes in land use and land cover. In this regard, the global results and behavioral patterns obtained at a large scale using remote sensing will be contrasted in the next paragraphs, complementing the analysis with a detailed analysis based on high-precision georeferenced local cartography. This mixed approach will allow a global understanding at a large scale of the main phenomena of the impacts on the landscape because of the phenomena of territorial anthropization while it solves possible limitations of remote sensing in relation to the uncertainties caused by the relatively low spatial resolution.

At a specific level, the analysis of the case studies carried out leads us to a series of interesting conclusions, but also poses new questions. On the one hand, we observe how the urban sprawl phenomenon, despite being much more accentuated in the periurban area of the Murcia metropolitan area than in the theoretically agricultural area of Campo de Cartagena, does not generate a greater phenomenon of deterioration of the landscape. Moreover, in some subunits, the impact caused by the greenhouses and the fragmentation of the territory generated by the roads had a greater impact on the landscape than the phenomenon of dispersed urbanization associated to tourist gated communities and resorts that occurs in the Campo de Cartagena area. On the other hand, in the case of the coastal perimeter of the Mar Menor, the strong urban concentrations do generate a clear impact on the landscape from the point of view of its deterioration due to artificialization, although this statement does have several nuances.

If we analyze each of the three case studies individually, we can observe different patterns of interaction between territorial anthropization and alteration of the landscape that enable us to better understand phenomena that are currently difficult to determine

objectively. In the case of the Huerta de Murcia, the phenomenon of urban sprawl has caused an asymmetrical deterioration pattern of the landscape in that area of study. If we analyze the spatial behavior of the different landscape units in this area and its evolution over time, we perceive that the orchard area to the east of the city of Murcia presents landscape alterations associated with much greater anthropization phenomena than the orchard area to the west, as shown by the interaction patterns between indicators of anthropization and indicators of landscape quality from the Results section.

To understand the origin of this aggregated numerical phenomenon, we have analyzed in detail the temporal evolution over the last decades of various urban and land parameters of two small random samples of the same size (650,000 m^2, almost 1% of the total area of study) from both the east and the west sides of the Murcia orchard (Table 7). If we assess the evolution of the numerical values, we observe that despite having relatively similar values in the 1960s, the atomization of the plots' structure as a consequence of increasing the number of rural roads has led to an implicit process of dispersed urbanization, configuring a territory with a landscape closer to that of a garden city than to that of a traditional orchard agricultural structure (Figure 17).

Table 7. Data from the two samples analyzed of the eastern and western orchard zones of the Huerta de Murcia surface area.

Sample 1 (Western Orchard)		**Sample 2 (Eastern Orchard)**	
Analyzed surface area	654,387 m^2	Analyzed surface area	654,387 m^2
		1956	
Artificial surface area	8220 m^2	Artificial surface area	5343 m^2
Agricultural area	563,835 m^2	Agricultural area	606,911 m^2
Number of houses	201	Number of houses	33
Average plot size	15,600 m^2	Average plot size	16,300 m^2
Road length	1013 m	Road length	818 m
Cultivated land in use	555,245 m^2	Cultivated land in use	592,804 m^2
1956–1981 Average transformation rate	12.5%	1956–1981 Average transformation rate	11.7%
		1981	
Artificial surface area	27,514 m^2	Artificial surface area	9678 m^2
Agricultural area	556,976 m^2	Agricultural area	601,372 m^2
Number of houses	437	Number of houses	65
Average plot size	7400 m^2	Average plot size	14,800 m^2
Road length	4844 m	Road length	1399 m
Cultivated land in use	489,981 m^2	Cultivated land in use	565,701 m^2
1981–2020 Average transformation rate	67.3%	1981–2020 Average transformation rate	37.6%
		2020	
Artificial surface area	67,165 m^2	Artificial surface area	18,263 m^2
Agricultural area	523,632 m^2	Agricultural area	597,372 m^2
Number of houses	526	Number of houses	108
Average plot size	1600 m^2	Average plot size	12,200 m^2
Road length	9673 m	Road length	4836 m
Cultivated land in use	217,812 m^2	Cultivated land in use	486,785 m^2
Trend transformation rate in 2025 (linearized)	37.5%	Trend transformation rate in 2025 (linearized)	30.1%
Artificial surface area	67,165 m^2	Artificial surface area	18,263 m^2

Figure 17. Details of the main periurban configurations found in the sample analyzed (140,000 m^2, 20% of the sample) for the western orchard (left) and the eastern orchard (right) of the metropolitan area of Murcia.

This problem, which can be found in other cases of periurban agricultural spaces in Mediterranean regions (see [57–59]), is difficult to manage from the social point of view of policy implications [60]. In this case, traditional agricultural activity is becoming less attractive economically in the face of the economies of scale that intensive agriculture enables. This is leading the landscape of the study area of Murcia towards an irreversible inertia to the growing dispersed residential urbanization of the whole orchard area.

This action becomes particularly dangerous given the significant land transformation rates due to the dispersed urbanization phenomena that are currently taking place both in the eastern and western areas of the Huerta de Murcia. If we take the value of three dwellings per hectare as the transition limit from the traditional structure of the Mediterranean orchard landscape (sample of the west orchard from Figure 17) to the transitional urban structure towards a garden city (sample of the east orchard from Figure 17), we can perform the following schematic simulation of how the situation would develop in the forthcoming decades, according to the transformation rates of the last two decades (Figure 18).

Despite the seriousness of the current situation, there is margin for correction of the inertia detected. This situation could be mitigated to a certain extent by preserving the areas with the greatest landscape values LVQI and PNVI from fragmentation of the plots (mainly located, as has been verified, in the eastern zone of the Huerta de Murcia). A possible strategy to mitigate the current inertia of the loss of homogeneity SEI of the landscape due to dispersed urbanization processes could be the inclusion of a ban on the subdivision of larger agricultural plots or the generation of periurban paths in the urban regulations of the area, to preserve the uniformity and coherence of the current rural landscape. In this sense, after applying simple manual geoprocessing to determine the landscape preservation coverage ratio by plot size so that the plots remain profitable for agricultural use as opposed to their urban transformation, the proposal is to restrict this type of actions in plots of more than 5000 m^2 (this value, equivalent to a density of two houses per hectare, would cover all areas with high LVQI values unaltered to preserve the main current landscape structure, see Figure 19).

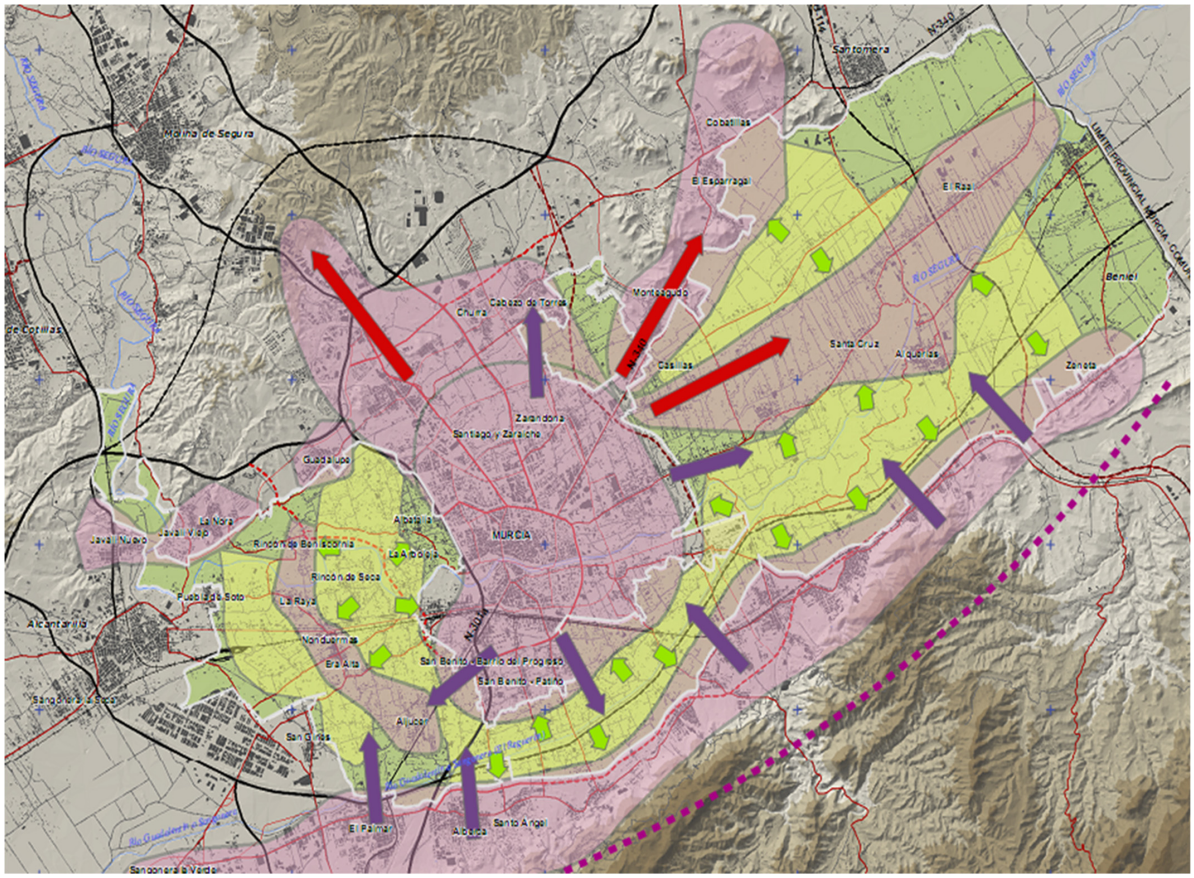


Figure 18. Schematic trend analysis of the process of spatial transformation of the periurban landscape of the Huerta de Murcia in the metropolitan area of Murcia based on the values of the temporal evolution in the phenomena of dispersed urbanization UFI and loss of homogeneity SEI (main UFI growth vectors graphed in red and areas of greatest LVQI fragility in purple).

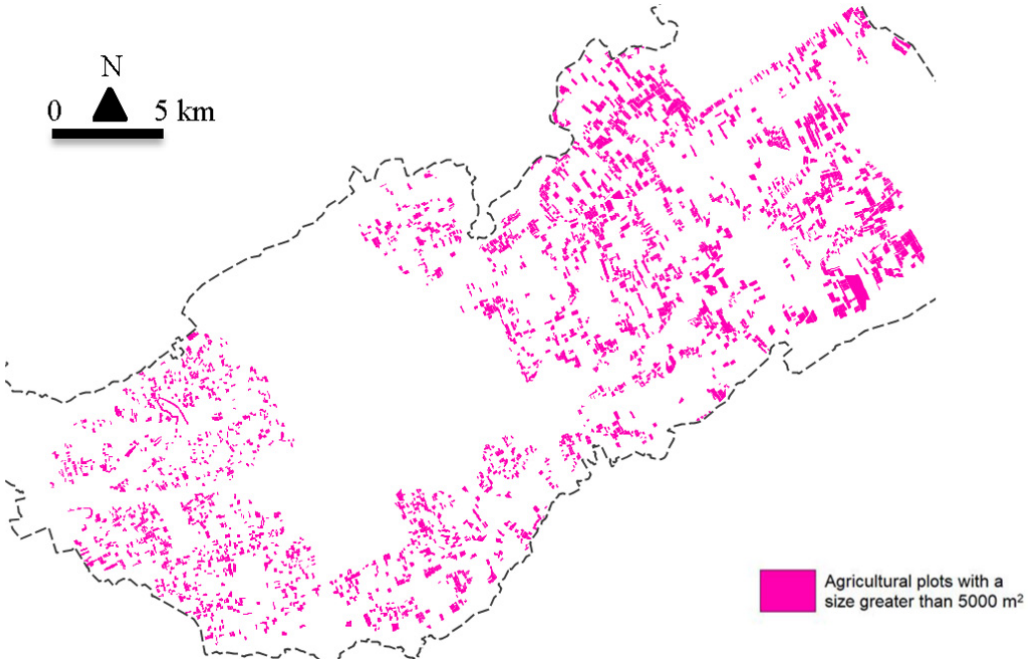


Figure 19. Selection of plots over 5000 m^2 of surface area in which a restriction on plowing or division with paths would be recommended to preserve the current landscape structure.

This phenomenon can be found in different periurban environments of the Mediterranean arc and corroborates the results of previous studies [61,62]. It is an increasingly common problem in the so-called orchard areas [63]. However, the analysis carried out has revealed various subphenomena associated with the processes of destructuring of the landscape in transitional urban areas with non-random growth patterns [64] and linked to the loss of attractiveness of local agricultural activity due to the growth of agro-industry that prevents it from competing without scale economics [65]. Under these boundary conditions, the impact of urban growth patterns on the landscape cannot be measured with traditional compactness indicators, as is executed, for example, in large cities in Asia [66] or Latin America [67].

In the case of the agricultural territory of Campo de Cartagena, the landscape impact of urbanization with low-density areas of golf resort-type and the growth of pre-existing concentrated urban settlements in the area as a consequence of the increase in agricultural and tourist activity does not globally result in an impact that currently causes a relevant landscape alteration. The appreciable deconfiguration of the landscape (more accentuated than in the previous case of the Huerta de Murcia due to the loss of land homogeneity as a result of the mix in uses) is derived mainly from the landscape impact of intensive agricultural activity, and specifically by greenhouse development.

However, it must be borne in mind that, as per urban planning in the area, there are numerous golf resort-type residential tourism projects planned. The execution of these periurban projects of tourist resorts and gated communities that were developed in the territory following a model of polyps adhered to large communication infrastructure, has been halted since the end of 2008. This was due to the global financial crisis, which in the case of Spain, had particular repercussions on the sector of real estate for tourism. Therefore, it is a variable to monitor in the coming years, when the economic recovery will make it possible to resume all such real estate projects in the area (Figure 20). Even so, this is a case that will be difficult to manage from the point of view of policy implications since the accentuated loss of SEI homogeneity throughout the territory makes it difficult to implement specific protection instruments to mitigate the current inertia of global deterioration of the landscape. These boundary conditions possibly make this inertia irreversible in the medium to long term in this study area.

Figure 20. Schematization of the polyp model of growth for resorts: urban settlements in black, road infrastructures in red and tourism resorts in green (left) and map of resorts currently built and planned for the future in the Campo de Cartagena area (bottom right).

This problem of loss of landscape homogeneity associated with land use transformation caused by intensive agriculture is not exclusive to Mediterranean environments: it has significant origins in the United States [68] and other European countries [69]. However, this problem, combined with the growth of the golf resort sub-phenomenon, gives the main problem an added complexity, which has been interestingly diagnosed through the indicators used and the proposed methodological framework of geostatistical correlation. In this regard, it is interesting to point out that we find in the case study analyzed intersecting phenomena that can also be found in the landscape impact studies of periurban environments in Asia [70], for example.

Last, in the case of the coastal perimeter of the Mar Menor, we observed the highest values of landscape alteration at a global numerical level as a consequence of massive urbanization with high levels of concentration. It should be noted that, despite having highly altered landscapes, these areas cohabit with sub-units of great PNVI landscape value due to the presence of natural or ecological spaces. It is therefore a configuration in which there are no serious SEI homogeneity problems, but there are strong landscape contrasts with clearly altered areas that coexist with others of a certain value, threatened by the same anthropization factors as deteriorated areas.

This situation adds an extra risk to the territorial context due to the high levels of LF fragility of the entire study area, but also a greater capacity to regulate the problem through a simpler implementation of landscape protection instruments in specific areas of the coastal perimeter. On the other hand, despite the significant landscape fragility detected, it should be noted that a certain stability is also appreciated in the spatiotemporal inertia of the evolution of the landscape. The urban transformation phenomena in the coastal perimeter were largely concentrated on the west side during the 1970s, 1980s and 1990s due to the expansion of the phenomenon of mass tourism in coastal areas. This contrasts with a certain stability with only limited development in the northeast area during the last two decades.

As with the previous case, the current stability is due to the existence of an economic crisis that stopped real estate development during the last decade but also to a specific phenomenon of "real estate saturation" of the coastal perimeter. The urban clogging of the coastal perimeter, and therefore the deterioration of its landscape, has produced a drop in the attractiveness of this area for tourists, causing a fall in the value of land as a real estate asset. This has meant that many areas pending development have finally not been built due to the difficulty of matching supply expectations with the actual demand in the real estate market.

This phenomenon of loss of global value as a tourist destination due to the deterioration of the landscape can be clearly observed in the eastern coastal perimeter of the Mar Menor called "La Manga". This old dune belt started to be urbanized from the south to the north in the 1960s, with its southern half becoming completely saturated in the first two decades. This caused a loss of value in the landscape that resulted in a slowdown in tourist demand for land in the northern area pending urbanization, to the point that today there are still areas of high landscape value that could be preserved (see Figure 21).

Therefore, in relation to the protection of the landscape from the point of view of land management, efforts for this third case study should currently be focused on ensuring the protection of natural spaces with a certain ecological value and those interstitial urban spaces with sufficient LVQI or PNVI value currently preserved from urban development. This last aspect is vitally important because, although there is a certain uniformity of deterioration of the landscape within the urbanized areas, there are also occasional spaces on undisturbed but developable land. Such spaces have a relevant landscape value either because they are still in a naturalized state or are good as they have some kind of cultural or scenic value that must be preserved from planned urbanization. This casuistry, although it reaffirms the results of other studies on the impact of mass tourism in the coastal urban landscape in various parts of the world [71–74], has its own idiosyncrasy in the Mediterranean context [75,76].

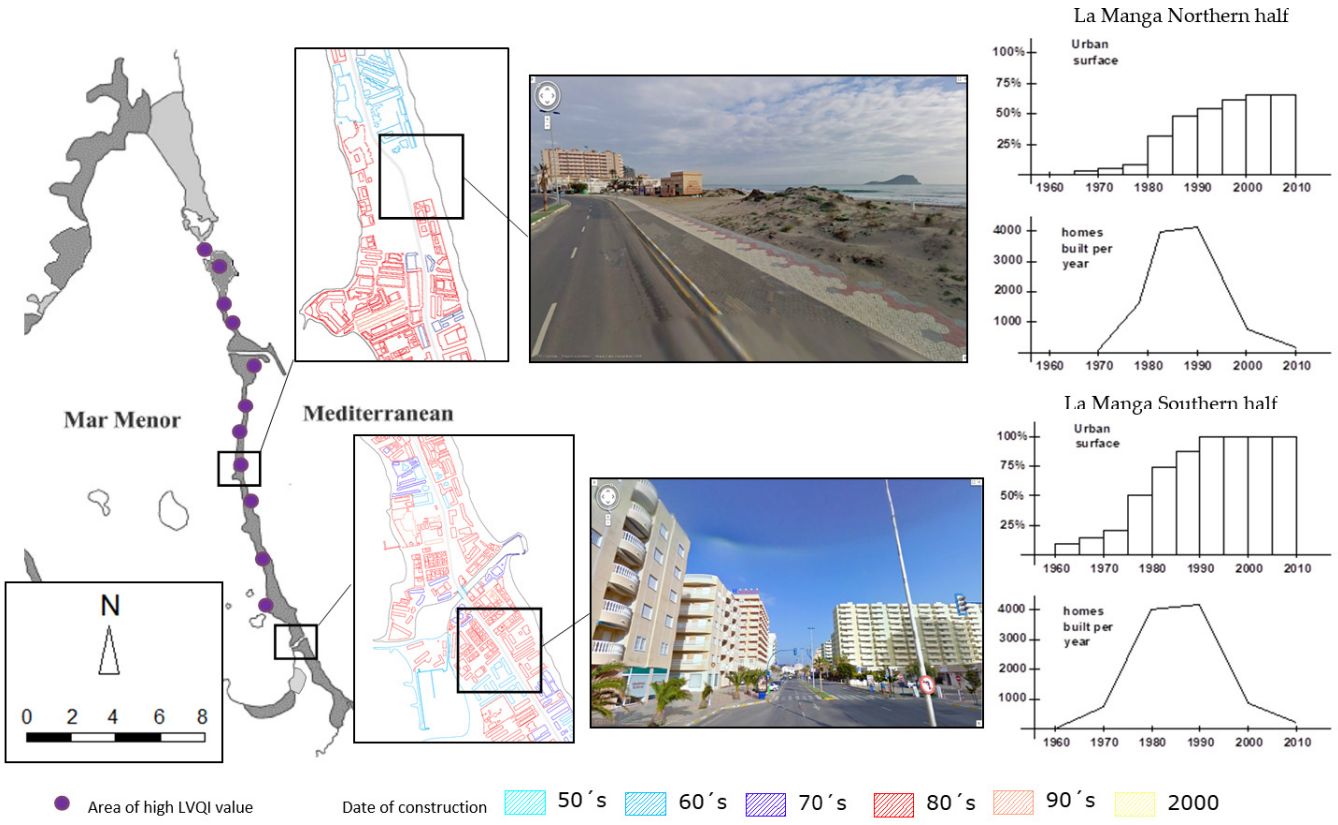


Figure 21. Temporal evolution of construction in the eastern coastal perimeter of the Mar Menor and stocks of valuable landscapes still in saturated urban areas (contrast between the southern area completely saturated by buildings versus the northern area where there are still undeveloped spaces with important landscape value).

6. Conclusions

The evaluation of the landscape impacts caused by diffuse territorial anthropization phenomena from an objective numerical point of view is an increasingly complex issue. This field of research needs new methodologies to correctly analyze landscape transformation processes under certain boundary conditions, such as that of the proposed case studies. The present research proposes a methodological framework based on spatial statistics for structured analysis based on the calculation of GIS indicators of landscape valuation (homogeneity SEI, scenic values LVQI, natural values PNVI and landscape fragility LF) and diffuse territorial anthropization that have been applied to three territorial contexts located in the southeast of Spain with different boundary conditions. The results of the spatial statistical correlation between these indicators show how dispersed urbanization (UFI anthropization parameter), the construction of roads and linear transport infrastructures (IFA parameter) and the artificial transformation of the territory (ILA parameter) generate different impacts on the landscape in the three case studies.

In the first of these cases, corresponding to the Huerta de Murcia, the phenomenon of dispersed urban sprawl appears to have the greatest impact, with its origin associated primarily to the generation of rural roads and small linear infrastructure that atomizes the plot structure and disfigures the orchard landscape, thus encouraging an inertia of abandonment of agricultural activity in favor of urban development. In this first case, the analysis methodology shows how preserving plots larger than 5000 m^2 could mitigate the loss of parameters, such as the SEI homogeneity or LVQI scenic value of the environment.

In the second case, the analysis shows how agricultural transformation in the Campo de Cartagena area has led to a loss in landscape homogeneity expressed through the SEI parameter and whose current deterioration inertia is difficult to reverse. We must also add

that the UFI impacts associated with the low-density urbanization of numerous tourist resorts has slowed down in recent years, but in view of existing urban planning, it is foreseeable that such urbanization will resume in the future, thereby accentuating the current alterations of the territory.

Last, in the third case, we found a highly consolidated environment with high values of SEI homogeneity and LF fragility because the landscapes there that have been strongly altered by construction coexist with natural areas of ecological value which require protection. However, preservation should not be limited to the protection of natural spaces. Some undeveloped urban areas have been detected within the coastal perimeter which have high values in the scenic quality landscape indicators LVQI or the PNVI natural values and, as they belong to areas planned as buildable, must be saved from the urbanization process.

Supplementary Materials: A GIS file of the study area including some indicator metadata can be downloaded at https://www.mdpi.com/article/10.3390/ijgi12080323/s1.

Author Contributions: Conceptualization, Salvador García-Ayllón; methodology, Salvador García-Ayllón; software, Salvador García-Ayllón and Gloria Martínez; validation, Salvador García-Ayllón; formal analysis, Salvador García-Ayllón; investigation, Salvador García-Ayllón and Gloria Martínez; resources, Salvador García-Ayllón and Gloria Martínez; data curation, Salvador García-Ayllón and Gloria Martínez; writing, Salvador García-Ayllón and Gloria Martínez. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement: Not applicable.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The detailed cartography data used are summarized in Table A1.

Table A1. Technical characteristics of the georeferenced dataset used.

Mapping Data	Pixel Size Projected on the GSD Ground (cm)		Planimetric Accuracy (X,Y) Mean Squared Error (m)	Altimetric Accuracy (z) Mean Squared Error (m)	Mesh Step
	Flight	Orthophoto			
1956–1980	60	75	<2.00	<2.00	5 × 5
1981–1999	45	50	<1.00	<2.00	5 × 5
2000–2004	45	50	<1.00	<2.00	5 × 5
2005–2022	22	25	<0.50	<1.00	5 × 5

Appendix B

The criteria used in the dynamic indicators of territorial transformation have been based on the following Corine Land Cover 2018 categories:

- Agricultural transformation: categories 212, 213, 221, 222, 223, 231, 241, 242, 243 and 244.
- Urbanized areas: categories 111, 112, 133 and 142.
- Artificial land transformation: agricultural transformation and urbanized areas categories plus the following ones 121,122, 123, 124, 131, 132, 141 and greenhouses using [51] criteria.

Appendix C

Technical detail of semi-structured surveys carried out with local stakeholders for prospective analysis:

- Number of participants: 20 (5 from the scientific field, 5 from the social field, 5 from the political field and 5 from the business field).
- Survey process: Each interviewee had to indicate in a justified manner the five main phenomena of territorial anthropization and the five main values of landscape quality in the study area. The responses were subsequently analyzed and grouped by homogeneous concepts of a simplified nature.
- Scoring and selection of indicators: The interviewees had to give a score from 0 to 60 to each of the selected concepts. To avoid statistical biases due to exaggerated subjective evaluations, only those concepts whose box of a box and whisker diagrams posed a differentiated higher evaluation with respect to the median of the set of concepts evaluated, were selected. Applying this criterion, four indicators of landscape value and three indicators of territorial anthropization were selected.

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