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Landscape Analysis of the Arribes del Duero Natural Park (Spain): Cartography of Quality and Fragility

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Abstract: The landscape is a resource to be considered in the planning and sustainable management of the territory of natural spaces, such as the Arribes del Duero Natural Park. It is conditioned by environmental factors. They are highly influential on the quality of life of the people who live there. A historical analysis of the landscape was carried out with a qualitative and partially subjective character. In this work, we took advantage of current technologies, such as GIS techniques, to objectively and quantitatively calculate the variables. Firstly, it was necessary to draw up a map of landscape units, which is derived from the union of the abiotic (geomorphology and lithology) and biotic (vegetation) components in the background. Twelve homogeneous landscape units were identified by analyzing the quality and perceptual fragility of each one and considering intrinsic and extrinsic factors. The results obtained showed that the landscape quality presents areas with very high values in the fluvial canyon of the Duero river. The lowest values were found in very degraded and vegetated polygenic areas. On the other hand, the most fragile areas were those with some vulnerable character that prevents the development of human activities, such as areas with steep slopes. The procedure and results obtained constitute a useful tool for public administrations to carry out sustainable management of natural areas.

Keywords: landscape units; landscape quality; landscape fragility; GIS; Arribes de Duero

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1. Introduction

The term "landscape" integrates a set of natural elements: rocks, water, air, plants, and animals that interact with human beings, their arrangement, and their distribution in a territory [1–3]. Thus, the study of landscape has been developed on the basis of different disciplines, such as geology, geography, architecture, and biology, generating different definitions and constituting a multisensory perception of a system of ecological relations that differentiates a perceptible and an imperceptible part, and a functional and causal factor, respectively [4].

The landscape represents a resource that establishes the degree of naturalness and integrity of the natural environment; therefore, its preservation is key to the quality of life of the population. For this reason, our society has developed a set of procedures that guarantee its protection with correct spatial planning through strategic and impact assessments [5–11].

A correct analysis of the landscape implies the study of the components of the physical environment, since it is a result of the interaction of all of them. They are as follows: geology, geomorphology, climate, edaphology, vegetation, hydrology, fauna, and anthropic activities. Geomorphology is the primary component, because it defines the main landforms, considering the morphogenetic processes triggered by the agents that caused the erosion and deposition that gave rise to the Earth. The second most important is geology, because its resistance to external geodynamic agents affects the different geological materials, producing rocks of different coloring and causing effects on the spatial structure of the landscape [12,13].

Another component of the physical environment, which affects the perception of the landscape at a more detailed level, is the plant formations. These determine the spatial structure and affect its texture according to their heights (trees, shrubs, herbaceous species) and types (deciduous or evergreen), characterizing the visible background [13–15].

By comparison, low population density and uneven distribution generate a variety of interconnected landscapes, so that land exposed to little human intervention tends to be more natural [14,15].

In order to carry out this landscape analysis in a simpler way, different studies [Natural heritage mapping of the las Batuecas-Sierra de Francia and Quilamas Nature Parks (SW Salamanca, Spain); Characterisation of the Susceptibility to Slope Movements in the Arribes Del Duero Natural Park (Spain); When landscape planning becomes landscape governance, what happens to the science?; Progress in the remote sensing monitoring of the ecological environment in mining areas; Spatial distribution and influencing factors of settlements in the farming–pastoral ecotone of Inner Mongolia, China; Multitemporal analysis of land-use changes and their effect on the landscape of the Jerte valley (Spain) by remote sensing] have opted for the implementation of geographic information systems and remote sensors. These allow landscape studies of areas of special interest to be carried out with the support of spatial data analysis programs that are more precise in determining the temporal dynamics of the landscape, and have led to a significant leap in landscape concretization [16–21].

Currently, there are different methods for landscape analysis. On the one hand, there are indirect methods, which study the total landscape or phenosystem (sensitive part); on the other hand, there are direct methods, which study the visual aspect or cryptosystem (intangible part).

The use of indirect methods has increased since 2000 due to advances in GIS [22,23]. These methods identify the distribution of landscape components, in interrelation with thematic components of the natural environment (relief, vegetation, hydrogeology, etc.) [24,25]. They are the first factor used to describe the interrelationship between space and process in ecological systems and multi-scale analyses of landscape heterogeneity [26,27].

Direct methods, prior to indirect methods, assess the natural environment on the basis of aesthetic criteria or the perception of forms as visual, auditory, or olfactory sensations [22,28,29]. In natural spaces, the analysis of the landscape will allow the correct location and arrangement of elements and uses of the territory. It will show the degree of acceptance and the impact of the use of the physical environment by anthropic activities. The landscape constitutes a meeting point between technical, scientific, social, and political aspects and allows civil participation in land-use planning proposals [28,30].

The aim of this work was to identify the landscape units that make up the Arribes del Duero and to capture their quality and fragility in different cartographies, considering the components and elements that make it possible to establish the degree of singularity and representativeness for rational land-use planning.

2. Materials and Methods

2.1. Study Area

The area in which this study was carried out is the Arribes del Duero Natural Park. It is made up of 38 municipalities and has a population of 17,000 inhabitants (Figure 1). This area was declared as protected in 2002 [31], has a surface area of 1061 km^2, and is located to the west of the provinces of Salamanca and Zamora, bordering Portugal. The study area is characterized by two climates in the valley area: mild winters and very hot and long summers with an average temperature of 17.1 °C and rainfall of 500 mm. The climate in the plains is extreme continental, with temperatures of 12.2 °C and rainfall of 750 mm [32]. The landscape is characterized by an undulating peneplain (with a uniform height of 700–800 m) and by the steep slopes formed by the canyons (with heights of 130 m) carved by the fluvial system (Duero, Tormes, Uces, Huebra, and Águeda rivers). In terms of vegetation, the lowland areas are characterized by a rich mosaic of species, e.g., Quercus genus (holm oak, Spanish oak, cork oak, and gall oak), mixed with other tree species (ash) and scrubland (scrubland and broom), pastures, and dry crops (wheat, barley, rye, and vines). Meanwhile, on the slopes, olive and almond trees are cultivated using cultivation techniques such as terraces or "banccales", only to be displaced by oak and holm oak groves and juniper groves where agricultural use has been abandoned [33,34]. It should also be noted that there are large dams and hydroelectric power stations. It is one of the areas with the greatest hydroelectric potential on the Iberian Peninsula.

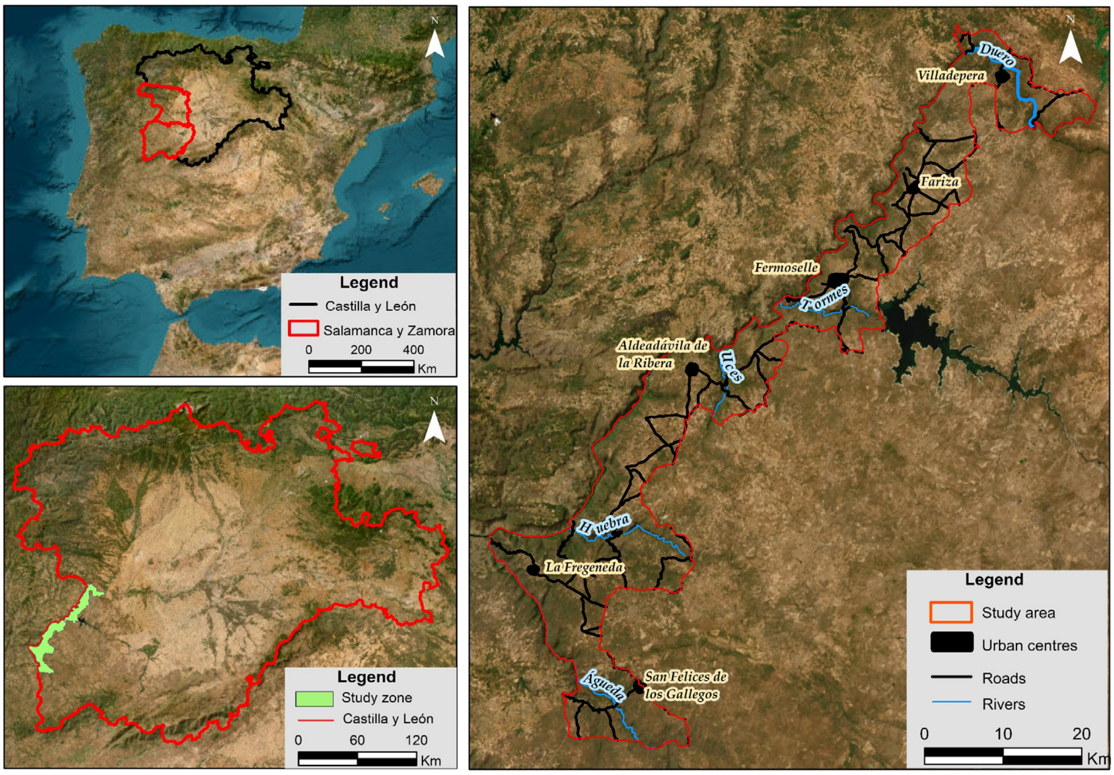

Figure 1. Study area.

2.2. Cartography of Natural Landscape Units

The methodological scheme used in this study to map the landscape units (Figure 2), was carried out in two phases. The first was the creation of parametric cartographies that define the components of the landscape (geological, geomorphological, vegetation, hydrology) [28,30,35]. To do this, intensive photo-interpretation work was carried out on the aerial photography of the 1957 American flight and also on orthophotos from more recent years, i.e., 2004, 2020, and 2023. This phase made it possible to define the characteristics of the different units on the basis of the natural components and to delimit their territorial extension. The most significant components are [12,28]:

- The geomorphological component: This is obtained on the basis of the cartography of geomorphological units, and it is synthesized into a cartography of geomorphological domains. Then, these domains are grouped according to their representativeness in the landscape.
- The lithological component: The lithological zoning was obtained from the geological cartography and used to generate the lithological cartography, which was then synthesized into lithological units with a landscape impact.

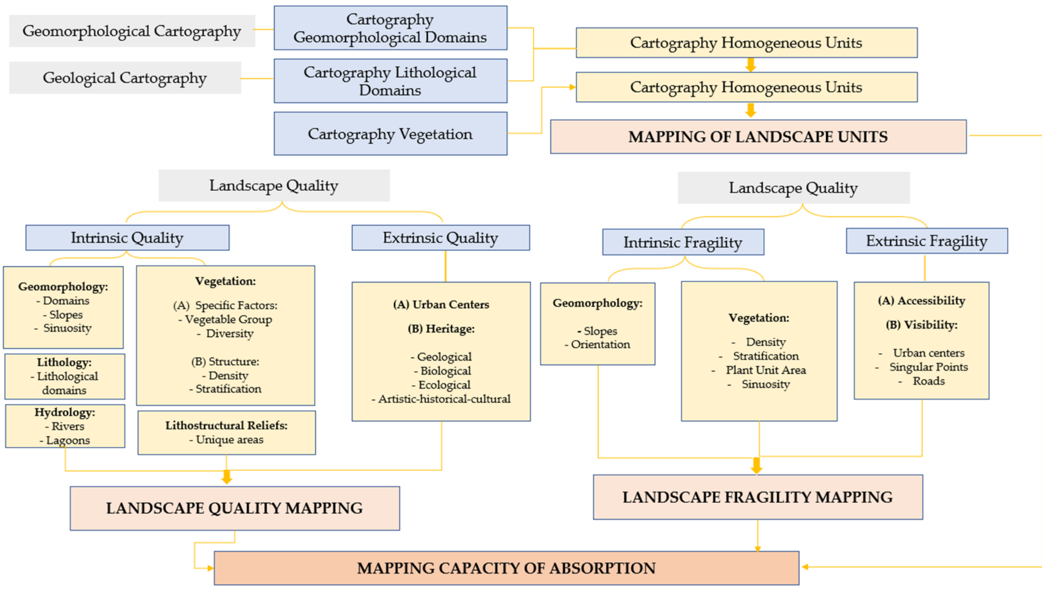

Figure 2. Methodological scheme.

In the second phase, several field campaigns were carried out to determine and characterize the landscape elements that define each of the units or sectors, which were grouped on the basis of the different components studied previously. The texture of the environment, scale, relief distribution, height, and horizontal stratification of tree species or color were observed [12,28,36].

The above components were grouped using map algebra and GIS techniques to obtain the cartography of homogeneous units. The cartographies of the components of the physical environment were simplified based on the elements and their visual analysis in the territory, by studying the degree of visibility and representativeness of each component. In addition, some of them needed to be eliminated and/or grouped according to the following criteria [12,28]:

- ✓ Smaller, scattered units that are perceptually unrepresentative should be included in larger and more conspicuous units.
- ✓ Those units that are similar to others should be integrated into the dominant group.
- ✓ Units that constitute relatively homogeneous portions of the terrain, in their environmental conditions and landscape components, should be grouped with those of greater perceptual impact.

Once the geomorphological and geological components were studied, the analysis of the third component involved in the landscape, the biotic factor, conformed by vegetation, was performed [12,28]. This component was obtained from the simplified cartography of vegetation units, resulting in a synthetic cartography for use in landscape.

Finally, considering the cartography of homogeneous units (geomorphology and geology) and vegetation cartography, a cartography of natural or environmental units of the landscape was generated [12,28].

2.3. Landscape Quality Cartography

The analysis of landscape qualities serves to identify areas where the aggregation of its components shows greater relevance, uniqueness, and importance, and require greater preservation. Thus, for a more detailed analysis, intrinsic and extrinsic landscape quality is considered:

- Intrinsic quality: this refers to the perception that an observer has, at any point in the territory, from where each unit is visible. It is based on the study of the components of each adjacent territorial sector with a pixel size of 1 meter. The different parameters are then weighted, considering the landscape preference of various authors and consultations with experts in the area [3,37,38]. These studies show that, in general, sites with topographically high and hilly areas are preferable to those with flat surfaces, especially if there is water and vegetation dominates the area, with the presence of trees being more highly valued than scrub. Moreover, landscapes with a high diversity or mosaic structure are valued more highly than those that are monotonous and homogeneous. Five factors are considered for this analysis [12,28]:

1. Geomorphological factor: This is the most relevant factor because the geomorphological domains condition the layout of the relief. Thus, some types of terrain have a more positive landscape assessment (ridges, river valleys, boxed valleys, canyons, escarpments, inselbergs) than others (erosion surfaces, pediments, terraces, sanding zones, floodplain). For the analysis of this factor, it is necessary to weight the following parameters:

    (A) Geomorphological domains: These determine the spatial disposition of the relief units with respect to the adjacent terrain by considering the processes that generate them and grouping them according to morphogenetic systems, i.e., each geomorphological unit is grouped into domains based on the agent that generated them and their associated processes. Table 1 shows the weighting of this parameter.

Table 1. Assessment of geomorphological domains.

Weighting	Geomorphological Domains
10	Fluvial canyon and "sierros"
8	Inselbergs and incised valleys
6	Lomes, valleys, colluviums, and cones of dejection
4	Surfaces and pediments
2	Floodplain, sandy zones, and meanders

    (B) Slopes: These are obtained from the 1-metre DTM, which generates a raster that will subsequently be reclassified into the following intervals (Table 2).

Table 2. Slope assessment.

Weighting	% Slope
0	0–5
2	5–15
4	15–30
6	30–60
8	>60

    (C) Sinuosity: this evaluates the more or less curved nature of the lines of the terrain. An index comparing the area and perimeter of the polygons defined between contour lines has been used for this purpose using GIS techniques [39]. The assessment is shown in Table 3.

Table 3. Sinuosity assessment.

Weighting	Sinuosity
8	Alta
4	Media
0	Baja

2. Lithological factor: Lithology predisposes chromatism in the landscape, which is very decisive when it comes to assessing the intrinsic quality of the natural environment. The color will depend on the different rocky outcrops, with lighter colors being more highly valued than darker ones. In this way, based on the different lithological units

and their relationship with the mineral composition, these units are reclassified in Table 4 into materials with a high percentage of leucocratic or melanocratic minerals:

Table 4. Assessment of lithological chromatism.

Weighting	Lithology
6	Granites, granodiorites, gneisses, and quartz dykes
4	Quartzites and metapelites
2	Slates and shales
0	Conglomerates, pebbles, sands, and clays

3. Hydrological factor: The presence of bodies of water represents an additional value for the nearby natural environment. This refers to watercourses, lagoons, and reservoirs which, in turn, generate a wetland area that can be inhabited by numerous organisms and favor the naturalness of the environment. In this way, the sectors close to watercourses (value 4) and to bodies of water (value 2) are valued. The former are more highly valued because they have a greater perceptual importance in terms of the visual and acoustic senses, as a consequence of the movement of water.
4. Morpho-structural relief factor: This refers to those elements that are singular on a perceptual level and correspond to litho-structural reliefs. These elements are defined by geological structures, such as folds, valleys, and river canyons. The factor is valued at 10.
5. Vegetation factor: Due to the variability of the vegetation, this is a parameter to be considered in the analysis together with the different types of vegetation. To carry it out, two parameters are analyzed:
    (A) Specific composition: this refers to the composition of the various plant associations, characterized by two aspects: plant grouping and diversity. The first is defined as the ecological value of the plant community analyzed, which depends on the dominant species in each plant association, its importance, and also the way in which it conditions the association. Diversity, on the other hand, refers to the fact that the mixture of species reduces the monotony of the landscape and favors the presence of mosaic distributions and particularities of the landscape. The ratings for plant grouping (Table 5) and plant diversity (Table 6) are as follows:

Table 5. Assessment of the plant grouping.

Weighting	Plant Grouping
8	Arboreal postage
6	Shrub
4	Sub-shrub
2	Herbaceous
0	No vegetation

Table 6. Assessment of specific diversity.

Weighting	Specific Diversity
6	More than 3 main species
4	3 main plant species
2	2 main plant species
0	1 or no plant species

    (B) Vegetation structure: This takes into account the presence and distribution of the different elements within each plant association and is defined according to plant density and stratification [40]. Density analyzes the horizontal structure of the vegetation mass and focuses on the amount of vegetation per unit area.

This parameter is assessed in three classes using the Covered Cover Fraction (FCC) (Table 7). The plant stratification, on the other hand, analyzes the vertical structure of the plant elements. In this way, three strata of possible height (herbaceous, shrub, and tree) are differentiated, in addition to the absence of plant strata (Table 8):

Table 7. Plant density assessment.

Weighting	% FCC
4	>40
2	<40
0	0

Table 8. Assessment of plant layering.

Weighting	Plant Layering
6	3 herbaceous + shrub + woody strata
4	2 herbaceous + shrub strata
2	1 herbaceous layer
0	No vegetative layer

To obtain the vegetation valuation cartography, each of the above four parameters is evaluated, reclassified, and superimposed using GIS techniques (map algebra) and applying Equation (1):

$$\sum \text{Vegetation factors} = (\text{Plant grouping}) + (\text{Plant diversity}) + (\text{Covered Cover Fraction}) + (\text{Plant stratification}) \quad (1)$$

Finally, to carry out the total assessment of the intrinsic landscape quality (ILQ), all the above factors were considered. They were superimposed using GIS techniques. By applying Equation (2), we obtained the corresponding cartography:

$$\text{CPI} = \sum \text{Geomorphological factors} + \text{Lithology factor} + \text{Hydrology factor} + \text{Structural relief factor} + \sum \text{Vegetation factors} \quad (2)$$

- Extrinsic quality: This refers to those elements that form the natural and cultural heritage and also to the presence of urban settlements, which add value to the quality of a landscape. In terms of heritage, it is evaluated considering its state of conservation, durability, value (natural and cultural), and social characteristic. In this way, natural heritage includes [12,28]:

(A) Geological heritage: Points of geological interest are considered. All these factors are grouped and weighted with a value of 10.

(B) Biological heritage: This groups plant and faunal heritage together. With regard to biological plant heritage, the areas where there are plant species must be considered by establishing an area of influence of 100 meters and weighting them with a value of 4. The faunistic heritage, on the other hand, groups together the critical areas and points of presence of faunistic species of interest, with an area of influence of 100 m. These, unlike the previous ones, receive a lower weighting (value 2), due to the fact that their presence is more restrictive to the visual field.

(C) Ecological heritage: The different sectors of natural ecological interest are grouped together by considering different criteria: reserve areas, which represent sectors of greater natural quality, weighted with a value of 6; special protection areas for birds (SPAs), which are weighted with a value of 4; and sites of community interest (SCIs), with a value of 2.

With regard to the valuation of the historical and cultural artistic heritage, those constructions and areas of great interest are considered and are subsequently grouped and weighted according to their uniqueness. Thus, the most singular are weighted with a value of 6 (for example, hermitages or churches) and the least singular with a value of 2 (archaeological areas and livestock trails).

On the other hand, the presence of urban settlements with a typology that does not damage the environment is also considered. They are considered as elements that provide recognition to the landscape, such as some of the sites of cultural interest (BIC). Therefore, their presence or absence is valued [41]. Thus, to carry out this assessment, a cartography is generated with the different urban centers, considering a radius of influence of 100 meters. The weighting was carried out in such a way that those sectors that are within the sphere of influence of the population were weighted with a value of 2, while those that are outside were given a value of 0.

Finally, to assess the quality of the landscape, the different thematic coverages were superimposed by considering Equation (3), thus obtaining the final landscape quality map. Intrinsic quality was weighted more highly than extrinsic quality, as it is more noticeable in the landscape [12,18].

$$\text{Landscape Quality} = 0.6 \times \text{Intrinsic Quality} + 0.4 \times \text{Extrinsic Quality} \quad (3)$$

2.4. Cartography of Landscape Fragility

Landscape fragility can be defined as the susceptibility of the landscape to certain human actions or other external impacts by analyzing the response capacity of the natural environment caused by its use. Thus, high landscape fragility is a negative aspect for the landscape because it is highly vulnerable to anthropic action, while low fragility corresponds to those sectors that have suffered less impact, and are valued positively [26,42].

In order to assess landscape fragility, it is necessary to carry out a cartographic analysis of intrinsic and extrinsic fragility to obtain a landscape fragility map. For this purpose, several parameters, such as geomorphology and vegetation, which have already been used to assess landscape quality, have been considered. However, this does not mean that they can affect fragility in the same way [12,28].

Firstly, the factors that determine intrinsic landscape fragility were studied. They are as follows [12,28]:

(A) Geomorphological factor. For the study of this factor, the following aspects have been considered:

- Slope: The increase in slope raises the susceptibility to human activities, accompanied by changes in the visual aspect of the landscape elements. For example, higher slopes do not favor human activities and the result is higher fragility values. The assessment is the same as that used for intrinsic quality (Table 2).
- Orientation: Spatial orientation (north, south, east, and west) is an important factor in the calculation of fragility. Thus, the areas of Solana have greater illumination due to the degree of sunshine they receive and present greater fragility than the sectors oriented towards shady areas, which receive less sunshine or less luminosity. Table 9 presents this evaluation:

Table 9. Orientation assessment.

Weighting	Orientation
6	North
4	East
2	West
0	South

(B) Area factor of the landscape units. The larger the area of a landscape unit, the more stable it is, the more difficult it is to modify its characteristics, and the less fragile it is. In order to carry out the analysis of this factor, the cartography of landscape units has been considered to calculate, in hectares, the different areas of each of them.

(C) Vegetation factor. This is responsible for evaluating the following aspects of vegetation:
- Density: A high density of the vegetation mass makes it more stable in the face of possible disturbances, increases its resistance, and decreases the probability of changes caused by external factors. In this way, the lowest densities are those with the highest values of fragility, due to the fact that they are sectors that are easier to modify and that receive a greater impact from external factors. In this case, the procedure to make this map consists of inverting the values of the density map for the quality of the landscape, as discussed above.
- Vegetation stratification: The diversity of strata of the vegetation mass has a direct influence on the analysis of fragility. The highest values of stratification provide the lowest fragility. The assessment is the same as in the case of quality, but with inverted values.
- Area of vegetation units: This refers to perceptual fragility, which increases or decreases with the influence of area and as the perception of impacts on the landscape increases or decreases. Any environmental modification is less perceptible in larger areas, i.e., the larger the area, the lower the fragility of the landscape, giving a value of 0. In the case of areas of greater fragility, the value would be 6.
- Vegetation sinuosity: This refers to the ratio of perimeter^2/vegetation area and allows the effect of this ratio on a vegetation unit to be assessed. Thus, the higher the ratio, the greater the fragility of the landscape, because these areas are more susceptible to possible actions. Its effects are more easily observable, with the valuation shown in Table 10.

Table 10. Assessment of vegetation sinuosity.

Weighting	Fragility of Sinuosity
6	Very High
4	High
2	Low
0	Very low

Once the above factors have been studied and their corresponding cartographies have been drawn up, the cartography of intrinsic landscape fragility (ILF) was obtained from the sum of the cartographies of the above factors, by means of GIS techniques and using Equation (4):

$$\text{ILF} = \text{Geomorphological Fragility Cartography (slopes + orientation) + Landscape Unit Area Fragility Cartography + Vegetation Fragility Cartography (density + vegetation unit area + sinuosity)} \quad (4)$$

Then, extrinsic landscape fragility was determined by considering the following factors [12,28]:

- Accessibility: An area is said to be accessible when it is close to an urbanized sector or access infrastructures. Thus, to calculate the areas with greater accessibility, urban centers and roads are considered, to which we apply a zone of influence of 500 m from the point or line of immediate access. In this way, the areas of easy access are those with greater fragility, compared to the sectors farther away from the areas where human concentration is lower or practically non-existent due to the lack of inaccessibility [43].
- Visibility: This can be analyzed through the creation of visual basins, from the DTM. Therefore, the visual incidence of the different human activities and/or natural elements can be determined. In this way, to carry out this analysis, the points of social interest of greater human affluence are considered, as well as the linear coverage of roads.

Once the two previous factors have been studied, the cartography of extrinsic landscape fragility (ELF) is carried out, which is obtained after integrating the cartographies of fragility, accessibility, and visibility and by applying Equation (5).

$$\text{ELF} = \text{Cartography Fragility accessibility} + \text{visibility} \quad (5)$$

Finally, the cartography of landscape fragility (MLF) was obtained by weighting and summing all the layers obtained. Intrinsic fragility is of greater importance because it influences the vegetation physiography and conditions the vulnerability and the capacity to absorb activities that may be installed in each unit of the territory. Extrinsic fragility, on the other hand, is the inverse perception because it intervenes in the perception of an observer located at a point in the environment of one or several specific units. In other words, this concept reflects the potential views of each landscape unit, with less influence than the intrinsic fragility, which indicates what each unit shows. For this purpose, Equation (6) was applied using GIS techniques.

$$\text{MLF} = 0.6 \times \text{Intrinsic Fragility Cartography} + 0.4 \times \text{Extrinsic Fragility Cartography} \quad (6)$$

3. Results

3.1. Cartography of Landscape Units

This cartography (Figure 3) is used to describe the different landscape units by considering the inventory of the different components that make up the landscape and their integration. In this way, different useful maps have been obtained in territorial planning. Once these cartographies were made, the on-site check was carried out, which consisted of direct observation on foot and by car and taking photographs.

Twelve different landscape units were determined in the study area:

Landscapes of fluvial canyons: These constitute one of the most striking landscapes corresponding to the deep incision of the Duero River. They present great scenic value of great naturalness, in an encased space with a scale with a location effect, and with a limitation to the observer with respect to its position, due to the presence of steep walls with a vertical distribution. Two different units can be distinguished:

Fluvial canyons on granite and gneiss rocks with arboreal and sub-shrub formations: The slopes are characterized by rounded shapes with the presence of arboreal formations such as "piorno", together with sub-shrub species such as broom (Figure 4A,B). This unit occupies 1.8% of the total area.

Canyons on metamorphic rocks with tree and sub-shrub formations: The slopes are not as well defined as in the previous case, with the same tree formations (Figure 4C). They have an extension of 1.2%.

Landscapes of incised valleys, colluviums, and cones: These correspond to the incised valleys of the most abundant tributaries of the Duero River (Águeda, Huebra, and Tormes). These are sectors in which the relief is a great protagonism. Landscapes have a great scenic value and a high degree of naturalness. These are closed landscapes due to the existence of abrupt walls that act as visual barriers. Two different units can be distinguished in this landscape:

Boxed valleys with granites and gneisses with arboreal–bush formations. There are rocky outcrops on the slopes and tree formations where the edaphic power is greater, such as mixed formations of holm oaks and juniper, and shrubs such as white broom (*Citysus multiflorus*) or broom (*Genista hystrix*) (Figure 4D). This is a unit with a surface area of 3.4%.

Valleys incised with metamorphic rocks with arboreal–shrub formations and crops, pastures, and fallow land. Unlike the previous ones, they present higher tree density as riparian forests with ash groves (*Fraxinus angustifolia*) (Figure 4E). Their surface area is 2.7%.

Valley landscapes: These correspond to valleys with little incision in the terrain and usually link the surfaces with the valleys that present great incision. Two units can be distinguished:

Valleys with granites and gneisses with arboreal–subarbuscular formations, crops, pastures, and fallows (Figure 4F). This unit occupies 13.9% of the total area. These are open valleys where stream water begins to be channeled over granitic and gneissic lithologies, with scattered groups of arboreal and subarboreal formations with pastures and fallow lands.

Valleys with metamorphic rocks with arboreal–subarbuscular formations, crops, pastures, and fallow land (Figure 4G). These correspond to wide valleys with darker colors than the previous unit as they present metamorphic substrates with groupings of arboreal and subarbustive formations with pastures and fallow lands. This is the unit with the second largest extension, of 14.6%.

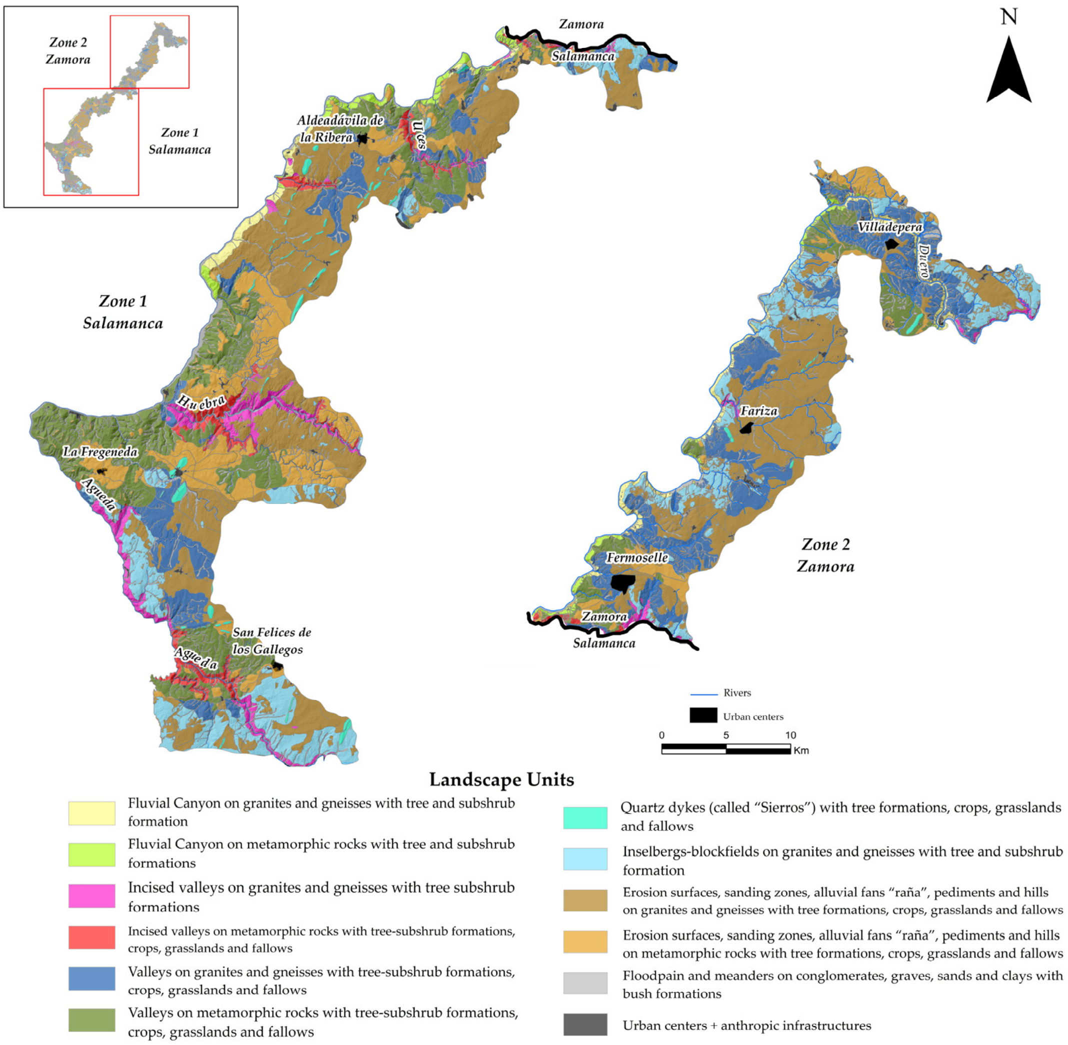

Figure 3. Cartography showing the 12 units that characterize the Arribes del Duero landscapes.

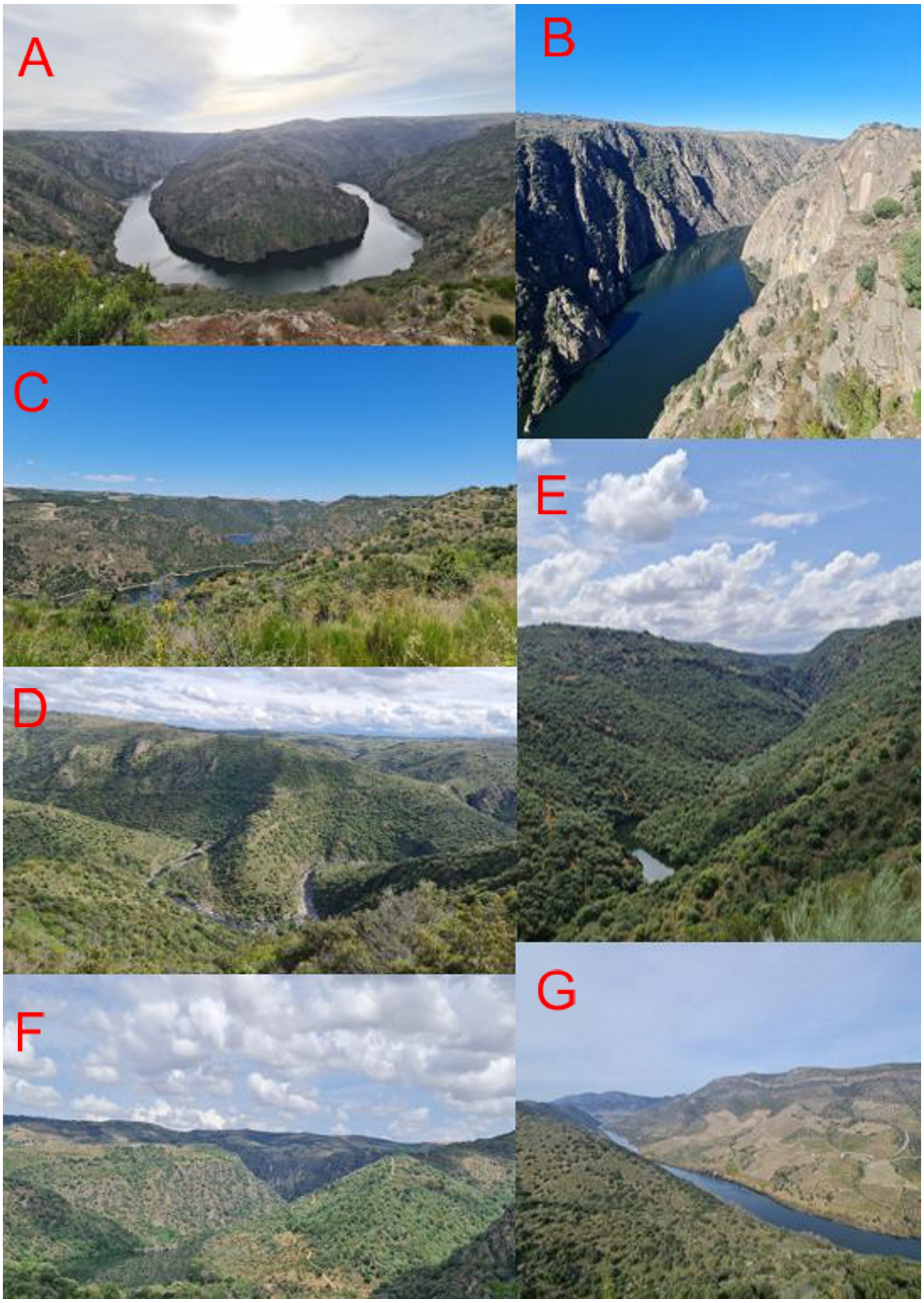

Figure 4. Fluvial canyons over granites and gneisses with arboreal and sybarbustive formations in Fornillos de Fermoselle (**A**) and in the vicinity of the Aldeadávila dam (**B**); fluvial canyons over metamorphic rocks with arboreal and subarbustive formations in Fermoselle (**C**); valleys incised with granites and gneisses with arboreal–sybarbustive formations in the Huebra area (**D**); valleys with metamorphic rocks with arboreal–sub-shrub formations and crops in the Uces river (**E**); valleys with granites and gneisses with arboreal–sub-shrub formations and crops in the vicinity of Fermoselle (**F**); valleys with metamorphic rocks with arboreal–sub-shrub formations and crops in the vicinity of La Fregeneda (**G**).

Landscapes of surfaces, alluvial fans (called “rañas”·), sanding zones, pediments, and hillocks. These correspond to sectors of more or less flat terrain, with hardly any slope and a great amplitude. They present two-dimensional forms, with lines in silhouette, a fine texture, and high contrast. The space is of a panoramic type with a scale that is characterized by a distance effect due to the amplitude of the unit. This is one of the largest landscapes in the study area. Two different units are distinguished:

Surfaces, “rañas”, sanding zones, pediments, and hillocks with granites and gneisses with tree formations, crops, pastures, and fallow land. These are located in the surroundings of the valleys and the fluvial canyon, with rounded shapes as a consequence of their lithology and with the presence of arboreal vegetation such as holm oaks (Figure 5A), and some woody crops (mainly fruit trees) and pasture crops in glacis areas (Figure 5B). This is the largest landscape unit, occupying 29.8% of the total area.

Surfaces, “rañas”, sanding zones, pediments, and hills with granites and gneisses with tree formations, crops, pastures, and fallow land. These are also located in the surroundings of the valleys, but not in the vicinity of the canyon. They present riparian forests of willow (*Salix salvifolia*) and dry crops, generally cereals (Figure 5C). They occupy an area of 11.1%.

Landscapes of valley bottoms and meanders: These occupy 7.9% of the total surface area. They are constituted by the alluvial valley bottoms of rivers and streams, with conglomerates, pebbles, sands, and clays. These landscapes are linked to the presence of surface water that allows the development of arboreal formations such as riparian forests. The relief has no very vigorous forms, so it does not have much prominence. It presents sectors with a great solid angle that increases its perception, in addition to visual basins of great extension with medium textures. Abandoned meanders are also observed, such as the one of the Saucelle dam (Figure 5D). Finally, another example of these landscapes can be found in the Huebra river, especially at the Molinera bridge (Figure 5E).

Landscapes of inselbergs (Figure 5F,G) and blockfields (Figure 5H). These correspond to large plutonic edifices and more degraded sectors interspersed with saprolites from the sandification of granite that generate, depending on their evolutionary state, different forms such as rocky ground, domatitic forms, and dispersed granitic blocks. They occupy 10.9% of the total area.

They correspond to alignments with a great morphological reflection in the landscape by highlighting quartzite elevations (white colors) on the horizon and in the middle of topographically flatter areas such as surfaces and glacis. This unit occupies the least surface area, i.e., 1% of the total.

3.2. Landscape Quality Cartography

This cartography was obtained from the integration of the components of greatest relevance, uniqueness, and importance. In the detailed analysis, the intrinsic and extrinsic quality were considered.

Intrinsic landscape quality: Based on the cartography of each of the territorial factors considered (Figure 6A–F), the intrinsic quality cartography was obtained (Figure 6G) and classified into five classes from very high to very low quality. Thus, it can be seen that the areas of very high quality correspond to areas of the Duero river, the valleys of the Tormes, Águeda and Huebra rivers, and the inselbergs, i.e., to very localized areas. The high and medium quality areas correspond to valley areas which are sectors with a certain lithological relevance. Finally, the sectors of low and very low quality correspond to erosive surfaces, pediments, sanding zones, and valley bottoms, with a lithology composed of conglomerates, pebbles, sands, and clays.

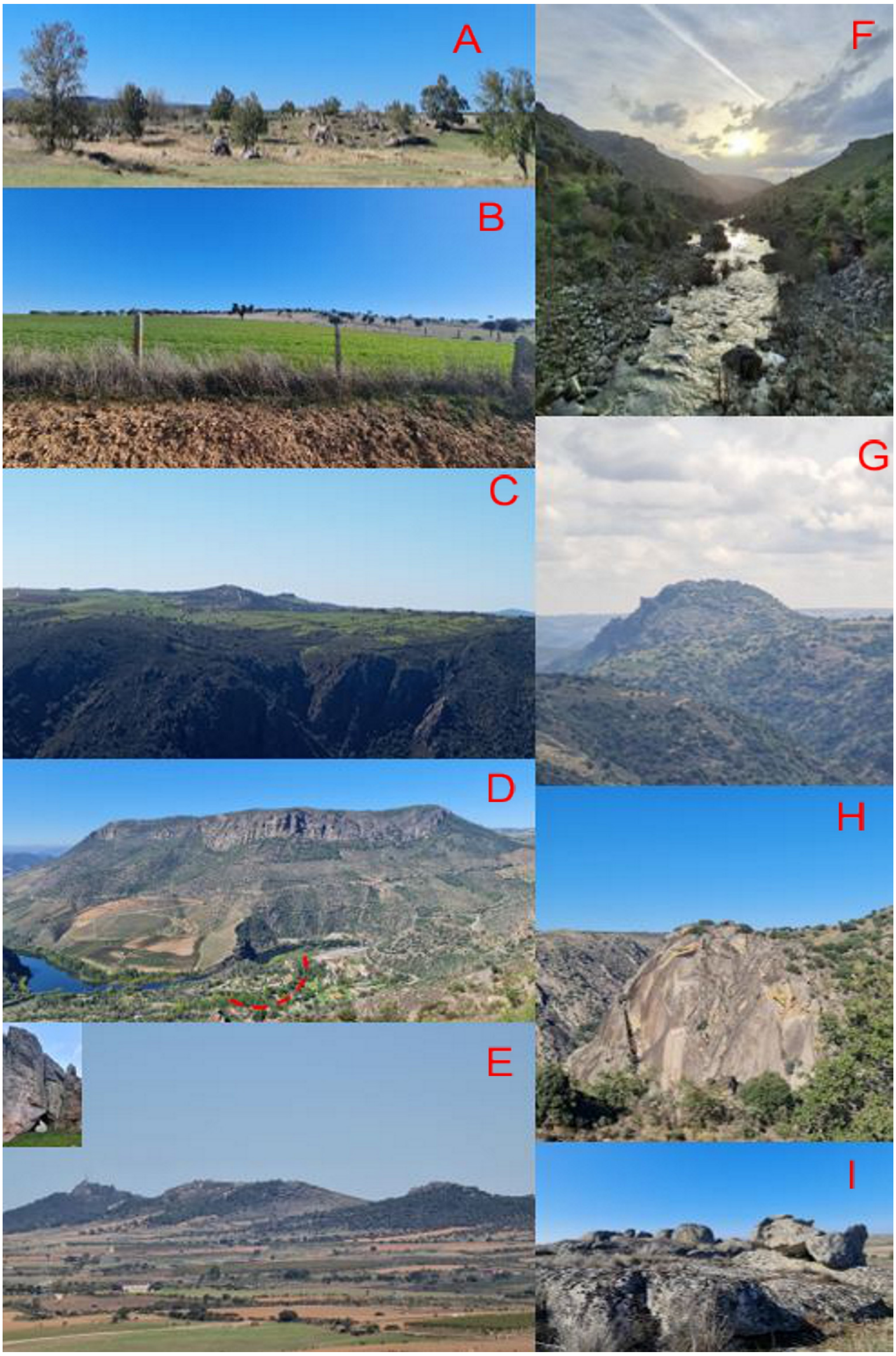

Figure 5. Surfaces, sanding zones, pediments, and blockfields with granites and gneisses with tree formations and crops in the vicinity of Zarza de Pumareda (**A**) and in the vicinity of Hinojosa de Duero (**B**); surfaces, sanding zones, pediments, and blockfields with granites and gneisses with tree formations and crops seen from the Puerto de la Molinera (**C**); abandoned meander in the Saucelle Dam (**D**) and valley bottoms in Huebra river (**F**); inselbergs in Aldeadávila (**G**,**H**) and blockfields (**I**); Sierro in Cerezal de Peñahorcada (**E**); mountain range landscapes (**I**).

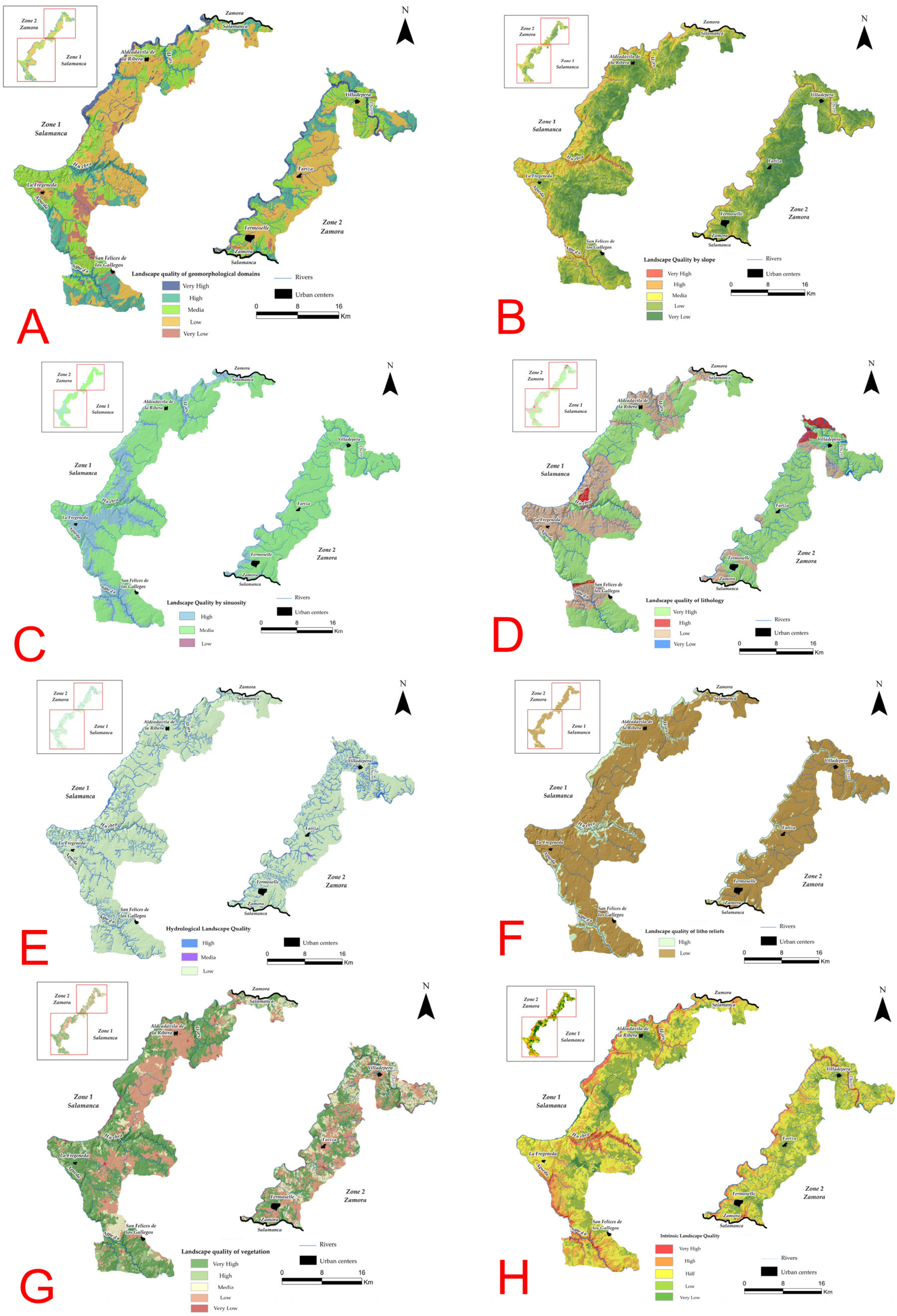

Figure 6. Quality cartographies of intrinsic factors: (**A**) geomorphological units; (**B**) slopes; (**C**) sinuosity; (**D**) lithology; (**E**) hydrology; (**F**) litho-structural reliefs; (**G**) vegetation; (**H**) intrinsic quality.

Extrinsic landscape quality: For its preparation, the cartography of each of the elements of the natural and cultural heritage, as well as the presence of urban settlements (Figure 7A–C), were considered. Like the previous cartography, the extrinsic landscape cartography (Figure 7D) was classified into five classes: the zones of very high, high, and medium extrinsic quality were very specific and coincide in areas where there is some type of protection, such as a special protection area for birds (ZEPA), or due to the existence of urban settlements. The low and very low quality zones are the most extensive, being areas of little interest from the point of view of cultural, biological, and ecological heritage.

Finally, by applying Equation (3), we obtain the cartography of landscape quality, as shown in Figure 8. This cartography shows that the areas of highest quality occupy 26% of the surface area and correspond to hilly areas such as the Duero river canyon and the valleys of the most abundant rivers (Tormes, Águeda, Uces, and Huebra). They are areas considered to be of special protection for fauna and also with flora protection figures (preferential attention, endangered, regulated use, and vulnerable), with the presence of tree formations and mosaic structure. The medium quality is the largest extension, occupying 39%, and corresponds to valley areas and crags with some form of flora protection. Lastly, the lowest landscape quality is 35% and corresponds to areas such as erosive surfaces, with little biological diversity homogeneous structure and without flora and fauna protection.

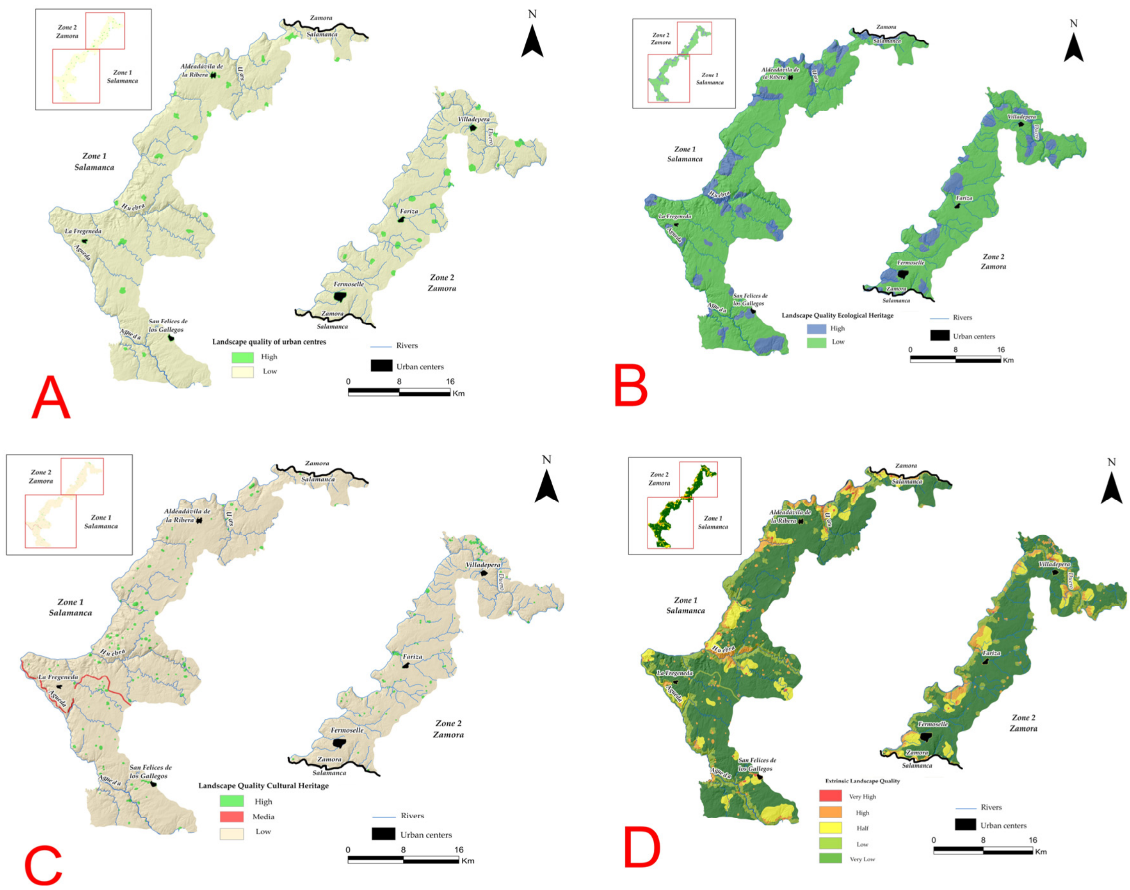

Figure 7. Extrinsic quality cartographies: (**A**) urban centers; (**B**) ecological heritage; (**C**) cultural heritage; (**D**) extrinsic quality.

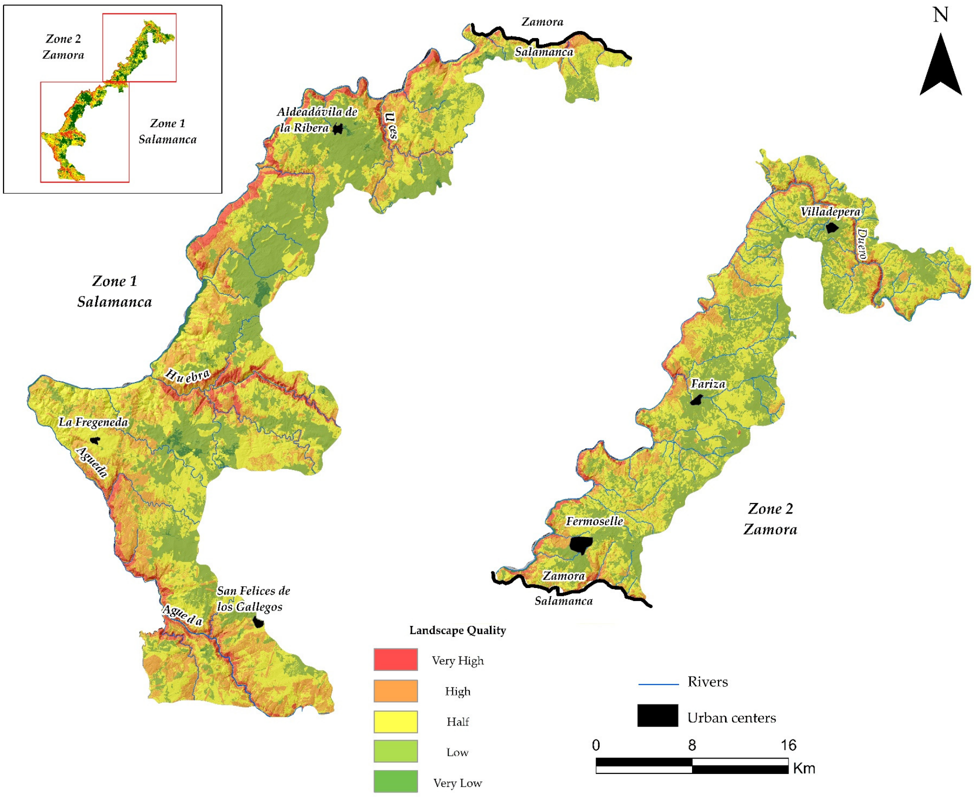

Figure 8. Landscape quality cartography.

3.3. Landscape Fragility Cartography

This cartography was based on the analysis of intrinsic and extrinsic factors, considering several parameters:

Intrinsic landscape fragility: From the integration of the cartographies made of the different factors (Figure 9A–F), the cartography of intrinsic landscape fragility was obtained (Figure 10A). As with the intrinsic quality, the values obtained are classified into five classes according to their degree of fragility (very high to very low). The highest values, i.e., the most fragile zones, were observed in areas of high slope that do not favor the settlement of human activities, such as the fluvial canyon, with a north-east orientation, which constitutes the sunny area and receive greater insolation. With respect to vegetation, these areas are characterized by low density and stratification, due to the fact that they are prone to modification, in addition to receiving a greater impact from external factors. On the other hand, the lowest values were observed in areas with little or no slope, such as erosive surfaces, with a south-west orientation and high stratifications and densities.

Extrinsic landscape fragility: This cartography, like the previous one, was carried out considering the integration of the different extrinsic factors, thereby obtaining a cartography of extrinsic landscape fragility (Figure 10B), classified into five classes. Thus, in the cartography it can be seen that the areas of greatest extrinsic fragility are those with good accessibility, either because of the existence of roads or municipalities, and those with greater visibility of different natural elements (protection areas, points of geological interest, etc.).

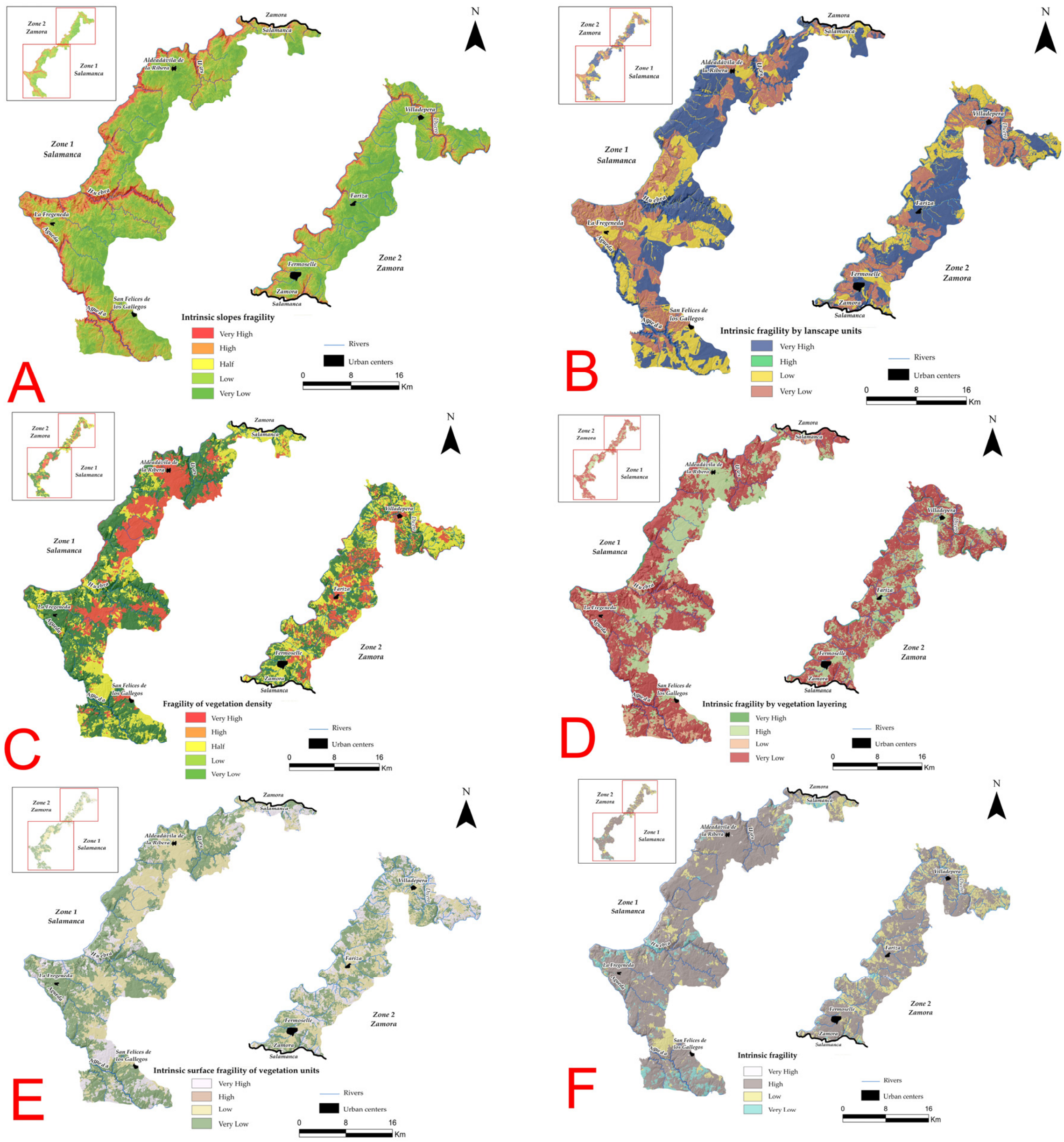

Figure 9. Intrinsic cartographies: (**A**) slopes; (**B**) landscape units; (**C**) FCC; (**D**) plant stratification; (**E**) surface area of plant units; (**F**) sinuosity.

Finally, once the previous cartography was carried out and the equation applied, the cartography of landscape fragility was obtained (Figure 11), with values between 2 and 30 and classified into the five fragility classes. On this map, it can be seen that the areas of greatest fragility are scarce, occupying barely 4% of the surface area, and are concentrated in the outskirts of the municipalities and in the areas of the Duero river basin. The areas of medium fragility are larger than the previous ones, 23%, and are located in surface areas. As for the less fragile areas, they occupy the largest part of the study area, i.e., 73% of the surface area, and correspond to erosive surfaces with crops, trees, or some anthropic activity that give them a greater reception capacity.

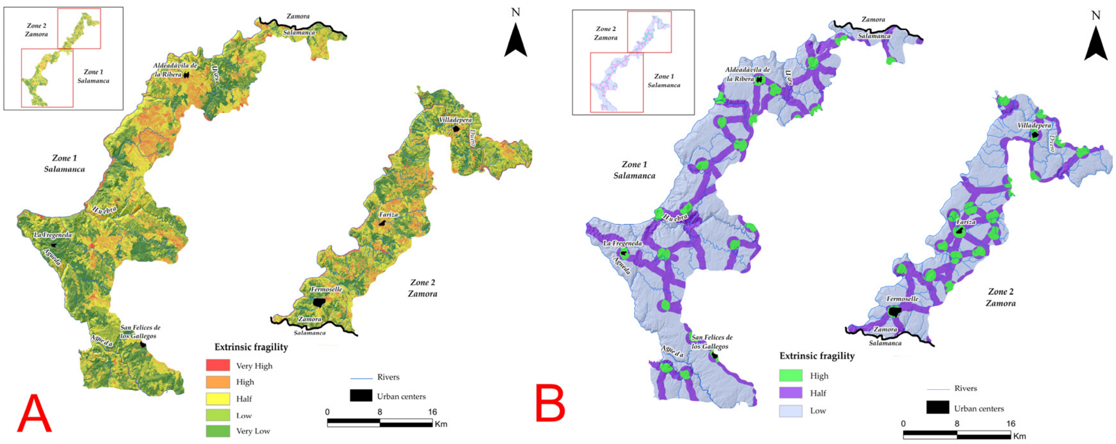

Figure 10. Cartographies of fragility: (**A**) intrinsic; (**B**) extrinsic.

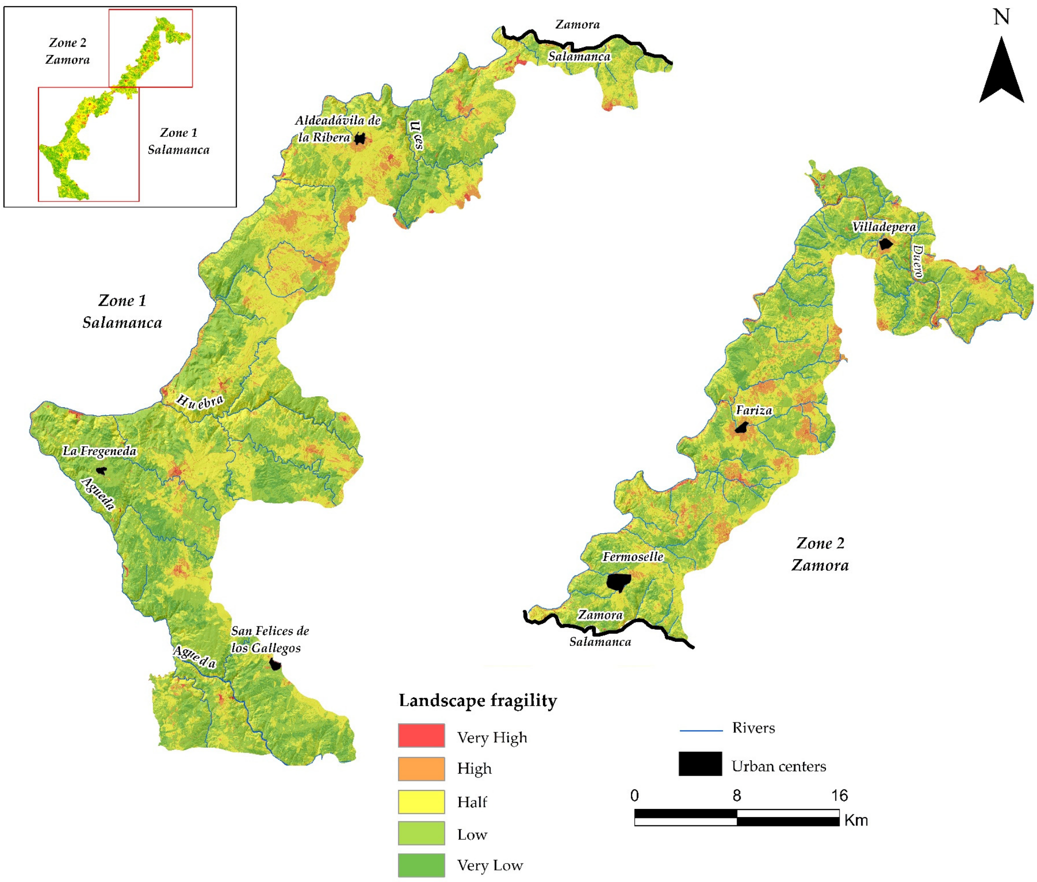

Figure 11. Cartographies of fragility.

4. Discussion

Until now, landscape studies have been considered, for the most part, very subjective because they were conditioned both by the existing environment in each territory and by the psychosocial interests of the observer himself, emphasizing the social, psychological, and economic points of view of the potential observers (urban, rural, religious, ethnographic, etc.). Following the European Landscape Convention, the need to carry out inventories and determine the different landscapes that encompass the singularities of each territory was established, and for this reason, this objective methodology is proposed, based on the creation of geo-referenced and quantifiable cartographies of the different landscape units, based on the natural components of the territory and its singular elements on a smaller scale. In this way, subjectivity is objectified, since the components are measurable and, with the help of GIS techniques, their gain or loss can be measured and assessed in terms of the potential natural capital of possible ecosystem services, since the landscape is a growing resource that is directly involved in the socio-economic environment of a natural space. In this sense, progress is being made in detailed studies of landscape metrics in urban environments or very specific, small areas, or in studies that make it possible, using automatic procedures, to obtain a satellite image to establish the singularities of the area studied.

Our proposal establishes a methodology capable of determining and characterizing territorial landscape units (which to date were simply a physiographic reclassification of the territory according to the different heights of the terrain) that define possible future actions and minimize the vulnerability and environmental impact of anthropic activities or even serve as a tool for prevention in pre-project strategic evaluations.

A landscape analysis is a complex process due to the need to understand the different resources of the physical environment (geology, geomorphology, edaphology, vegetation, etc.), as well as the internal relationships that exist between them. It is therefore a multidisciplinary approach that requires the application of different methods to tackle the complexity of the environment, which converge in a fundamental principle despite their diversity: the territorial reality.

Landscape studies carried out in recent decades have been conducted from two fundamental perspectives: an objective one, which focuses on the evaluation of the natural quality of the landscape, and a subjective one, aimed at appreciating its perception and beauty. As far as this work is concerned, the cartographies generated from these natural resources prioritize geomorphology as a central element in the configuration of the landscape. In addition, these maps synthesize information on lithology and vegetation, reflecting their visual attributes in a comprehensive manner [12,13].

The cartography model implemented in the Arribes del Duero Natural Park constitutes an exhaustive analysis of the resources of the natural environment. The assignment of values is carried out by means of a weighting of different parametric cartographies by considering a multiplicity of criteria and coefficients, which are adjusted according to intrinsic or extrinsic variables. This complexity requires the process to be automatic and leads to the creation of interpretative and synthetic cartographies, based on GIS techniques.

The validation of these cartographies, in order to guarantee their accuracy, was carried out by means of direct methods through direct observation in the field, where different aspects of the landscape were recorded and analyzed. Photographs were also taken. In this way, the landscape units identified in the field through these direct methods are in precise agreement with those obtained by means of the cartography methodology based on indirect methods. This validation, carried out without resorting to GIS techniques, which shows the reliability of the procedure in our study area, as has been evidenced in works that also do not use such techniques [2,6].

The identification of sites of special interest in different areas implies the determination of landscape units with the highest quality and natural beauty for their conservation, knowledge, and protection. This is facilitated by landscape quality cartography, which simplifies the identification of areas requiring conservation measures, especially those with abundant natural resources of great uniqueness and minimal human intervention. The quality cartography obtained shows that the areas of highest quality occupy 26% of the surface area and correspond to hilly areas such as the Duero river canyon and the valleys of the most abundant tributaries of the Duero. The areas of medium quality occupy the largest area, i.e., 39% of the surface area, and are the valleys and crags. As for the areas of lower quality, they cover 35% of the surface and correspond to very regular and flat sectors, such as erosive surfaces.

The analysis of the landscape vulnerability of each zone according to the different land uses requires an analysis of the fragility of the landscape. Landscape fragility is defined as the inverse capacity to absorb alterations without experiencing a decline in quality. The fragility cartography obtained shows that the most fragile areas are scarce and are located in the Duero river basin, coinciding with the areas of highest quality.

Finally, the analysis of the landscape, and its quality and fragility, makes it possible to determine and characterize territorial landscape units which, until now, were simply a physiographic reclassification of the territory according to the different heights of the terrain. This analysis serves to define possible future actions that minimize the vulnerability and environmental impact of anthropic activities or even serve as a tool for prevention in pre-project strategic evaluations.

5. Conclusions

The characterization of homogeneous units identified in the terrain makes it possible to assess the impact and visibility of each one in the natural environment, and thus to establish the quality and fragility of the landscape.

Twelve landscape units were differentiated. They were mapped and identified in the field by direct observation and by analyzing the components and elements of each perceptual unit. This allowed us to analyze of the quality and fragility of the landscape.

In terms of quality, the highest quality areas were found in the areas of the Duero river canyon and the medium quality ones are located in the larger areas. They coincide with the valleys and crags. The areas of lower landscape quality are made up of erosive surfaces, lacking in natural elements that stand out due to the monotony of the peneplain.

In terms of fragility, the areas of greatest landscape fragility are those with the least extension. They are very localized in areas of urban centers and in areas of steep slopes where human settlements are difficult.

Finally, the least fragile areas are the most representative in the area and occupy erosive surfaces with the presence of herbaceous and/or woody crops that give them a greater reception capacity.

The methodology presented is very useful as it provides landscape maps that represent the locations of high quality and fragile landscape areas that need to be protected from human activities, especially in protected areas such as Arribes del Duero. Moreover, it is easily applicable to any place on the planet. It can be used to promote sustainable land management in natural and rural areas, in order to define possible future actions to reduce the vulnerability and environmental impact of anthropogenic activities.

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