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Assessment of landscape visual fragility in the Natural Protected Area Sierra de las Nieves (southern Spain)

Evaluación de la fragilidad visual del paisaje en el Espacio Protegido Sierra de las Nieves (sur de España)

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Abstract

Visual fragility is a fundamental analysis of landscape quality, especially for protected natural areas highly valued for their biodiversity, geodiversity and cultural heritage. This is the case of the Sierra de las Nieves Protected Natural Area, located in southern Spain, declared a national park in 2021 and which brings together outstanding natural systems. Its aesthetic character is a key point for both the local population and visitors, so phenomena such as fire pose a territorial threat. This study analyses which are the most fragile landscapes from a visual point of view. Thus, using spatial analysis techniques in GIS, the landscape units were delimited and their visual fragility was evaluated considering a 5x5m DEM of spatial resolution and defining visual basins from geolocated points along the road network, which included paved roads, unpaved roads and official trails of the study area. The results indicate a broad spatial variability in visual fragility depending on the observation point, throughout the natural area, although the landscapes with the highly valued forests of *Abies pinsapo* Boiss. and *Quercus alpestris* showed the greatest fragility, especially those located in the central, southern and eastern sectors over 900 m above sea level. These results contribute to managing the areas most exposed to threats with a visual impact, such as fire, which can negatively influence the aesthetic character of the landscapes of the Sierra de las Nieves.

Keywords: Landscape units; visual fragility; road network; natural protected area; Sierra de las Nieves.

Resumen

La fragilidad visual es un análisis fundamental en la calidad del paisaje, especialmente, para espacios naturales protegidos muy valorados por su biodiversidad, geodiversidad y patrimonio cultural. Este es el caso del Espacio Natural Protegido de la Sierra de las Nieves, situado en el sur de España, declarado parque nacional en 2021, que reúne sistemas naturales destacados. Su carácter estético es un punto clave tanto para la población local como para los visitantes por lo que fenómenos como el fuego suponen una amenaza territorial. Este estudio analiza cuáles son los paisajes más frágiles desde el punto de vista visual. Así, utilizando técnicas de análisis espacial en SIG, se delimitaron sus unidades de paisaje y se evaluó la fragilidad visual de estas, considerando un MDE de 5x5m de resolución espacial y definiendo cuencas visuales desde puntos geolocalizados a lo largo de la red viaria, que consideraba carreteras asfaltadas, caminos sin asfaltar y senderos oficiales del espacio natural. Los resultados indican una gran variabilidad espacial en la fragilidad visual dependiente del punto de observación, en todo el espacio natural, si bien los paisajes con bosques muy valorados de *Abies pinsapo* Boiss. y *Quercus alpestris* mostraron la mayor fragilidad, especialmente, aquéllos localizados en los sectores central, meridional y oriental por encima de 900 m.s.n.m. Estos resultados contribuyen a gestionar las zonas más expuestas a amenazas con impacto visual, como es el fuego, que pueden influir negativamente en el carácter estético de los paisajes de la Sierra de las Nieves.

Palabras claves: Unidad de paisaje; fragilidad visual; red viaria; espacio natural protegido; Sierra de las Nieves.

1. Introduction

Studies on landscape analysis are usually faced following a dual approach: i) the total landscape or phenosystem analysed based on indirect methods such as inventory, description, and distribution of the interrelated landscape components (reliefs, vegetation, hydrology, etc), and their features (slopes, orientation, etc.); ii) the visual aspect of the landscape or cryptosystem based on indirect methods assessing either the natural environment with aesthetic criteria of beauty or forms perception (García-Quintana et al., 2005; Klauko et al., 2017; Martínez-Graña & Valdés, 2016). The land management planning should be based on the carrying capacity of the territory, determining the different levels of protection required for important natural features, obtaining input from human activities as prescribed the resilience or land use grade integrating the results with environmental values (Bastin et al., 2013; Martínez-Graña et al., 2019; Nativi et al., 2013). A significant environmental impact, especially in nature protected areas, is linear infrastructure (e.g., roads, power lines, pipelines, forest paths, hiking trails, etc.) but also climate change (Gutiérrez-Hernández et al., 2018) and wildfires (Ojeda et al., 2021), especially in Mediterranean environments. All of them may affect the environmental quality of areas with high biodiversity and geodiversity, but also of cultural heritage, so an active management by public administration is fully desirable (Martínez-Graña et al., 2014; Samarasinghe & Strickert, 2013).

The European Landscape Convention (2000) signified the methodological review of the relationships between land observable components in an accessible way by the average subject and their current spatio-temporal composition. Thus, the approach to landscapes from the scientific perspective incorporated features, which are aesthetically identified by the observer (Saeidi et al., 2017; Vallina Rodríguez, 2020). Landscape is no longer seen and treated as a combination of sciences but is placed above them to become a universal way of observing the environment. This study adopted the conception of landscape made by Cancer (1994), which defines it as a set of visible or invisible facts, from which the observer perceives, at a given moment, a global result of a territory. Thus, if the landscape has an evident exteriorization of visual character, it seems coherent to consider in its analysis also the observer himself and the evocations or sensations of aesthetic nature that he perceives Faced with these new challenges posed by the field of knowledge on landscape, the sciences, and more specifically the geographical sciences, reacted decades ago with the emergence (Hermes et al., 2018) of new techniques and procedures of valuation and aesthetic and/or environmental objectification of the perceived landscape, that is, the visual landscape.

The determinations that can be made about visual quality from any scientific discipline are among the most difficult aspects to quantify in terms of the quality of the visual experience with regard to the environment, since their calculations must constantly balance naturalness and the preservation of pre-eminent values (Franch-Pardo & Cancer, 2017). All these estimates, of course, are theoretical level, but they have an empirical reflection based on specific landscapes, with multiple and varied interests for the population, and where it will be necessary to consider the uses that are or may be developed in these landscapes (Vallina Rodríguez, 2020). Two are the components that will generally be used in the determination of the overall value of landscape quality: quality and visual fragility, both of which can be evaluated by means of direct or indirect methodologies. This research will only consider visual fragility as a basis for landscape assessment, understood as the degree of susceptibility to deterioration through the incidence of certain actions (Dos Santos Pires, 2011). Thus, the visual fragility of landscape may be used as a criterion for evaluating its vulnerability to human activity or any other risk factors causing the loss of its pre-existing visual quality may be one feasible approach. In fact, there have been conducted scientific studies dealing with this concept to assess the impact of linear infrastructures (Martínez-Graña et al., 2019), rapid changes in vegetation cover (Scarfò et al., 2013), and wildfires (Ojeda et al., 2021).

In natural protected areas, it is a key issue delimiting and inventorying which natural systems are more exposed to threats leading to decrease biodiversity and geodiversity. However, those areas are usually highly valued from an aesthetic point of view by both locals and visitors alike as well. The study of the aesthetic-visual dimension of landscapes has been extensively approached by numerous authors, among whom the Anglo-American school of "Landscape planning and architecture" stands out first (Linton, 1968; Litton, 1972; M. Laurie, 1983; I. C. Laurie, 1975; Lovejoy, 1973; McHarg, 1969; Zube, 1976; Ramos et al. 1976). In subsequent decades, various methodological approaches applied to land use planning have emerged with authors such as Aramburu Maqua & Escribano Bombín (2014). The development of informatics and computers since the second half of the 1980s allowed one constant expansion of knowledge in this field and the possibility of making a quantitative treatment to a wide variety of data (Sang et al., 2016; Parrilla Alcalá et al., 2005; David et al., 2013; Giolito & Meyer, 2016; Vallina Rodríguez, 2020). Through the quantification of visual fragility, the degree of deterioration of the landscape properties can be obtained depending on the type of activity that affects it. The methodology to be followed for this quantification has been addressed by numerous authors from different points of view (Fischer, 1995; Bishop, 2002, 2003; Turner & Gardner, 2001).

The Natural Protected Area of Sierra de las Nieves (NPA Sierra de las Nieves, in advance) has recently become member of the Spanish National Park Network because of the existence of remarkable natural systems, especially, those of fir forest (*Abies pinsapo* Boiss.), pine forest in peridotites relieves, and high mountain oaks (BOE, 2021). But this territory is not only outstanding due to the ecological values, but also for remarkable aesthetic values for the local population and visitors. Besides, it is in a region of a wide variety of threats such as climate change with implications to the type and vegetation cover, wildfires, water resources, and sudden land use changes (Delgado-Peña et al., 2017; Martínez-Murillo et al., 2016). Accordingly, it is justified the aim of this study as the assessment of the visual fragility in the landscape units from the NPA Sierra de las Nieves. Namely, the specific objectives are the following: i) describing landscape units in the study area; and ii) determining the visual fragility of the landscape units considering visual basins from road network including main and unpaved roads, and trails because of their great use by tourist and local population to visit and moving around the NPA Sierra de las Nieves.

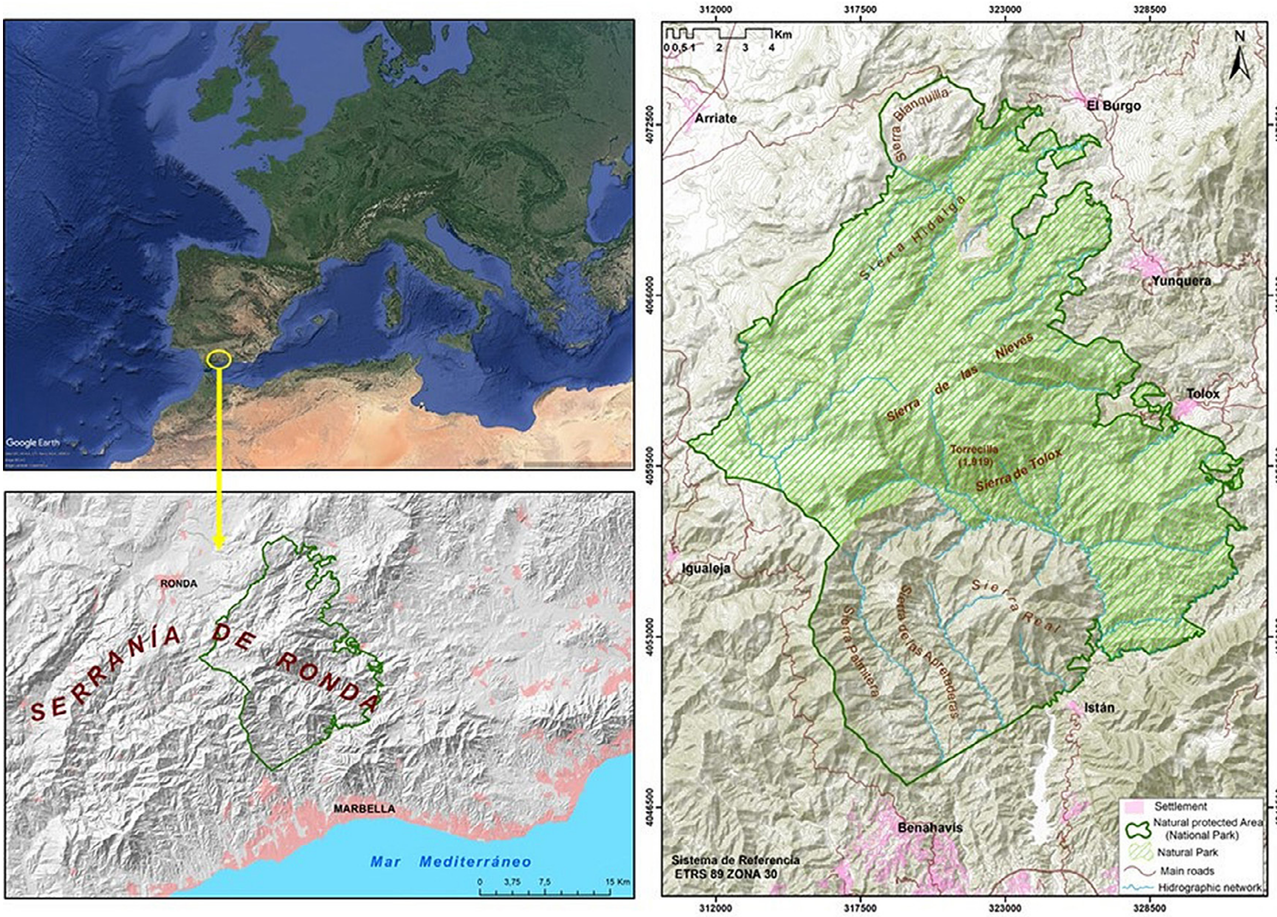
2. Methodology

2.1. Study area

The NPA Sierra de las Nieves includes both the territory declared as a Natural Park in 1989 and National Park in 2021, located in southern Spain (Figure 1), namely, closed to Marbella urban area in the West Coast of the Province of Málaga. In total, the NPA has a total area of 29,576.76 ha (National Park: 22,979.76 ha, Natural Park: 6,597.00) (MITECO, 2023). The geographic area of the NPA covers a territory integrated into the Serranía de Ronda, pouring into three watersheds: Guadalhorce, Verde, and Guadiaro rivers. The relief is structurally controlled in a series of orographic accidents, with altitudes that generally range between 300 and 2,000 m.a.s.l. (maximum altitude: Torrecilla Peak, 1,919 m.a.s.l.). This complex orography is resolved either in deep stream valleys towards the southern area, where peridotite and schist lithologies dominate, and mountain ridges on the northern one. Both are separated by a raised massif and plateau in the central sector, crowned by the Torrecilla Peak, all constituted fundamentally by calcareous rocks, affected by strong jointing and karstic processes.

According to the climatic classification proposed by Olmedo-Cobo & Gómez-Zotano (2017) for the Serranía de Ronda, the NPA is characterized by a Mediterranean climate but with spatial differences due to altitude and exposure to humid westerly winds: i) subhumid to humid oceanic Mediterranean climate at the lowest and southern altitudes near the coast; ii) mid-mountain coastal humid oceanic Mediterranean climate in western; iii) hyper-humid to humid semi-oceanic Mediterranean climate in western upper areas; iv) Mediterranean subhumid to humid semi-continental climate in the lowest altitudes in its eastern and north-eastern sectors; humid semi-continental Mediterranean climate in the centre and norther areas; and iv) hyperhumid semi-continental Mediterranean climate above 1,500 m.a.s.l. In general, rainfalls present an altitudinal gradient of increase but also from East to West, with averages ranging from 500 mm y^{-1} on the lowest and east-facing slopes, towards the Gualdahorce river valley, to more than 1,300 mm y^{-1} in the areas exposed to humid Atlantic air masses and above 1,500 m.a.s.l. Meanwhile, average temperatures are highly affected by altitude, proximity to the sea and exposure, with average values ranging from 15.5-18.0 °C at the lowest altitudes near the coast and lowest eastern slopes to less than 6-9°C above 1,500 m.a.s.l.

Figure 1. Location and limits of the Natural Protected Area Sierra de las Nieves



Source: BOE (2021), Consejería de Sostenibilidad, Medio Ambiente y Economía Azul (2023), Google Earth Pro, and geodata available in Centro de Descargas del CNIG and Red Ambiental de Andalucía (2023)

The orographic, geological and climatic diversity translates into a wide variety of natural systems. As stated in the Declaration of the Sierra de las Nieves National Park (BOE, 2021), among those stands out (Figure 2): "fir forests", with a massive and outstanding presence of *Abies pinsapo* Boiss., distributed mainly in the central and northern sector of the NPA; "peridotite black pine forests of the western *Malacitano* biogeographical sector" in the peridotite relieves, "Eurasian junipers", "cork oaks" in the schistose metamorphic reliefs with abundant rainfall; and the "high altitude shrubs and prairies" in the high and central sector plateau massif, providing a high mountain landscape. However, since we are dealing with an eminently Mediterranean mountain, these natural systems are not exempt from the human footprint which has been carved since prehistoric times, with the passage of different cultures and civilizations that have taken advantage of the territory resources. Massive felling trees to obtain charcoal as well as shipbuilding, grazing activity, and fire have been shaping agents of the current landscape, introducing changes in the composition, physiognomy and structure of the vegetation cover, in the geomorphological system, especially, due to the action of surface runoff waters and the consequent erosive processes, and in soils that have suffered remarkable processes of degradation and desertification.

Figure 2. Views of the main natural systems in the Natural Protected Area of Sierra de las Nieves: Fir forest of *Abies pinsapo* Boiss. (top), pine forests in peridotite relieves (middle), and pastures and disperse deciduous oaks (*Quercus alpestris*) in higher altitudes (bottom)

Photographs by authors

2.2. Data

Data to delimit the landscape units as well as the spatial analysis of visual fragility is included in Table 1. Vector and raster layers related to topography, geology, climate, and land uses were retrieved from public cartographic databases. This information was completed with data published in scientific journals and field campaigns.

Table 1. Variables and data source

Source	Type of data	Data
National Geographic Institute (IGN)	Vector and raster layers	DEM (resolution, 25 m). 2022-aerial photo.
Geological and Mining Institute of Spain (IGME)	Vector layer	Geological map.
Environmental Data Network of Andalucía (REDIAM)	Vector layers	Limit of protected natural area. Hydrographic network. Land use (2018-SIPNA). Road, unpaved road, and trail networks.
Scientific publications	Bibliographic data bases	Publications about geographical settings, climate, and landscape.
Field work	Mapping	Validation of maps.

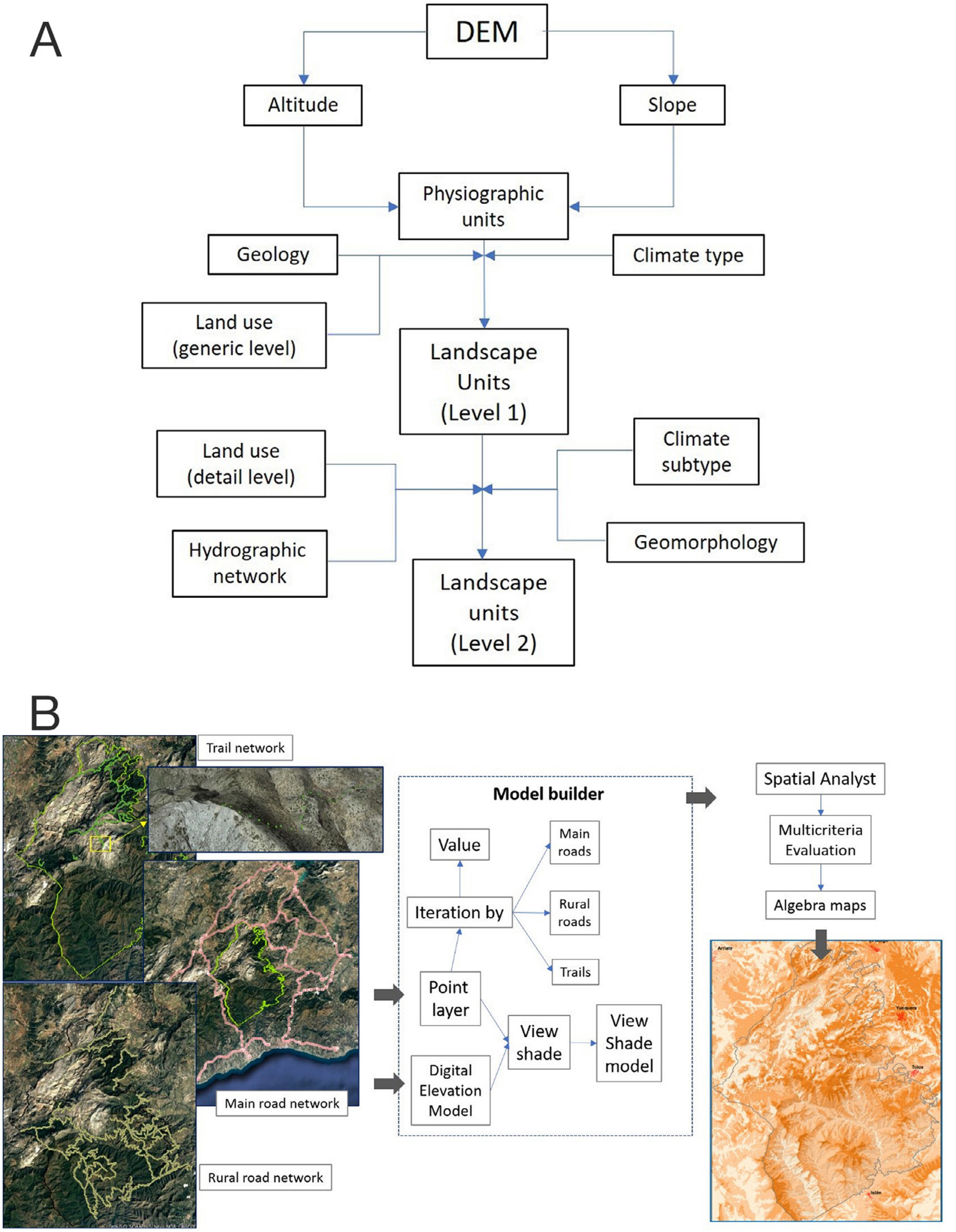
Own elaboration

2.3. Delimitation of landscape units

To delimit, inventory, and describe the landscape, there have been proposed numerous methods, especially from the cartographic point of view with the development of geographic information technologies during the last three decades. In a systematic review, Simensen et al. (2018) found three methodological strategies to delimit landscape units: i) evaluation approaches of the holistic nature of the landscape; ii) landscape characterization methods based on the a priori selection of geo-ecological properties and land use; and iii) approach to the biophysical characterization of the landscape, which largely relies on statistical analysis to identify variation gradients in the presence and/or absence of landscape elements and properties. In accordance with those authors, this study can be included in the second one strategy. Indeed, this one was selected because of three main reasons: i) the great variety of topographical, geological, climatological, and land use and vegetation features in the study area, ii) the freely available spatial data of these variables in public digital repositories, and iii) major objectivity in the mapping process.

In the classification and mapping of landscape units, different procedures can be used based on the analysis of different thematic maps in GIS (Quintela, 1995; Priego-Santander et al., 2003; Ramón et al., 2009). This approach constitutes from the practical point of view one oAf the most complicated aspects in all landscape research, due to the hierarchy that must be taken into account in the natural components and the very nature of the data and its dissimilar representations in the GIS. In the present work the map of landscape units is made according to the initial scheme proposed by Quintela (1995). The method is based on the superimposition of different vector layers of each of the selected variables, at two levels of spatial approximation. The superposition leads to the generation of a new cartographic product, which is in turn refined based on two criteria: i) the minimum mappable area; and ii) the expert criterion for the spatial reorganization of the new topologies generated according to attributes. The resulting maps of landscape units is based on the superpositions of geodata files (vector type) delimited in two spatial scale of approach (E=1:100.000 -generic level- and E=1.25.000 -detail level-). Once the landscape units are obtained in both spatial approaches, calculations of their extension and perimeter are made, as well as their geo-ecological description. Figure 3A and 3B shows the methodological flow followed to delimit the landscape units and determine the visual fragility in this study, respectively. Firstly, at the generic approach, the physiographic units are defined based on topographical attributes. Secondly, these units are superimposed to geology and climate spatial units, obtaining what can be considered as structural landscape units. Finally, these ones are featured from the land use and land cover point of view. In a second approach, the detail one, the generic landscape units are thoroughly described and delimited adding other variables: hydrographic network, geomorphological landforms, climatic subtypes, and detailed land use and land cover. As the landscape units are mapped at both spatial approaches, a database of units and associated features is constructed.

Figure 3. Flow chart of the methodology to delimit landscape units (3A, top) and quantify and map the visual fragility (3B, bottom)



Own elaboration

2.4. Spatial analysis of visual fragility

The spatial analysis of visual fragility was performed as shown in Figure 3B. The procedure was conducted using the 3D-Analyst package for ArcMap 10.8.2. Firstly, the road network was selected including paved and unpaved roads, and official trails. This road network was selected based on the following criterion: i) due to technical constraints, only the closet road network to the study area and those within it were selected to not operate with a large amount of spatial data, and ii) only the official trails from the NPA Sierra de las Nieves established by their land managers. After the selection of the road network, a number of observation points were generated at an equidistance of 100 metres along these one and used to delimit visual basins based on one 5-metres of spatial resolution DEM; the selection of multiple observation points was required because it was assumed that the potential observers were in motion along the road network. The procedure resulted in raster maps of visual basins from each observatory points. An important issue to solve was the above-mentioned repeated generation of visibility analysis. For this purpose, it was necessary to design a model in a GIS environment, which linked the analysis performed with the maps involved in the process, allowing it to be repeated from each observation point and integrating the result in a single final map through the sum of the models obtained from each observation point in raster format. The following step consisted in the integration of those maps in a one final raster of visual basins using Multicriteria Evaluation techniques (MCE) per each road network (main roads, unpaved roads, and trails). Due to the lack of data about daily mean intensity in the road network, the weight given in the MCE for each of them was equalled to 1/3. This described process was applied similarly to the three networks of paved and unpaved roads, and official trails to make comparable the results.

Regarding the measurement of visual fragility, the fragility values were calculated for each cell of the viewshed to build the visual fragility map covering the visible areas from the observation points defined in each network. In order not to build maps with either many different classes of visual fragility, a simple scoring system was adopted with 4-classes of fragility based on the classification of the original data of visual fragility according to natural breaks: 0 = null, 1 = low, 2 = medium, and 3 = high. Namely, the visual fragility map shows the number of times a 25m^2 cell (given that a 5x5 m spatial resolution DEM has been used as a basis) is visible from the considered road network (including paved and unpaved roads and official trails), on a continuous scale from zero to one and then reclassified into 4 intervals based on Jenks' natural cut-off algorithm.

Finally, to determine the specific visual fragility of each landscape unit an overlay mapping procedure was performed resulting in quantitative data of different degrees of fragility for each one of those units. This let analyse both global and specific visual fragility of the PNA and their landscape units. To do this, it was used the spatial analyst tool 'Extract point value from raster' in ArGIS 10.8.2.

3. Results

3.1. The landscape units in the Natural Protected Area of Sierra de las Nieves

The NPA Sierra de las Nieves has been divided into 4 landscape units at level 1 (E = 1:100,000) (Figure 4). Each of these four units occupy a relative area equal to: unit I, 34.4%; unit II, 13.2%; unit III, 46.4%, and unit IV, 6.0%. The variety of the geological substratum and the climatic variability introduced by altitude and exposure, which impose their influence on the composition and development of the vegetation cover, differentiated the landscape units. Also, Figure 4 includes the landscape units at level 2 with more detail.

The geo-ecological features of the landscape units at level 1 and 2 are the followings:

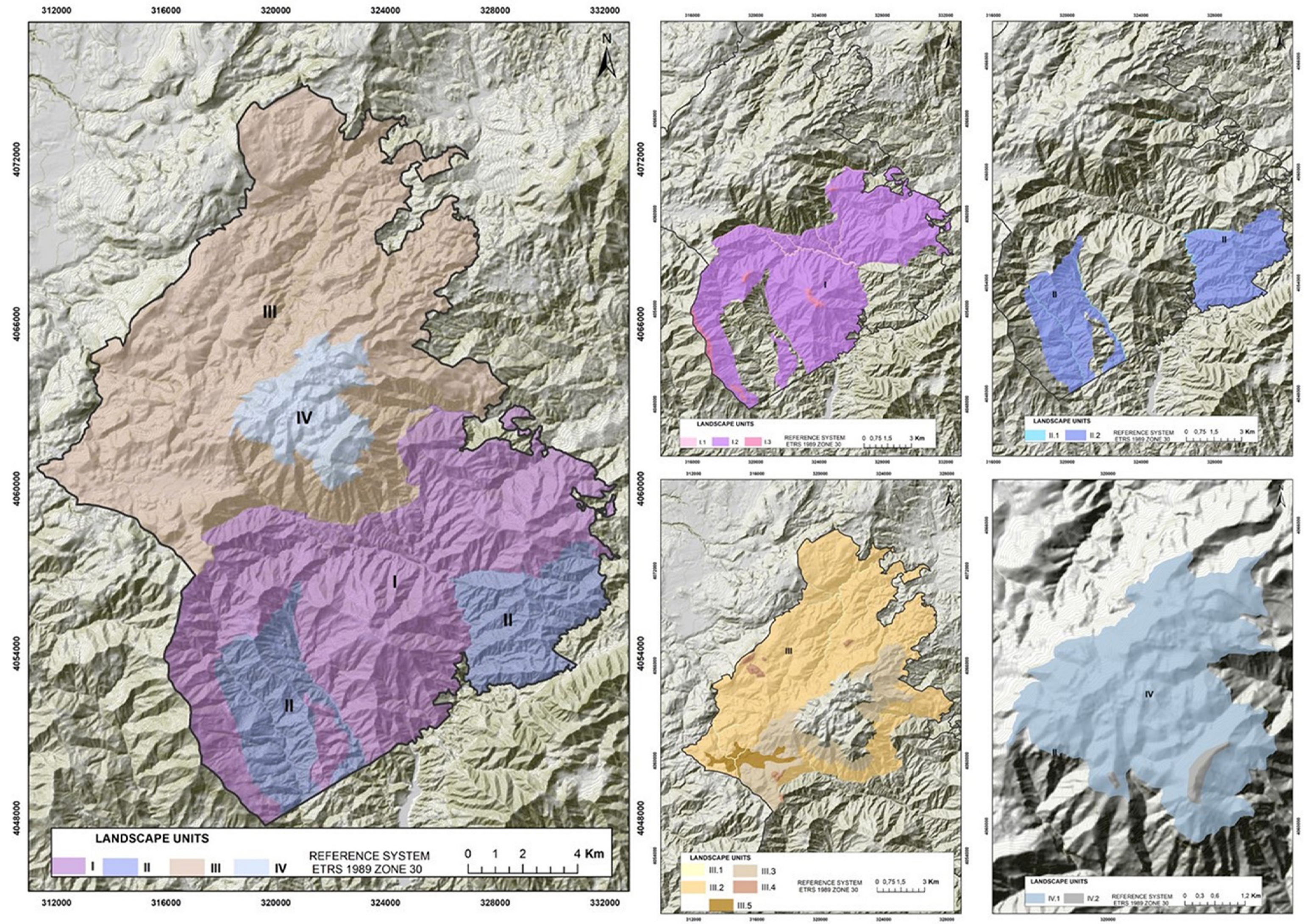
-*Unit I: medium altitude mountains of plutonic bedrock with incised valleys, oceanic Mediterranean climate, and forestry land use*.

-Unit I.1: thalwegs and channels in mid mountain valleys, 300-1,500 m.a.s.l., moderate to steep slopes; bedrock of peridotite and serpentinite; humid oceanic Mediterranean climate; vegetation: riparian vegetation; denudative relief, fluvial processes and morphologies; land use: forestry.

-Unit I.2: hillslopes in mid mountains, 300-1,500 m.a.s.l., moderate to steep slopes; bedrock of peridotite and serpentinite; humid oceanic Mediterranean climate; vegetation: forest (conifers: *Pinus pinaster*); denudative relief, hillslope and fluvial processes and morphologies; land use: forestry and extensive grazing.

-Unit I.3: summits in mid mountains, 600-1,500 m.a.s.l., slight to moderate slopes; bedrock of peridotite and serpentinite; hyper-humid oceanic Mediterranean climate; vegetation: prairies and rock outcrops, and sparse shrub; denudative relief, hillslope and gravitational processes and morphologies; land use: forestry and extensive grazing.

Figure 4. Maps including units at level 1 and 2 of approach in the Natural Protected Area Sierra de las Nieves



Own elaboration

-*Unit II: medium altitude mountains of metamorphic bedrock with incised valleys, oceanic Mediterranean climate, and forestry land use.*

-Unit II.1: thalwegs and channels in mid mountain valleys, 300-1,500 m.a.s.l., moderate slopes; bedrock of schist and gneiss; humid and subhumid oceanic Mediterranean climate in hillslopes and valley bottom, respectively; vegetation: riparian vegetation; denudative relief, fluvial processes and morphologies; land use: forestry.

-Unit II.2: hillslope mid mountains, 300-1,500 m.a.s.l., moderate slopes; bedrock of schist and gneiss; humid and subhumid oceanic Mediterranean climate in hillslopes and valley bottom, respectively; vegetation: mixed forests (quercineae: *Quercus suber* and *Quercus faginea*; conifers: *Pinus halepensis* and *Pinus pinaster*) and shrubs; denudative relief, hillslope and fluvial processes and morphologies; land use: forestry and extensive grazing.

-*Unit III: medium altitude mountains of calcareous bedrock, structural relief, semi-continental Mediterranean climate, and forestry land use.*

-Unit III.1: thalwegs and channels in mid mountain valleys, 600-1,000 m.a.s.l., moderate slopes; calcareous bedrock; humid and subhumid oceanic Mediterranean climate in hillslopes and valley bottom, respectively; vegetation: riparian vegetation; structural relief, and fluvial processes and morphologies; land use: forestry.

-Unit III.2: hillslope mid mountains, 600-1,000 m.a.s.l., moderate to steep slopes; calcareous bedrock; semi-continental and subhumid Mediterranean climate in mid altitudes and West facing hillslopes, respectively; vegetation: mixed forests (quercineae: *Quercus suber* and *Quercus faginea*; conifers: *Pinus pinaster* and *Abies pinsapo* Boiss.) and shrubs; structural relief, karstic processes and morphologies; land use: forestry and extensive grazing.

-Unit III.3: hillslope mid mountains, 800-1,100 m.a.s.l., steep slopes; calcareous bedrock; humid and subhumid semi-continental Mediterranean climate in low altitudes and East facing hillslopes, respectively; vegetation: mixed forests (quercineae: *Quercus sube*r and *Quercus faginea*; conifers: *Pinus pinaster* and *Sylvestris* and *Abies pinsapo* Boiss.) and shrubs; structural relief, hillslope and karstic processes and morphologies; land use: forestry and extensive grazing.

-Unit III.4: summits and ridges of mid mountains, 1,100-1,500 m.a.s.l., slight to moderate and steep slopes; calcareous bedrock; humid and subhumid semi-continental Mediterranean climate in mid altitudes and West facing hillslopes and in low altitudes and East facing, respectively; vegetation: rock outcrops, prairies, and spare shrub; structural relief, hillslope and karstic processes and morphologies; land use: forestry and extensive grazing.

-Unit III.5: high plateaus, 1,100-1,200 m.a.s.l., flat to low slopes; calcareous bedrock; humid and subhumid semi-continental Mediterranean climate in mid altitudes and West facing hillslopes and in low altitudes and East facing, respectively; vegetation: mixed forests (quercineae: *Quercus ilex* and *Quercus faginea*; conifers: *Abies pinsapo* Boiss.), and shrubs; structural relief, karstic and fluvial processes and morphologies; land use: forestry and extensive grazing.

-*Unit IV: High Mountain of calcareous rocks, structural relief, semi-continental Mediterranean climate, and forestry land use.*

-Unit IV.1: hillslopes and high plateaus, >1,500 m.a.s.l., moderate slopes; calcareous bedrock; hyperhumid semi-continental Mediterranean climate; vegetation: prairies and open forest (quercineae: *Quercus alpestris*; conifers: *Abies pinsapo* Boiss.); structural relief, and karstic, fluvial, and periglacial processes and morphologies; land use: forestry and extensive grazing.

-Unit IV.2: summits and rigdes, >1,800 m.a.s.l., slight to moderate and steep slopes; calcareous bedrock; hyperhumid semi-continental Mediterranean climate; no vegetation, rock outcrops; structural relief, and hillslope, and periglacial processes and morphologies; land use: forestry and extensive grazing.

3.2. Visual fragility of the landscape units from Sierra de las Nieves

In general, when the total visual fragility is taken into account (the sum of visual fragility calculated from the observation points along the paved roads, unpaved roads, and official trails) the NPA Sierra de las Nieves is mainly characterised by visual fragility degrees of 1 and 2 covering 2/3 of its extension (37.9 and 33.7%, respectively). Meanwhile, both null and class 3 (the highest fragility) affect about 14% of the study area. When considering the relative surface area at level 1, the landscape unit with the highest class of visual fragility is the unit IV followed by III, I, and II: 45.6%, 14.3%, 13.4%, and 0.6%, respectively. On the contrary, the order in the landscape units when the null fragility is highlighted: unit III, 21.4%, unit II, 21.0%, unit IV, 6.3%, and unit I, 3.8%. These data can be divided into the corresponding relative areas (percentage) with regard to each landscape sub-unit at level 2 (Table 2, 3, 4 and 5, and Figure 6, 7, 8 and 9). So, these tables show the relative areas in percentage that correspond to each fragility class respect to the total area occupied by either a certain unit or subunit landscape. When considering the total visual fragility, in the unit I, the sub-unit I.2 is the most exposed to highest visual fragility as well as in the unit II, where this corresponds to the sub-unit II.2. In the landscape unit III, the sub-unit III.2 also showed the highest values of relative surface at all classes, while the sub-unit IV.1 did it in the IV one. Similar trends can be observed per sub-unit landscape when considering separately the visual fragility from the paved road, unpaved road, and official trail networks.

Table 2. Relative surface area (%) in each landscape with different classes of total visual fragility, from the lowest (1) to the highest (4) class

Landscape unit		Visual fragility class			
		Null	1	2	3
I	I.1	0.4	0.9	0.02	0.0
	I.2	3.4	43.9	37.3	11.7
	I.3	0.0	0.05	0.6	1.7
	Total	3.8	44.9	37.9	13.4
II	II.1	1.6	0.9	0.05	0.0
	II.2	19.4	60.8	16.5	0.6
	Total	21.0	61.7	16.6	0.6
III	III.1	0.8	0.6	0.2	0.04
	III.2	19.1	27.5	26.6	8.9
	III.3	1.3	3.9	7.3	4.9
	III.4	0.03	0.2	0.5	0.4
	III.5	0.2	0.6	2.1	0.02
	Total	21.4	27.5	36.6	14.3
IV	IV.1	6.0	22.9	25.0	43.3
	IV.2	0.0	0.001	0.1	2.2
	Total	6.0	22.9	25.6	45.5

Own elaboration

Table 3. Relative surface area (%) with different classes of visual fragility from the main roads in each landscape unit

Landscape unit		Visual fragility class			
		Null	1	2	3
I	I.1	1.3	0.02	0.001	0.0
	I.2	65.4	7.2	14.1	9.6
	I.3	0.4	0.3	0.9	0.8
	Total	67.0	7.5	15.0	10.5
II	II.1	2.6	0.0	0.0	0.0
	II.2	86.4	4.6	6.1	0.6
	Total	89.0	4.6	6.1	0.6
III	III.1	1.4	0.04	0.03	0.1
	III.2	52.3	10.3	8.1	6.4
	III.3	9.1	1.1	3.2	4.0
	III.4	0.2	0.2	0.4	0.2
	III.5	2.9	0.0	0.004	0.0
	Total	65.9	11.6	11.8	10.7
IV	IV.1	30.1	7.9	18.9	40.7
	IV.2	0.1	0.1	0.1	2.1
	Total	30.2	8.0	19.0	42.8

Own elaboration

Table 4. Relative surface area (%) with different classes of visual fragility from the unpaved roads in each landscape unit

Landscape unit		Visual fragility class			
		Null	1	2	3
I	I.1	1.3	0.02	0.001	0.0
	I.2	65.4	7.2	14.1	9.6
	I.3	0.4	0.3	0.9	0.8
	Total	67.0	7.5	15.0	10.5
II	II.1	2.6	0.0	0.0	0.0
	II.2	86.4	4.4	6.1	0.6
	Total	89.0	4.4	6.1	0.6
III	III.1	1.4	0.04	0.03	0.1
	III.2	52.3	10.3	8.1	6.4
	III.3	9.1	1.1	3.2	4.0
	III.4	0.2	0.2	0.4	0.2
	III.5	2.9	0.0	0.004	0.0
	Total	65.9	11.6	11.8	10.7
IV	IV.1	30.1	7.9	18.9	40.7
	IV.2	0.1	0.01	0.1	2.1
	Total	30.2	7.9	19.0	42.8

Own elaboration

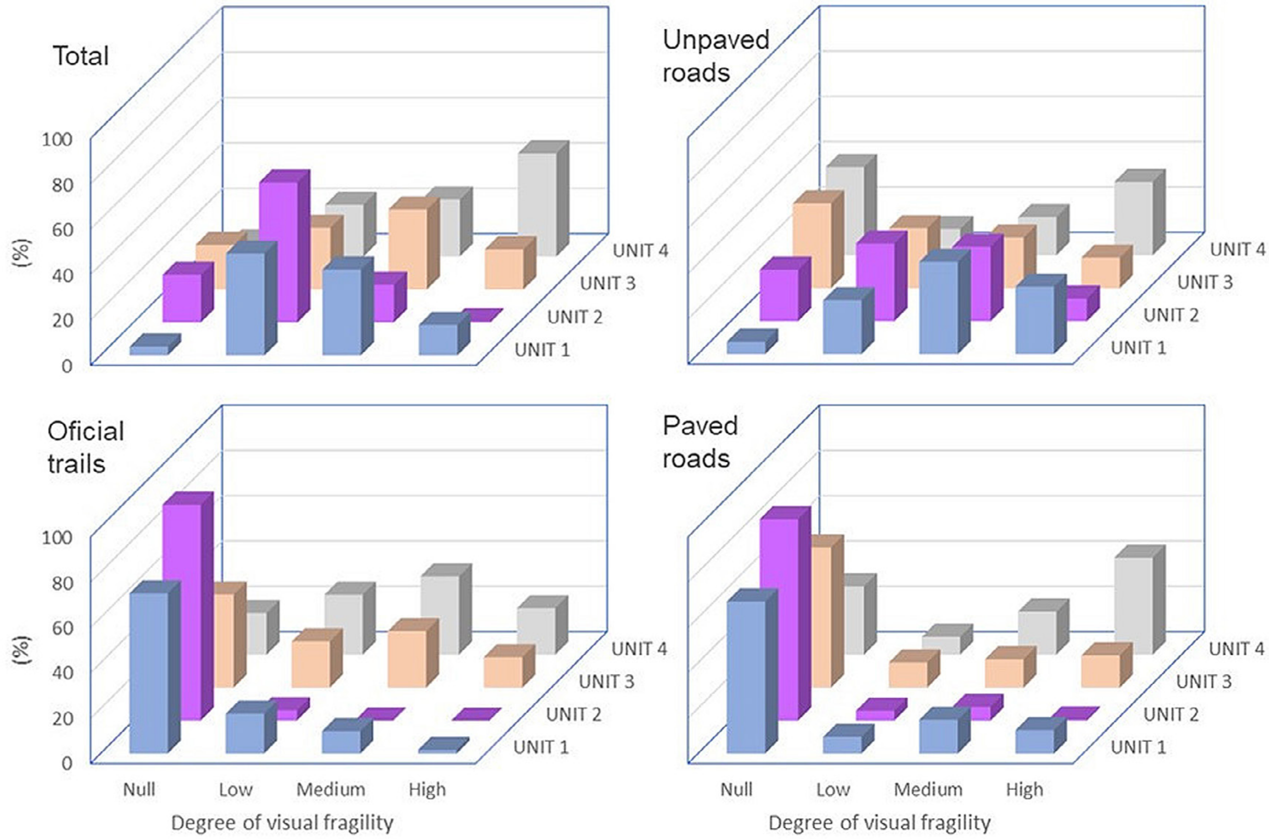
Table 5. Relative surface area (%) with different classes of visual fragility from the official national park trails in each landscape unit

Landscape unit		Visual fragility class			
		Null	1	2	3
I	I.1	1.2	0.1	0.02	0.0
	I.2	69.2	16.9	8.5	1.7
	I.3	0.3	0.6	1.5	0.0
	Total	70.6	17.7	10.0	1.7
II	II.1	2.6	0.1	0.0	0.0
	II.2	92.8	4.5	0.1	0.0
	Total	95,4	4.5	0.1	0.0
III	III.1	1.0	0.4	0.2	0.02
	III.2	36.6	15.4	16.1	8.9
	III.3	5.8	3.4	4.9	3.3
	III.4	0.3	0.2	0.4	0.3
	III.5	0.4	0.3	2.1	0.1
	Total	44.0	19.7	23.7	12.6
IV	IV.1	18.3	26.1	34.1	19.2
	IV.2	0.1	0.4	0.5	1.3
	Total	18.4	26.5	34.6	20.5

Own elaboration

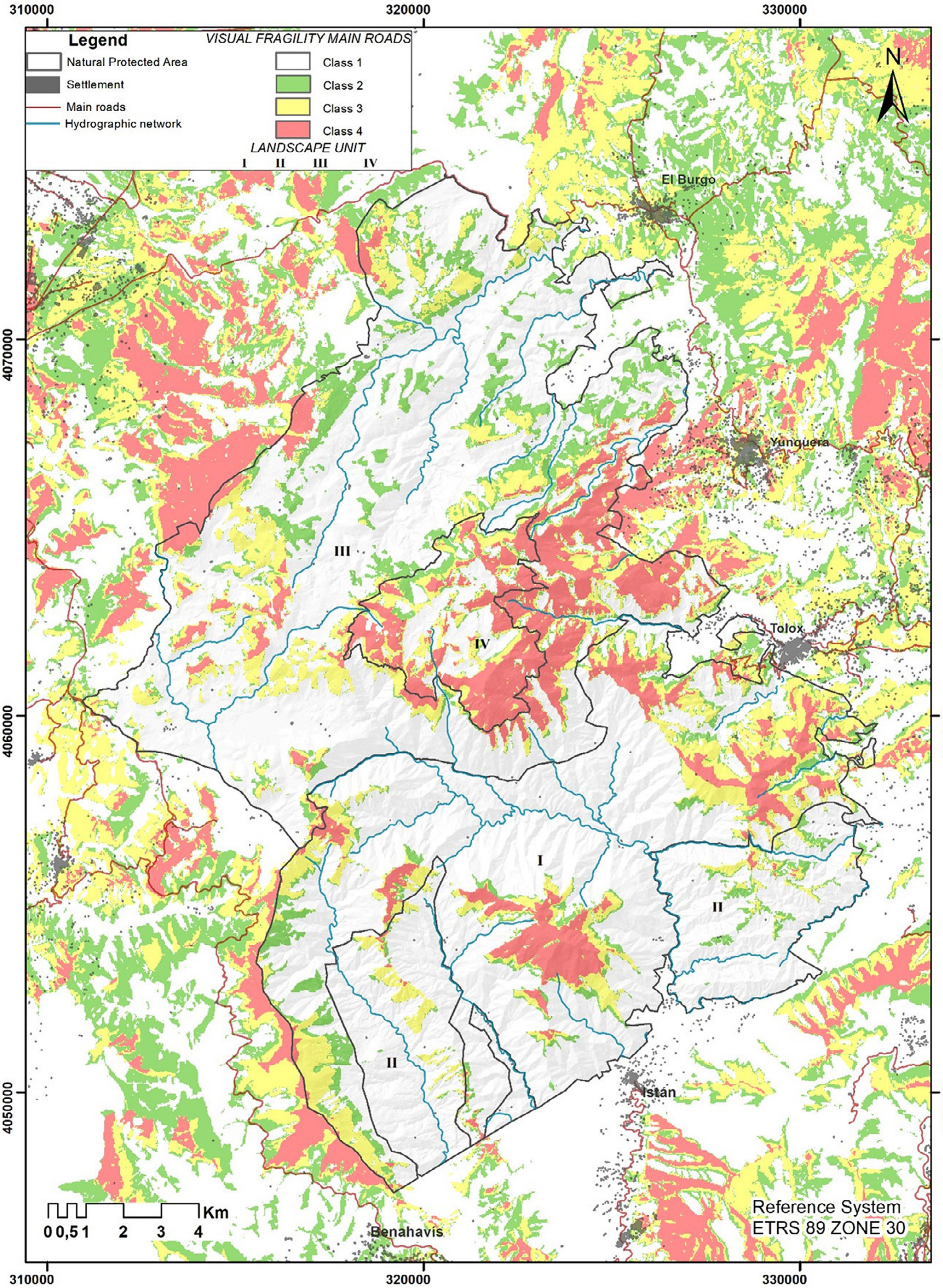
Figures 6, 7, 8 and 9 shows the maps for each visual fragility analysed considering unpaved and paved roads and official trails of NPA Sierra de las Nieves, and the sum of all these, respectively. Globally, landscapes localised in upper areas as well as along the perimeter of the NPA are the most visually fragile, whilst those in valley bottoms and inner depressions the lesser. This is especially clear when only visual fragility from main roads is considered because there is only one crossing the NPA in its northern area. However, this is not the case for the other two networks considered in the analysis. The rural roads are more common in the eastern and southern area in the NPA, so the landscape located in these ones are those with higher levels of visual fragility. In the case of the official trails, the north-eastern area is the most fragile, besides the upper landscapes which are crossed with two very populated trails in the NPA. Those landscape units including summits and territories above 900 m.a.s.l tend to have the most exposed areas and therefore the highest visual fragility classes, especially, in the centre, southern and eastern areas of the NPA when considering the total fragility.

Figure 5. Comparison of relative surface areas (%) affected by different degrees of visual fragility considering total, main roads, unpaved roads, and trail networks



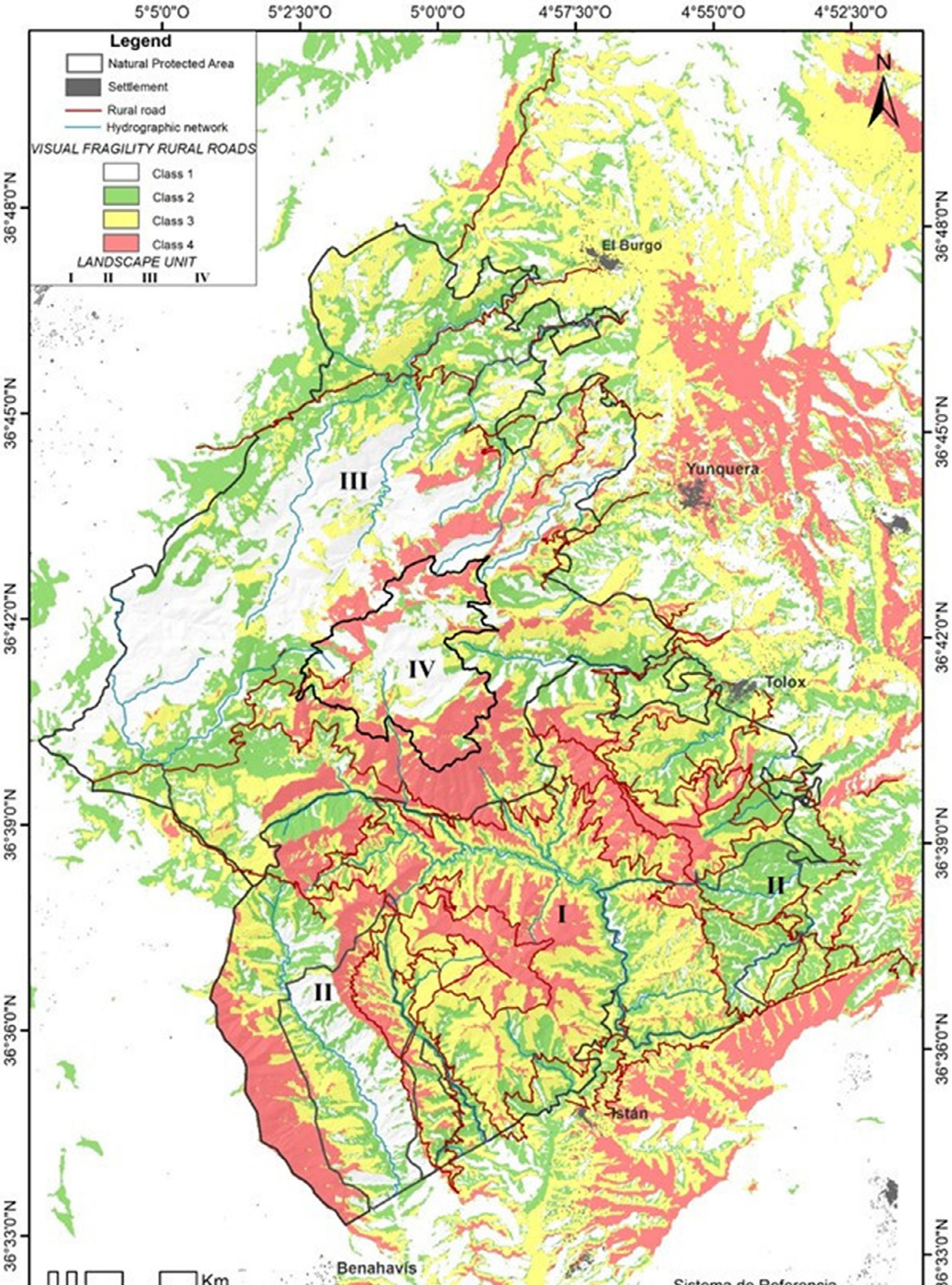
Own elaboration

Figure 6. Spatial variability of the visual fragility considering the paved road network in the Natural Protected Area Sierra de las Nieves



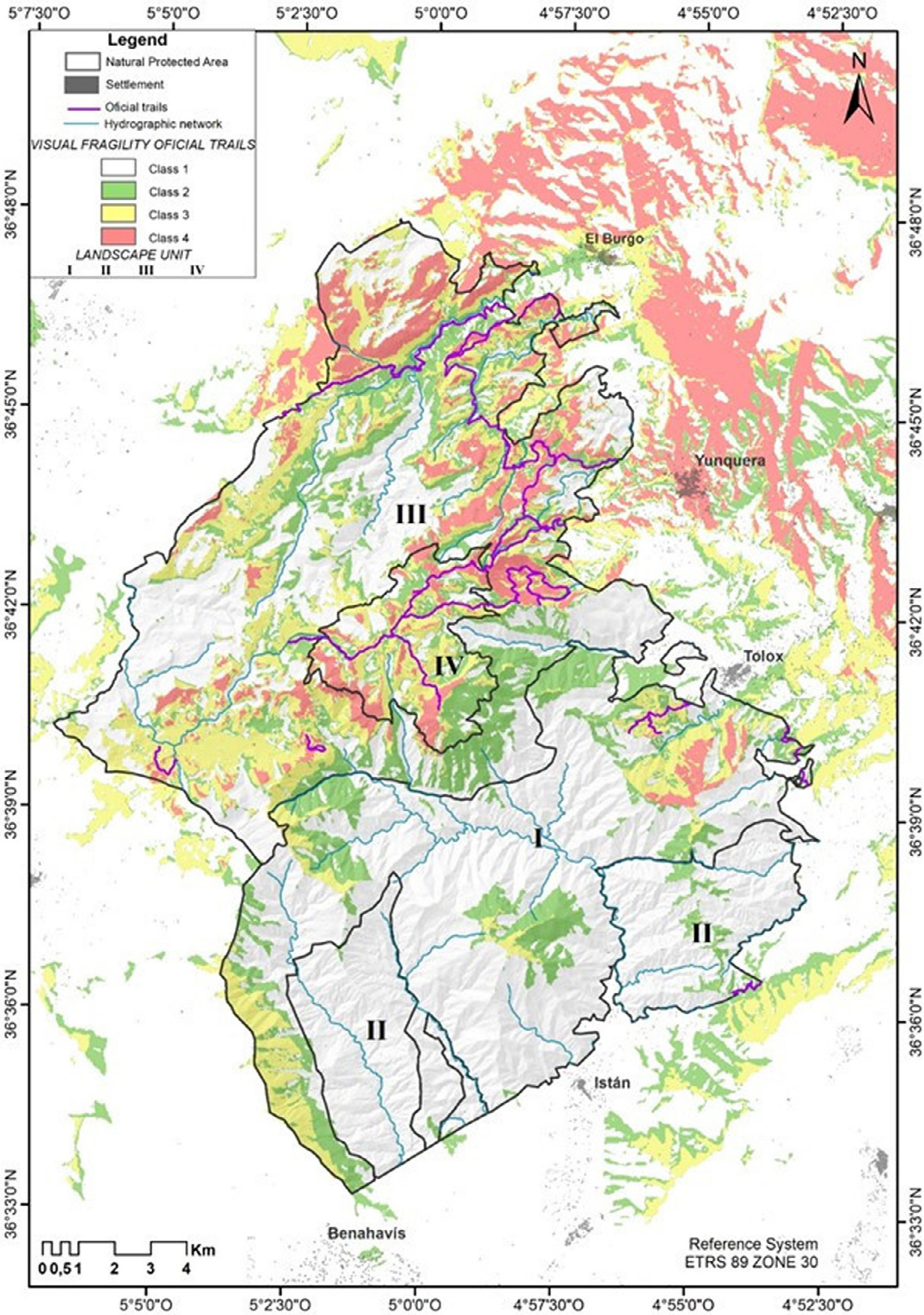
Own elaboration

Figure 7. Spatial variability of the visual fragility considering the unpaved road network in the Natural Protected Area Sierra de las Nieves



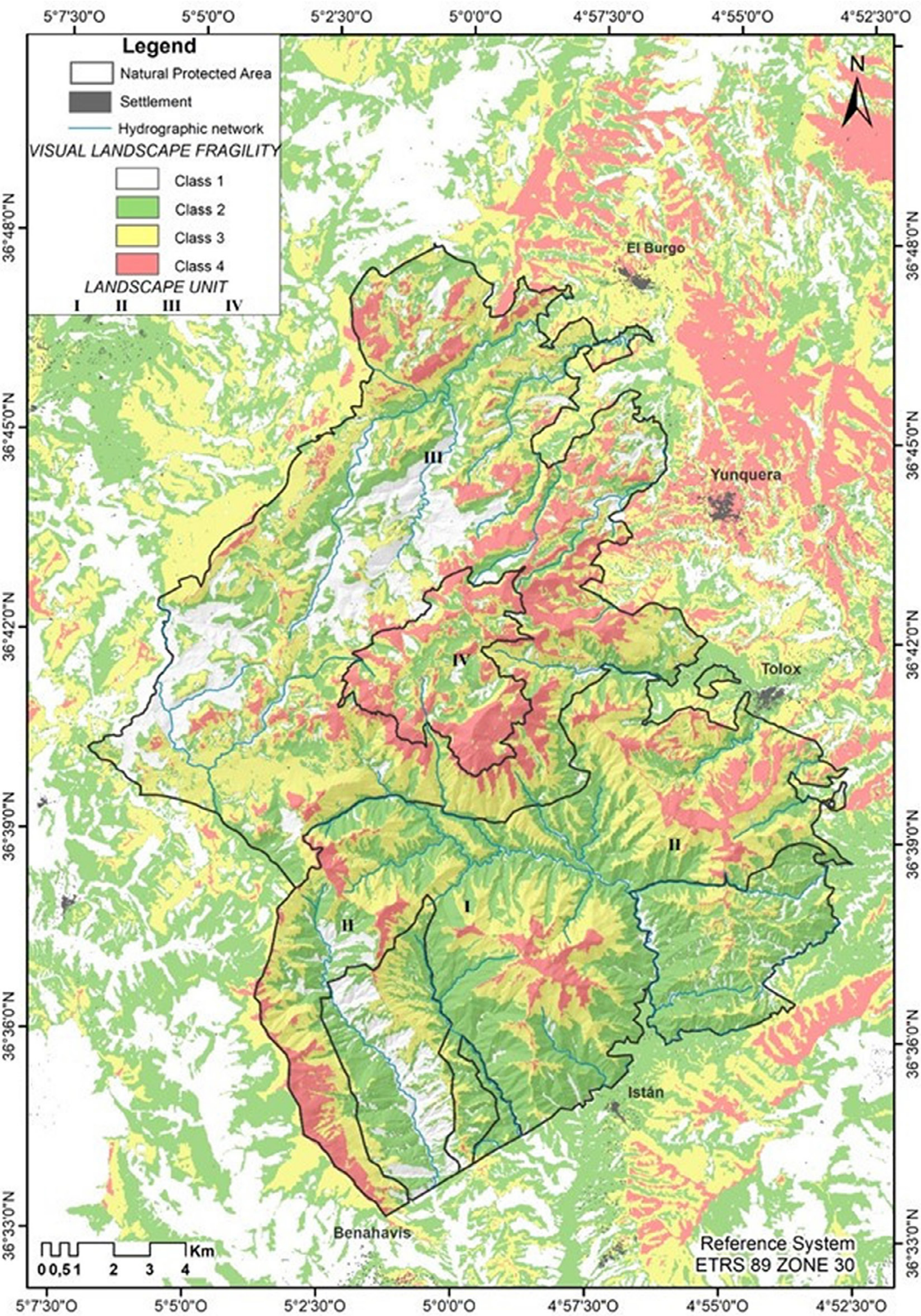
Own elaboration

Figure 8. Spatial variability of the visual fragility considering the official trail network in the Natural Protected Area Sierra de las Nieves



Own elaboration

Figure 9. Spatial variability of the total visual fragility in the Natural Protected Area Sierra de las Nieves



Own elaboration

4. Discussion

4.1 Delimitation of the landscape units

European Council (2000) established in 'The European Landscape Convention' the basis to identify the landscapes of the ratifying countries, to analyse their characteristics, to identify the forces and pressures that may impact them, and to implement strategies for landscape management, planning and protection. These challenging tasks implied the development of systematised knowledge about the variation at the range of spatial scales that define the landscape level, i.e. a typology of landscapes (Simensen et al., 2018). Landscape classified in types and delimited in spatial units is understood better from its complexity, variation and typologies point of views (Christian, 1958; Antrop & Van Eetvelde, 2017). Any system for spatial landscape characterisation inevitably implies a strong simplification of the almost infinite variability in landscapes, into spatial units suitable for communication in management and research (Bunce et al., 1996; Hazeu et al., 2011; Simensen et al., 2018).

Simensen et al. (2018) pointed out the multidimensional structure of the physical landscape makes all approaches involving classification artificial. The reason is found in drawing boundaries in a basically continuous environment, with its correspondingly continuous change in composition of landscape elements. There are plenty of approaches to describe the structure of the landscape, what is a per se a proof that no single correct characterisation method exists (Hettner, 1928; Simensen et al., 2018. Thus, choice of characterisation method and spatial resolution should rely on user needs, and which information is available with full area coverage.

The procedure applied in this study to delimit and classify the structure of the landscape in PNA Sierra de las Nieves focussed on its structural and more stable components by means of spatial analyst techniques in a GIS environment. Topography, geology, and geomorphology features are combined to delimit units of relief. Over these ones climate and watersheds are overlapped to obtain the final landscape structure units. Finally, the based-expert decision was applied to revise each unit and drawn their finally limits. Once this procedure was finished, all units at both level of approaching were inventoried and described considering their main land uses and vegetation types. This methodological strategy let define the structural components of landscape, which remain more stable in time, besides the characterization of their most changeable attributes, vegetation and human activity. The procedure was previously applied in studies dealing with touristic areas (Remond-Noa et al., 2022) but also with purpose for environmental and degradational process monitoring (Sillero-Medina et al., 2020) and landscape assessment (Serrano Giné, 2013).

4.2. The visual fragility of the landscape units in Sierra de las Nieves

Commonly, landscape researchers divide in two different types its study (Antrop, 2000; Bastian, 2008; Brabyn, 2009; Sarlöv Herlin, 2016): i) one approach to landscape characterisation based on biophysical features, which define it as tangible and physically delineated areas, adopted by physical geographers and landscape ecologists, and ii) another dealing with the character assessment of landscape units. The latter tradition contrasts definitions of landscape commonly used in landscape ecology and which are dependent on human perception and sociocultural relations to areas. This concept is implicit in the definition of landscape highlighted in the Landscape European Convention (European Council, 2000).

It is argued that approaching to the character of landscapes requires to make one previous biophysical inventory and mapping procedures. This is desirable to contribute to landscape management unifying the biophysical features and human perception as proposed in the Geography-Territory-Landscape method (Bertrand, 1968; Arias-García et al., 2018). These procedures may contribute positively to achieve a complete assessment of the landscape quality, which is based on both specific quality and visual fragility analysis. This study focusses on the fragility of landscape units from NPA Sierra de las Nieves. As visual fragility analysis is understood as the sensitivity of landscape to changes caused by human activity (Martínez-Béjar et al., 2001; Strevens et al., 2008). According to Alonso et al. (1986), this concept addresses the integrated effect on landscape quality of changes in its specific properties. In accordance with Scarfò et al. (2013), we identified three physical properties of the landscape that influence its visibility in the study area: i) the slope of the visible areas from the observer points, ii) the average height of the observer points in comparison with the average height of the visible areas, and iii) the distance of the observer points from the visible areas.

The analysis of all path networks (including main roads, rural roads, and trails) is vital for the land management in natural protected areas due two reasons: firstly, those may be places where threats for biodiversity and wildlife occur, and, secondly, local population and visitors use them to transit, so any impact in the landscape may imply a damage from the aesthetically point of view. Thus, landscape assessment (i.e., both quality and visual fragility) facilitate to select the path of least environmental impact from any starting point (Martínez-Graña et al., 2019).

The spatial analysis in this study let extract the degree of visual fragility per pixel in the NPA Sierra de las Nieves in 4-levels of approach: main roads, rural roads, official trails, and total sum. This let highlight the most visual fragility areas in the Sierra de las Nieves landscape and serve as basic spatial data for management purposes to either avoid and minimize possible impactful activities as well as give special attention to sudden phenomena (e.g., wildfire). So, the spatial data of visual fragility could help to reduce the impacts on the landscape, especially those of an ascetic nature, which are one of the most valued by the local population and visitors.

5. Conclusions

This study dealt with the assessment of the visual fragility in the landscape units from the Natural Protected Area Sierra de las Nieves. This NPA is of an outstanding value in the context of the western Mediterranean mountains owing to the existence of unique natural systems, especially, those of fir forests with *Abies pinsapo* Boiss*.* and pine forests on peridotites relieves. As Mediterranean mountain, the NPA Sierra de las Nieves is exposed to threats as wildfires and global warming with direct impacts on the landscape and, thus, in its aesthetic character. Besides biodiversity and geodiversity, this is one is a key issue for the NPA management because it becomes a valued input for local population and visitors, so the visual fragility analysis is demanded. As main conclusions the following ones may be addressed:

1) 4-landscape units were mapped in the Sierra de las Nieves. Structural components as relief and climate played a key role in the mapping procedure, whilst vegetation and land uses influenced more in the differentiation of landscape sub-units. The main units with regard the occupied area were those of ‘high mountain of calcareous rocks, structural relief, semi-continental Mediterranean climate, and forestry land use’ (unit IV) and of ‘medium altitude mountains of plutonic bedrock with incised valleys, oceanic Mediterranean climate, and forestry land use’ (unit I). Nevertheless, it is also remarkable the unit characterised by high-mid altitude mountain environment (unit V) owing to its very similar landscape to those found in other mountain areas but at higher altitude in the Mediterranean region.
2) The visual fragility analysis shed light on the most exposed area in the NPA from the observation points along the considered road network. In this regard, those landscape units including territories with altitude higher than 900 m.a.s.l. achieved the highest total visual fragility, especially, in the centre, southern, and eastern areas of the NPA. Although the three networks of observation points presented very visually fragile areas, those of rural roads and official trails must receive more attention in the NPA management because the most fragile areas from their observation points corresponded in many cases with landscape units of remarkable biodiversity, geodiversity, and cultural values, especially, due to the presence of either fir forests of *Abies pinsapo* Boiss*.* or high mountain opened forests of *Quercus alpestris.*
3) The landscape units delimited with the described methodology let the differentiation between types of landscapes in a very precise form. Also, it let inventory and describe thoroughly vegetation and land uses in a subsequent procedure step. In the case of the visual fragility methodology, this is feasible to apply in other regions because it follows a systematic and chained procedure using spatial data that is increasingly available and freely accessible through online repositories.

Further researches must be conducted, especially, those dealing with global quality landscape analysis focussed on more specific landscape components as previous step to propose mitigations solutions to reduce the impact of threats that can affect negatively the landscape, a main economic resource for the region where the NPA Sierra de las Nieves is located. Especially, it would be of great contribution to go deep into the spatial impact analysis of common threats in Mediterranean mountains (for instance, land use and land cover changes in very short period: e.g. fire, modification of cultivation type).

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