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Vulnerability of Nature Based Tourism to Climate Change in Risaralda, Colombia

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Abstract:

The study presents an approach to assess the vulnerability of nature-based tourism in Risaralda, Colombia, to climate change. An environmental reference model is adapted to the tourism sector. The results reveal high vulnerability at the municipal level, conservation areas, ecosystems and tourism supply, especially in high mountain ecosystems. This underlines the importance of adaptive tourism management and measures to reduce vulnerability, such as avoiding concentration of tourism supply, since some of the most vulnerable tourism destinations are paradoxically the most competitive in terms of sustainability. This approach is applicable to other tourism destinations.

Keywords: Vulnerability; tourism; climate change; ecosystems; Risaralda.
JEL Classification: L83; Q26; Q54; O18.

Vulnerabilidad del Turismo Basado en la Naturaleza ante el Cambio Climático en Risaralda, Colombia

Resumen:

El estudio presenta un enfoque para evaluar la vulnerabilidad del turismo basado en la naturaleza en Risaralda, Colombia, ante el cambio climático. Se adapta un modelo de referencia ambiental al sector turismo. Los resultados revelan una alta vulnerabilidad a nivel municipal, áreas de conservación, ecosistemas y oferta turística, especialmente en ecosistemas de alta montaña. Esto subraya la importancia de gestionar el turismo de manera adaptativa y tomar medidas para reducir la vulnerabilidad, como evitar la concentración de la oferta turística, dado que algunos destinos turísticos más vulnerables son paradójicamente los más competitivos en términos de sostenibilidad. Este enfoque es aplicable a otros destinos turísticos.

Palabras clave: Vulnerabilidad; turismo; cambio climático; ecosistemas; Risaralda.
Clasificación JEL: L83; Q26; Q54; O18.

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1. Introduction

This article examines the relationship between tourism and climate change at a regional level, stressing the need to understand this link and recognise local vulnerability to projected climate shifts.

Climate change is defined as a significant variation in average climate or its variability over an extended period (DNP & IDEAM, 2015). The tourism sector is highly vulnerable to climate change in socio-economic and territorial terms (Loehr and Becken, 2020; Cabana, 2023; Grimm et al., 2019; Velasco et al., 2014; Pulido and López, 2014; Becken, 2013; Araña et al., 2013; Gössling et al., 2012; Valls and Sardá, 2008; Rodríguez and Domínguez, 2011; Dubois and Cerón, 2006). Grimm et al. (2019) suggest declining mass tourism may lead to increased visits to conservation areas. Navarro (2019) predicts climate change will alter tourism flows in Latin America, impacting specific destinations economically. There is consensus on vulnerability in tourism destinations regarding climate, accessibility, comfort, and cultural ecosystem services (Rivera, 2021).

Climate change affects the tourism industry by altering supply and demand, impacting regional economies. In the case of Risaralda, a department in Colombia contributing 5.58% to GDP before the pandemic (Centro de Pensamiento Turístico, 2018), this is relevant.

The World Tourism Organization (2002) defines nature tourism as observing and appreciating nature and traditional cultures. Colombia's Nature Tourism Policy (2012) frames it as a sustainable activity centred on natural attractions.

Previous research (Fang et al., 2017) has aimed to identify pressing issues such as consequences, vulnerabilities, and necessary adaptations for climate change and tourism. Xuejie et al. (2023) suggest future priorities like spatial analysis, tourism in snowy ecosystems, and the role of parks in adaptation and mitigation, emphasising understanding climate impacts and balancing tourism development with sustainability.

In summary, this article focuses on assessing the vulnerability of nature-based tourism to climate change without estimating climate risks. It proposes a methodological approach applicable to this sector and other tourism territories.

1.1. Tourism supply and its relation to the probability of ecosystem transition by climate change

The relationship between climate change and impacts on biodiversity and ecosystem service provision has been raised in several studies (Ojija & Nicholaus, 2023; Shivanna, 2022; Muluneh, 2021; Shukla et al., 2021; Hemanth et al., 2020).

Colombia's MINAMBIENTE (2012) Integrated Management of Biodiversity and its Ecosystem Services policy recognises cultural ecosystem services like tourism have special links with local communities near parks and reserves.

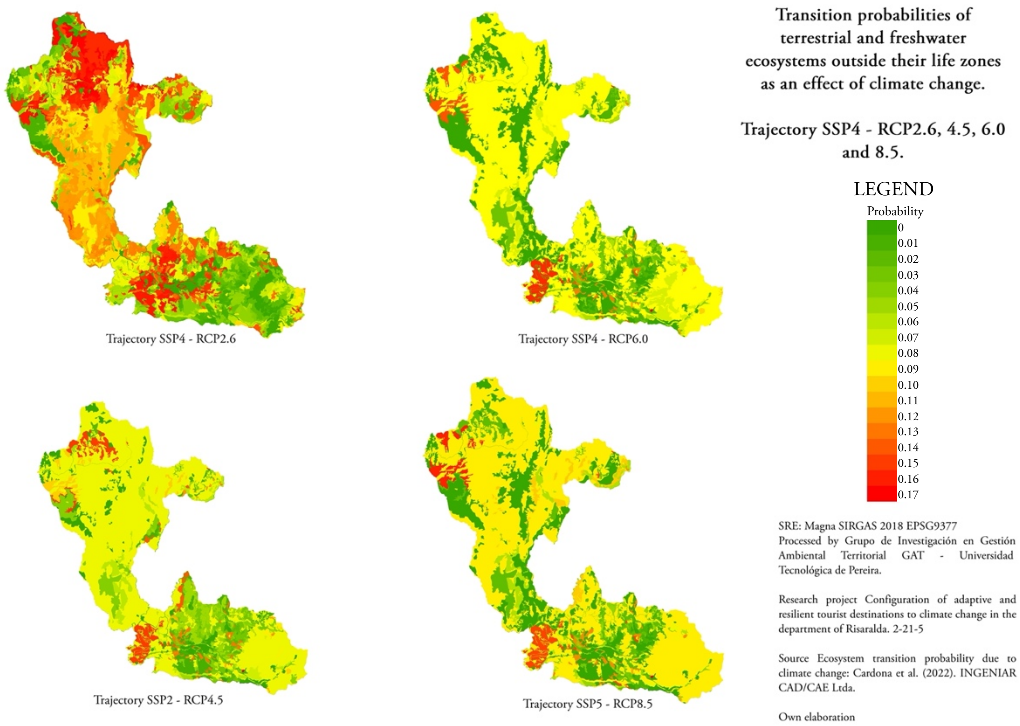
MINCIT's (2020) National Policy for Sustainable Tourism acknowledges tourism's concentration in vulnerable ecosystems. It highlights the need to address ecosystem services, local communities and nature-based tourism, underlining responsible practices, biodiversity conservation and local economic development.

MINCIT's (2008) National Ecotourism Policy includes tourism activities that contribute to sustainable biodiversity use through production and biotrade chains. Additionally, Colombia's sustainable tourism policy considers climate change a threat to ecosystems and biodiversity, affecting the provision of ecosystem services that drive tourism.

Habibullah et al. (2022) found climate change affects threatened species in 115 countries. McCreary et al. (2020) showed climate change alters nature-based tourism. Kevin and Coldrey (2020) warned of risks to high mountain conservation from declining tourism revenues.

Cardona et al. (2022) assessed Colombia's ecosystem transition risk from climate change, mapping probabilities for Risaralda under different scenarios (SSP1-RCP2.6, SSP2-RCP4.5, SSP4-RCP6.0, SSP5-RCP8.5).

Map 1.
Likelihood of transition of terrestrial and freshwater ecosystems outside their life zone as an effect of climate change for different climate trajectories



Source: Own elaboration based on data provided by Cardona et al. (2022).

1.2. Regional approaches to climate change vulnerability analysis

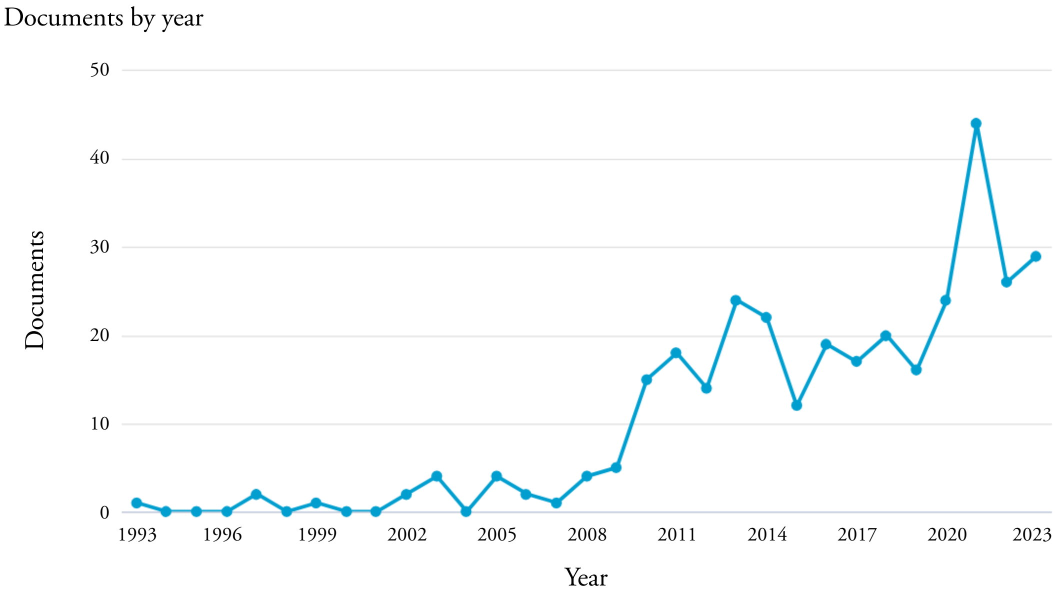
Through documentary analysis in the Scopus database, 326 publications related to vulnerability to climate change in tourism destinations were identified. This field of research has gained importance since 2010. (Graph 1.)

One of the first studies on the subject stated that climate change will significantly impact the Gulf of Mexico-Caribbean Sea-Bahamas-Bermuda-Guianas region and its ecosystems by 2025, with emphasis on socio-economic effects, especially on tourism and the influence of tropical storms (Maul, G.A. (1993).

Other authors have contributed to the study of the relationship between tourism and climate change, as well as to the application of local vulnerability analysis. Scott et al. (2016) have identified regional knowledge gaps in relation to the vulnerability of tourism to climate change, both in terms of understanding impacts and the effectiveness of adaptation strategies, as well as tourist response and mitigation policies.

Countries with the lowest vulnerability are found to be in Western and Northern Europe, Central Asia, Canada and New Zealand, while Africa, the Middle East, South Asia and Small Island Developing States are regions with high vulnerability in the tourism sector. In addition, tourism-related content in climate change reports has been found to be decreasing, and knowledge gaps have been identified in tourism growth regions such as South America, the Middle East and South Asia. A specific study by Dube and Nhamo (2020) on the vulnerability of nature-based resorts in Zimbabwe identified that they are particularly sensitive to climate change and extreme events such as droughts, heat waves, bushfires, frost and floods. Further research is required to quantify the impacts on flora and fauna associated with tourism.

Graph 1.
Publications related to climate change vulnerability Publications related to climate change vulnerability in tourism destinations



Source: Scopus (2024).

Colombia has different approaches to assess vulnerability to climate change. One of them is that of IDEAM (2017) which is based on the global analysis of the IPCC (2012, 2014), considering risk as the probability of occurrence of a hazard event combined with the exposure and vulnerability of the system. IDEAM (2017), citing Cardona et al. (2012), defines climate hazard as the potential occurrence of events with impacts in determined areas.

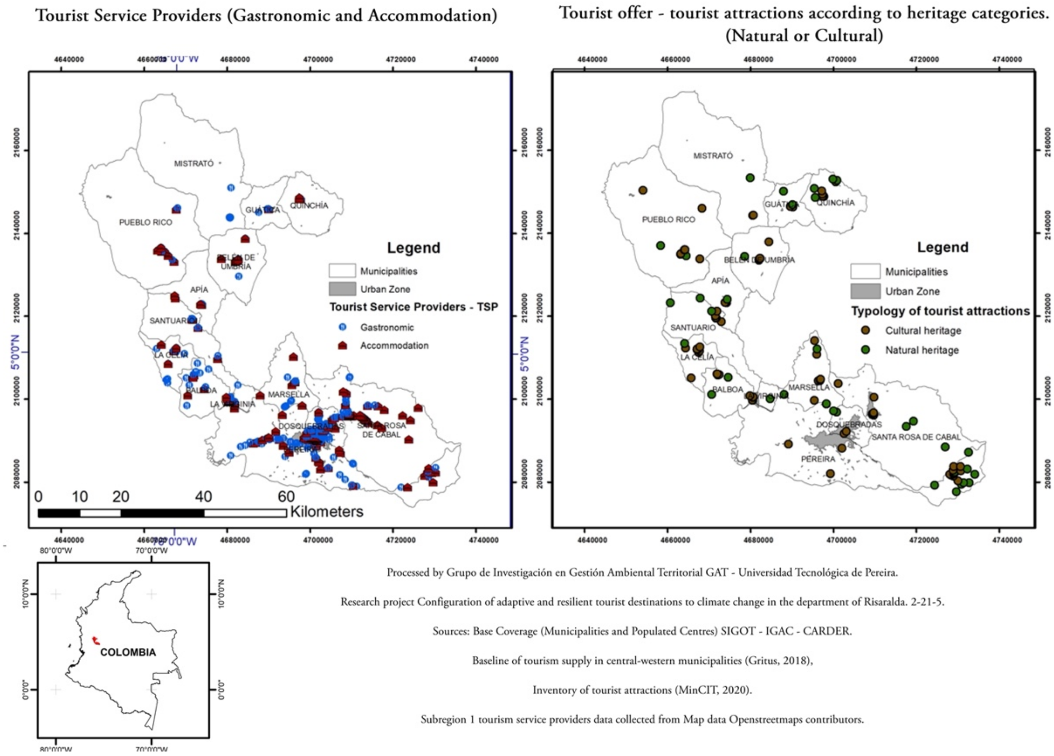
The IPCC (2014) defines exposure as the presence of elements in potentially affected areas, and vulnerability as the propensity to be adversely affected, which evolves as a factor not necessarily dependent on exposure (Cardona et al., 2012). The Government of Colombia (2021) adopted an approach for COP26 that assesses long-term risk, linking vulnerability to conditions that aggravate physical hazard, applied by Ingeniar Ltda. (2020) in sectors like construction and infrastructure.

1.3. Case study

In the previous section, advances in climate change vulnerability studies at the national level were presented, but there are no regional vulnerability studies applied to tourism.

Risaralda, home to 939,558 inhabitants (DANE, 2023) across 3,558 km2 and 14 municipalities, is a crucial part of Colombia's coffee cultural landscape. Marketed as "A destination full of life," it showcases natural and cultural attractions. Tourism drives Risaralda's economy, contributing 7.68% to employment, 5.34% to GDP, and 0.3% to investment. In 2020, it hosted 32,310 tourists, ranking among Colombia's top 5 competitive destinations (ICTRC, 2020) with growth potential (Florez, 2022). Spanning central western Colombia (Figure 1), Risaralda boasts 798 tourism providers, primarily gastronomic (72%) and accommodation (148 attractions, 73% cultural heritage, 27% natural) (GRITUS, 2018; OSM, 2023; MINCIT, 2020).

Figure 1.
Location of the tourist offer, Department of Risaralda, Colombia



Source: Prepared by the authors. Own elaboration.

This article introduces a method to assess nature-based tourism vulnerability to climate change, focusing on ecological fragility, ecosystem importance, and sectoral impacts. Municipal-level findings cover protected areas, ecosystems, and tourism services, with a case study illustrating collaborative adaptation efforts in tourist attractions. It concludes by emphasizing the regional policy and planning implications of these findings, highlighting the vulnerability of tourism offerings across destination life cycles.

2. Methods

2.1. Scope and objectives

This study connects ecosystem vulnerability with the vulnerability of nature-based tourism attractions and services, considering changes in ecosystem life zones due to climate change.

Using data on Risaralda's tourism offer, ecosystem fragility, and relevance, spatial and geostatistical analyses project regional vulnerability to climate change, represented as the coefficient of aggravation of physical risk. The results are processed using Cluster Analysis - Hierarchical Clustering in R-studio (quantitative data, squared Euclidean distance, Ward's method). Figure 2 shows the methodological process, which will be detailed in subsequent sections.

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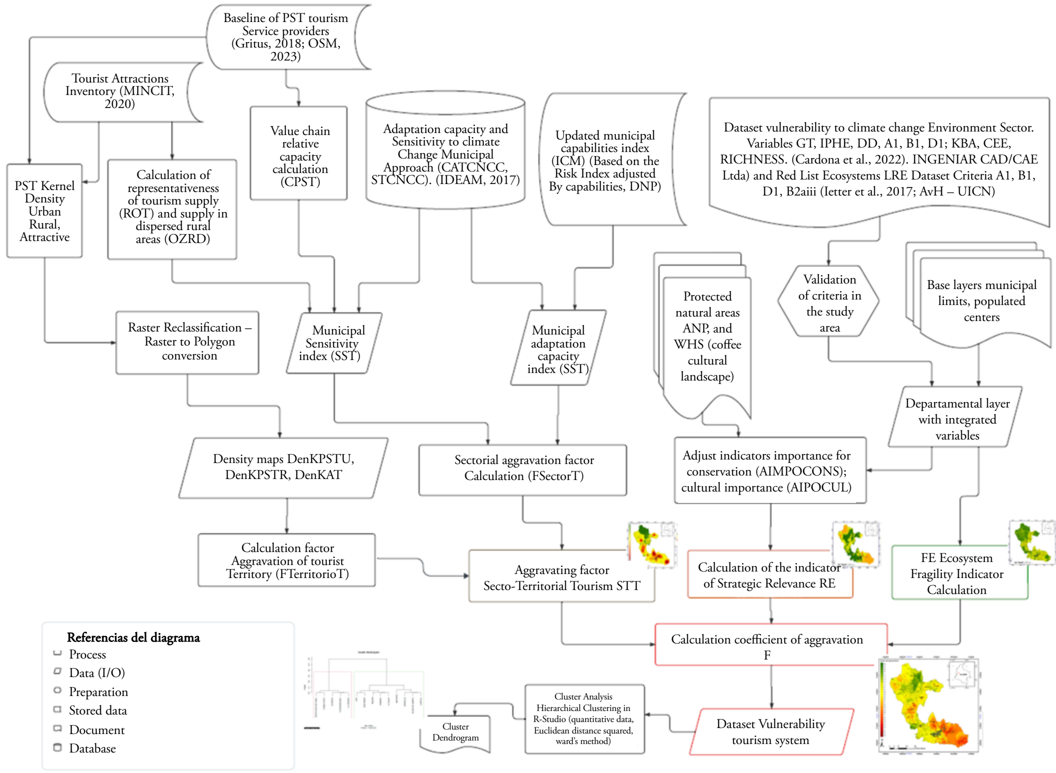
FIGURE 2.
Methodological process for estimating the vulnerability of the nature-based tourism system to climate change



Source: Own elaboration.

2.2. ESTIMATING TOURISM VULNERABILITY TO CLIMATE CHANGE

This study adapts Cardona et al.'s (2022) methodology to assess tourism destinations' vulnerability to climate change, considering tourism behavior at the sectoral and territorial levels.

Cardona et al. (2022) assess climate risk through climatic, economic, and ecosystemic dimensions, incorporating change drivers that negatively affect exposed ecosystems susceptible to transition or collapse. These drivers reflect ecological fragility and strategic relevance, defined as vulnerability factors determining the aggravation coefficient (F).

Total risk (RT) combines direct physical risk (RF) with additional context-related risk (RC), where RC is directly proportional to RF. RF represents a risk metric calculated as the Annual Expected Loss from probable risk simulations. Context-derived risk is articulated as follows:

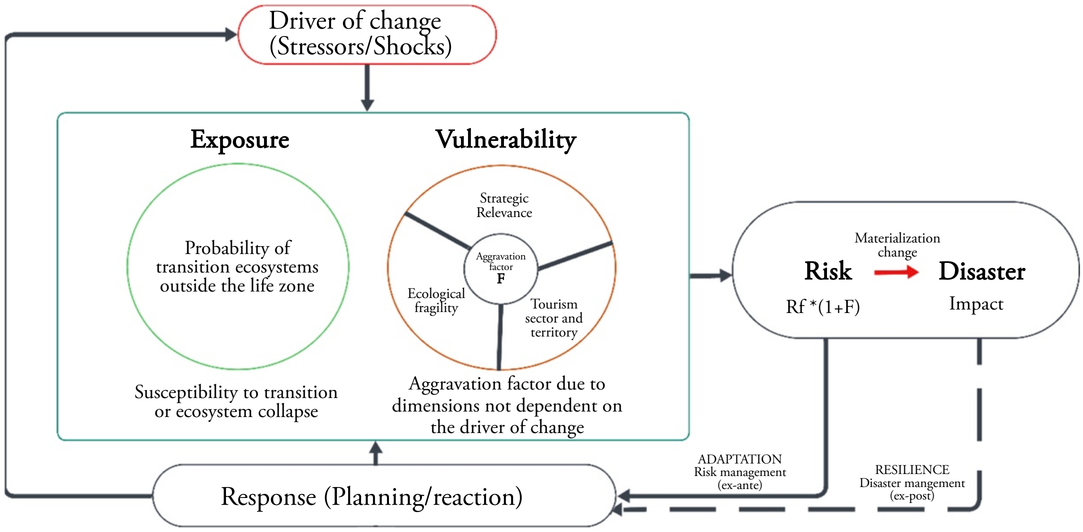
$$R_C = R_F \times \mathrm{F} \tag{1}$$

Context risk, representing vulnerability, depends on factors F that aggravate the socio-ecological context, contributing to Total Risk (Cardona et al., 2022):

$$R_T = R_F\ (1+\mathrm{F}) \tag{2}$$

Figure 3 presents the conceptual approach adapted to the object of study, where vulnerability is defined through the assessment of three aggravating factors: the Strategic Relevance of ecosystems, the Fragility of ecosystems, and the vulnerability of the sectoral and territorial tourism system.

FIGURE 3.
Conceptual approach to the analysis of tourism vulnerability to climate change



Source: Adapted from Cardona et al. (2022).

2.3. Vulnerability or Aggravation Coefficient (F) in the case study

The vulnerability or aggravation coefficient represents factors amplifying physical risk, independent of hazard conditions. Cardona et al. (2022) suggest using ecological fragility (EF) and strategic ecosystem relevance (SR) to assess environmental sector vulnerability to climate change. This study adds a sectoral-territorial category focused on tourism (STT).

Each category uses indicators from various sources, normalized and standardized to represent degrees of association with the aggravation coefficient (Annex 1). Ecosystem transition probability is based on Cardona et al. (2022).

Indicators are associated with the aggravation coefficient F using Zadeh's (1995) fuzzy set theory, as cited by Cardona et al. (2022). A membership function determines the contribution to aggravation, ranging from 0 (no contribution) to 1 (total contribution). Transformation functions make indicators commensurable, assigning social meaning to their contribution. Weights (W) adjust the relative importance of each indicator set, summing to 1 within each set, following a Dempster-Shafer decision structure, common in deep uncertainty estimations (Cardona et al., 2022).

The vulnerability or aggravation coefficient F results from the weighted sum of aggravation factors linked to ecological fragility (EF), strategic relevance (SR), and the tourism sector-territory (STT) category proposed in this study (Equation 3).

$$\boldsymbol{F} = \sum_{i=1}^{5} \boldsymbol{F}_{RE_i} \times \boldsymbol{w}_{RE_i} + \sum_{j=1}^{7} \boldsymbol{F}_{FE_j} \times \boldsymbol{w}_{FE_j} + \sum_{k=1}^{2} \boldsymbol{F}_{STT_k} \times \boldsymbol{w}_{STT_k} \quad (3)$$

Where:

- W weighting of each entity (w = 0.33 for all cases).
- FRE contribution to F of the strategic relevance of ecosystems.
- FRE contribution of ecosystem fragility to F
- FSTT contribution to F of the tourism sector and territory.

The indicators contributing to each category are presented below.

The suggested model can be adapted to different tourist destinations by adjusting the weights (W) according to the particularities of each location.

2.3.1. Ecological Fragility (FE)

This category, proposed by Cardona et al. (2022), uses indicators from national studies on ecosystem impacts unrelated to climate change, representing contextual risk that increases impact likelihood. The Red List of Ecosystems criterion B2aiii (Etter et al., 2017) is included as an additional variable due to its high values in protected areas.

The calculation of this variable uses geostatistical information from the LRE V2 layer (2017), accessible via the "TREMARCTOS-COLOMBIA" system and downloadable through the ArcGIS online REST API. Ecological fragility as an aggravation factor was estimated according to equation 4.

$$FE = (GT * w_{GT}) + (IPHE \times w_{IPHE}) + (DD \times w_{DD}) + (LREA1 \times w_{LREA1}) + (LREB1 \times w_{LREB1}) + (LREB2 \times w_{LREB2}) + (LRED1 \times w_{LRED1} \quad (4)$$

Where:

- W weighting of each entity (w = 0.14 for all cases).
- GT degree of transformation of the ecosystem by anthropogenic pressures.
- IPHE water pressure on the ecosystems.
- DD land degradation due to desertification.
- LREA1 decrease of ecosystem distribution.
- LREB1 restricted geographical distribution of ecosystems.
- LREB2 measure of the disruption of ecosystem condition.
- LRED1 loss of biotic processes.

The degree of transformation (GT) includes transformed ecosystems like crop agroecosystems, forests, fragmented forests with pastures and crops, secondary vegetation, and livestock agroecosystems, based on UPRA (2017) and IDEAM et al. (2017), cited by Cardona et al. (2022).

The index of water pressure on ecosystems (IPHE) represents pressure from productive activities, calculated in the IDEAM National Water Study (2019, 2020), evaluating the green water footprint.

Land degradation by desertification (DD), as defined by Cardona et al. (2022), indicates human pressures on soil, reducing its ecosystem functions and services, leading to biodiversity loss, decreased economic productivity, and reduced response to climatic disturbances, based on the IDEAM study (2021).

2.3.2. Strategic relevance of ecosystems (RE)

The RE index assesses ecosystems' social value based on their contribution to biodiversity conservation, endemic plant species, and cultural ecosystem services. The Key Biodiversity Areas (KBA) and Abundance Richness indicators by Cardona et al. (2022) were excluded as they showed zero values in the department.

The strategic relevance of ecosystems for tourism was estimated using equation 5.

$$RE = (AIMPOCUL \times w_{AIMPOCUL}) + (AIMPOCONS \times w_{AIMPOCONS}) + (CEE \times w_{CEE} \quad (5)$$

Where:

- W weighting of each entity (w = 0.33 for all cases).

- AIMPOCUL valuation assigned to areas providing a cultural ecosystem service.
- AIMPOCONS valuation assigned to areas considered relevant for biodiversity conservation.
- CEE valuation assigned to areas with the highest coefficient of endemic species (CEE) of native plants.

The area of cultural importance was recalculated by including the World Heritage Site (WHS) variable alongside those considered by Cardona et al. (2022), recognising UNESCO's (2011) declaration of the Coffee Cultural Landscape in 11 of Risaralda's 14 municipalities, assigning relationships of belonging as main or buffer areas (Annex 1).

2.3.3. Aggravating factor for tourism STT

The sectoral and territorial vulnerability for tourism reflects municipal tourism supply dynamics and concentrations of tourism attraction and services, which do not necessarily follow political-administrative boundaries. This relationship is detailed in equation 6.

$$STT = (FSectorT \times w_{FSectorT}) + (FTerritorioT \times w_{RterritorioT}) \quad (6)$$

Where:

- W weighting of each entity (WFSectoralT = 0.5, wFTerritoryT = 0.5).
- FSectorT vulnerability of the municipal context applied to tourism.
- FTerritorioT weighted Kernel density of the different territorial expressions of tourism supply considered in the study.

I. Aggravating factor for tourism - sectoral approach

The sectoral aggravation factor (FSectorT) involves the relationship between sectoral sensitivity (SST) as a local context factor, and the adaptive capacity of each tourist destination municipality (CAT) as a determinant of the capacity to respond to impacts as expressed in equation 7.

$$FSectorT = (SST \times w_{sst}) \div (CAT \times w_{CAT}) \quad (7)$$

Where:

- W weighting of each entity (wSST = 0.5, wCAT = 0.5).
- SST sensitivity of the tourism sector to climate change.
- CAT adaptive capacity of the municipal tourism destination.

Since CAT is a divisor, an increase in its value leads to a decrease in the value of FSectorT, following the IPCC (2014) methodology for assessing the relationship between sensitivity and adaptive capacity in vulnerability analysis.

In terms of sectoral sensitivity applied to tourism (SST), the following linked variables were assessed in equation 8:

$$SST = (CPST \times w_{CPST}) + (ROT \times w_{ROT}) + (OZRD \times w_{OZRD}) + (STCNCC \times w_{STCNCC}) \quad (8)$$

Where:

- W weighting of each entity (wCTSP = 0.3, wROT = 0.3, wOZRD = 0.3, wSTCNCC = 0.1).
- CTSP representativeness of capacity in the provision of tourism services.

- ROT representativeness of tourism supply.
- OZRD supply of attractions in dispersed rural areas.
- STCNCC municipal sensitivity to climate change.

The Representativeness of the capacity in the provision of tourism services - CTSP, is the proportion of the municipal capacity in the supply of rooms and tables, in the departmental total.

The Representativeness of the tourist offer (ROT) is the proportion of municipal Natural and Cultural tourist attractions in the departmental total. The supply of attractions in dispersed rural areas (OZRD) corresponds to the relative municipal value of attractions and TSP (gastronomic and accommodation) in dispersed rural areas as defined by DANE (2013).

Municipal Sensitivity to Climate Change (STCNCC) was measured by the third national communication on climate change IDEAM et al. (2017). The data were normalised using the 80th percentile before processing in the matching function (Annex 1). Given the 2017 national assessment, the STCNCC indicator was weighted at 0.1. The adaptive capacity of the municipal tourism destination (CAT) was assessed using the variables in equation 9.

$$CAT = (ICM \times w_{ICM}) + (CATCNCC \times w_{CATCNCC}) \quad (9)$$

Where:

- W weighting of each entity (wICM = 0.5, wCATCNCC = 0.5).
- ICM adjusted index of municipal capacities.
- CATCNCC municipal adaptive capacity to climate change.

The ICM was updated for this study in 2022, using the capacity-adjusted municipal risk index from DNP & DADS (2018). The financial and socio-economic components were updated (tax revenues, value added, population in headwaters, and business density), risk management (investment and tools for disaster risk management), and variables related to land-use planning, tourism planning, climate change management, and tourism associations.

Municipal Adaptive Capacity to Climate Change (CATCNCC) was measured by the third national communication on climate change IDEAM et al. (2017).

II. Aggravating factor for tourism - territorial approach

The tourism aggravation factor with a territorial approach FTerritorioT was calculated using geostatistical spatial analysis techniques, establishing a differentiated density measure for urban, rural and attractive TSPs, which expresses the incidence of this offer in the tourist territory.

Equation 10 establishes the relationship between the calculated densities, and constitutes the aggravation factor of the tourist territory:

$$FTerritorioT = DenkPSTU \times w_{DenkPSTU} + DenkPSTR \times w_{DenkPSTR} + DenkA \times w_{DenkA} \quad (10)$$

Where:

- W weighting of each entity (wDenkTSPU = 0.25, wDenkTSPR = 0.25, wDenkA = 0.5).
- DenkTSPU density of urban tourism service providers.
- DenkTSPR density of tourism service providers in the dispersed rural area.
- DenkA density of natural and cultural tourist attractions recognised in official inventories.

Kernel density analysis in ArcGIS (ESRI) calculated the density of gastronomic and accommodation TSPs and tourist attractions, using the quartic kernel function by Silverman (1986, p. 76, equation 4.5).

The default search radius was used, considering Risaralda's spatial configuration and entry points, correcting for outliers. Density values (0-1) relate directly to the aggravation factor, with higher density indicating greater exposure to tourism supply-demand dynamics.

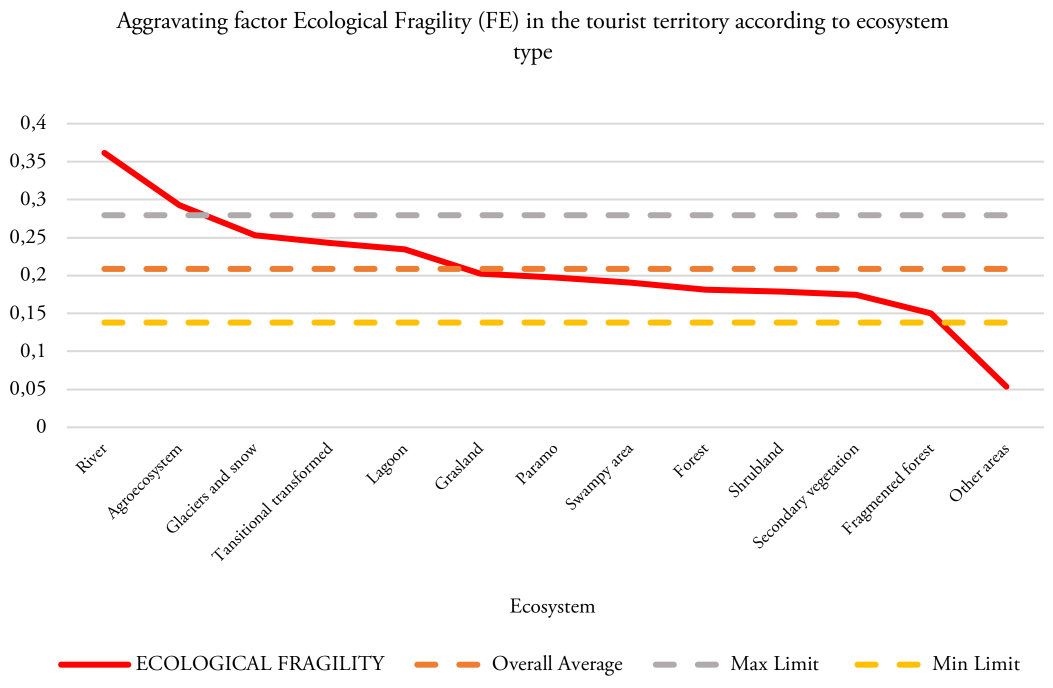
3. Results

3.1. Spatial distribution of aggravating factors

3.1.1. Ecological fragility

The average ecological fragility of each ecosystem exceeded the general average (0.2) of the department of Risaralda in several cases, such as Agroecosystems (0.29), Glaciers and Snow (0.25), Transitional transformed (0.24), Lagoon (0.23), and River (0.36), the latter exceeding the maximum limit (with standard deviation = 0.07) as shown in figure 4.

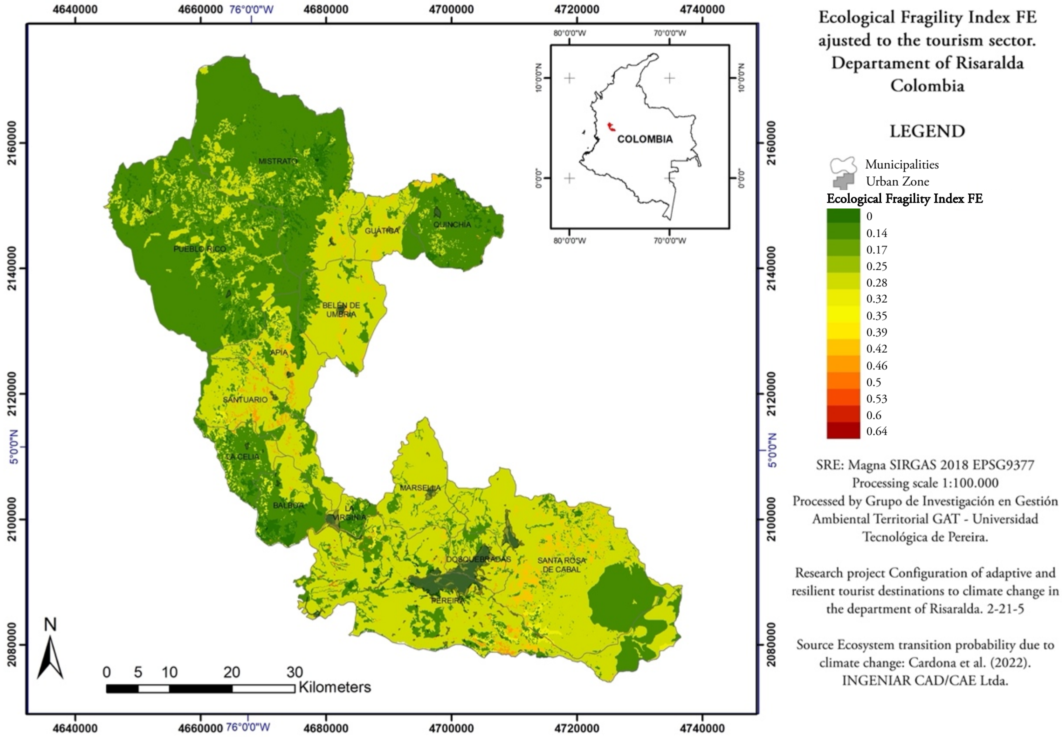
Figure 4.
Ecological fragility of ecosystems in the department of Risaralda - average values



Source: Own elaboration.

The average trend of ecological fragility in the department is classified as "Medium". However, specific areas such as Agroecosystems and Rivers (0.64), Forests, Transitional transformed and Secondary vegetation (0.5) present maximum values, visible in map 2.

Map 2.
Ecological fragility FE for the tourist territory of the department of Risaralda

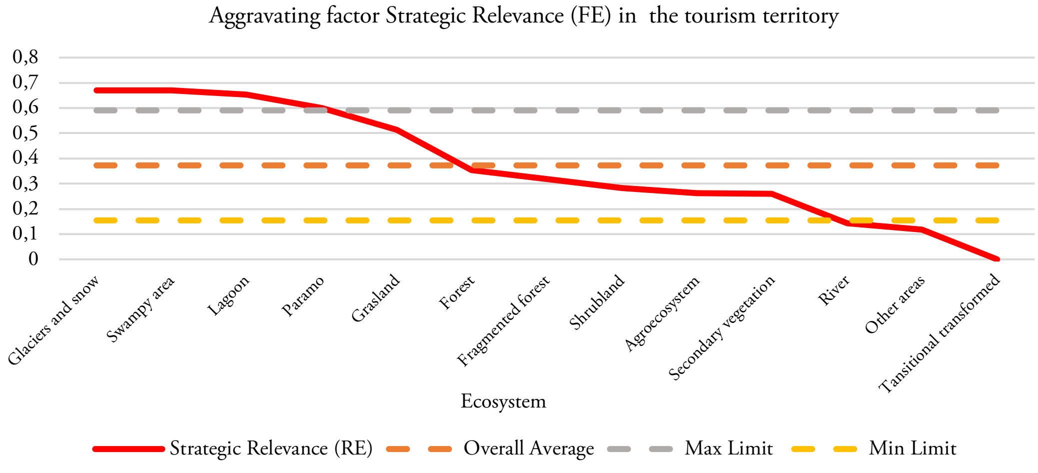


Source: Own elaboration.

3.1.2. Strategic relevance of ecosystems

The average Strategic Relevance (RE) of each ecosystem in the study area was above the departmental average (0.37) in the Grassland ecosystems (0.51) and above the maximum limit (with standard deviation = 0.21) in the Glaciers and snowfields, Wetlands (0.67), Lagoons (0.65), Paramos (0.59), as illustrated in figure 5.

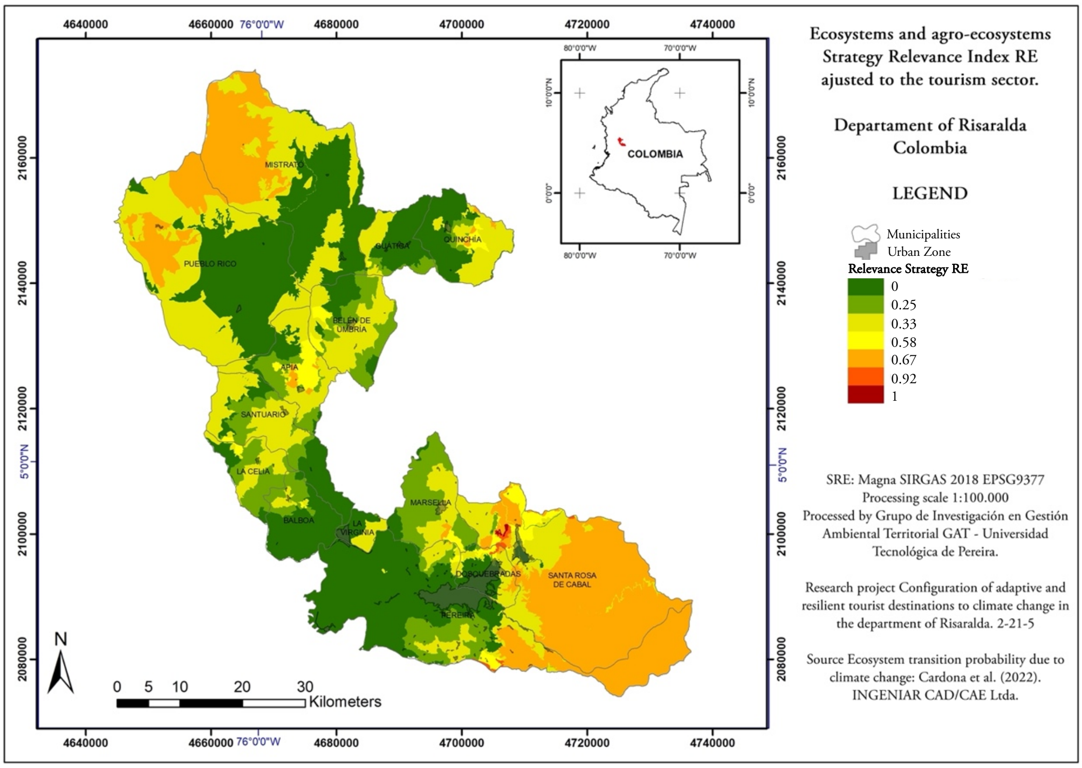
Figure 5.
Strategic Relevance (RE) of ecosystems in the department of Risaralda - average values



Source: Own elaboration.

The average of the ecosystem valuations in the department indicates a "High" relevance. However, in specific areas of the territory, such as Agroecosystems and Forests (1), Grassland and Secondary Vegetation (0.92), the maximum values are observed. A spatial distribution of this relevance is shown in map 3.

Map 3.
Strategic Relevance (RE) of the ecosystems for the tourist territory of the department of Risaralda



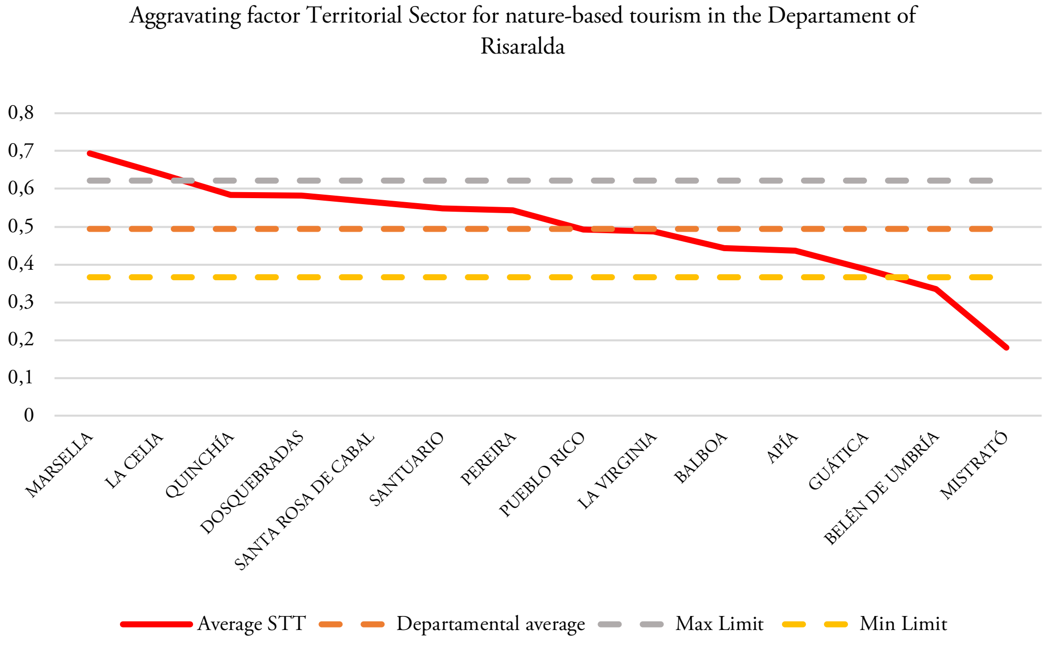
Source: Own elaboration.

3.1.3. Secto-territorial aggravating factor for tourism

The sector-territorial valuations for tourism show that municipalities such as Marsella (0.69), La Celia (0.63), Quinchía (0.58), Dosquebradas (0.58), Santa Rosa de Cabal (0.56), Santuario (0.54) and Pereira (0.54) have indices of aggravation of the tourism offer in the face of climate change (STT) above the departmental average (0.49). In contrast, the municipality of Mistrató has the lowest value (0.18), as shown in Figure 6.

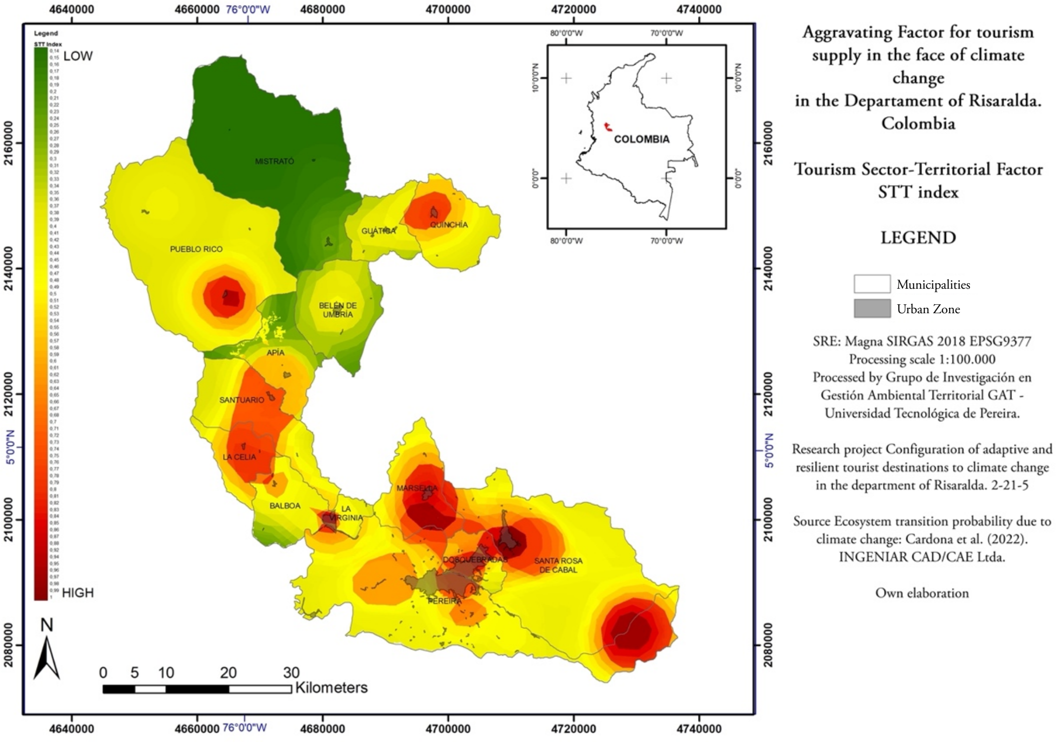
The STT factor, based on the Kernel density analysis previously described, highlights areas with high anthropic pressures due to the concentration of tourism service providers and natural and cultural attractions. Municipalities with high STT values include Santa Rosa de Cabal (1), Marsella (0.98), Pereira (0.97), Pueblo Rico (0.95), Dosquebradas (0.85), La Virginia (0.85), La Celia (0.8) and Balboa (0.8). This distribution reflects the attractiveness beyond municipal boundaries, driven by complementarity dynamics in tourism, as shown in Map 4.

FIGURE 6.
Secto-territorial aggravation factor for the tourist destination of the department of Risaralda - average municipal values



Source: Own elaboration.

MAP 4.
Aggravation factor of the STT tourism offer for the department of Risaralda

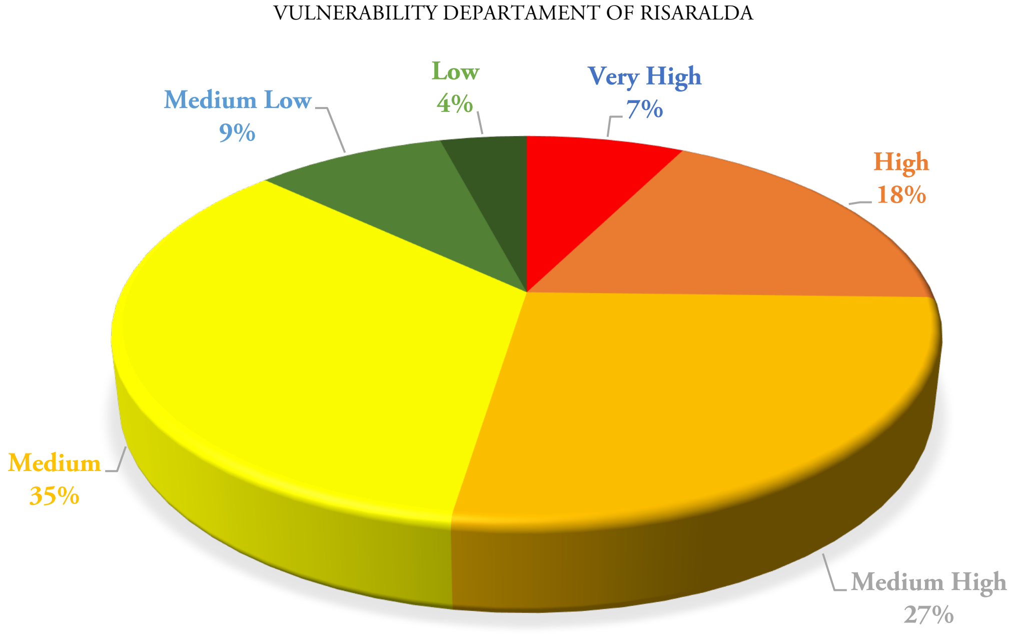


Source: Own elaboration.

3.2. Coefficient of vulnerability or aggravation (F) in the tourist municipalities of Risaralda

In the department of Risaralda, approximately 59% of its territory presents vulnerability coefficients (F) in the Medium High, High and Very High categories, of which 7% reach the highest level of assessment, as shown in Figure 7.

Figure 7.
Proportion of areas in the departmental total according to levels of vulnerability or aggravation coefficient (F)



Source: Own elaboration.

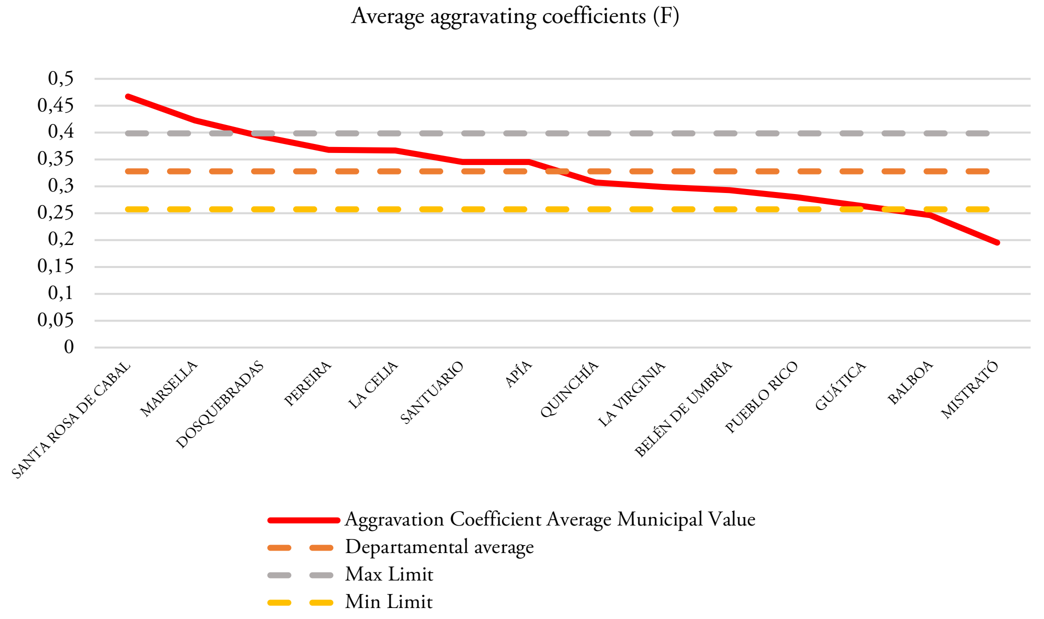
Municipalities with levels of vulnerability or aggravation (F) above the departmental average (0.32) include Apia (0.35), Santuario (0.34), La Celia, Pereira (0.36), Dosquebradas (0.39), and with values above the departmental maximum limit (with a standard deviation of 0.07) are Marsella (0.42) and Santa Rosa de Cabal (0.48), as illustrated in Figure 8.

The aggravation coefficient varies in Risaralda, with maximum values above 0.5 in eight municipalities related to nature-based tourism. Vulnerability levels also vary, with Santa Rosa de Cabal, Marsella and Dosquebradas standing out as having the most vulnerable areas. Map 5 and Figure 9 provide more details.

Hierarchical clustering of municipal factors and aggravation coefficients reveals two groups based on similarity, with Santa Rosa de Cabal, Pueblo Rico, Quinchía, Dosquebradas and La Virginia differentiated from the rest. However, when evaluating Tourism Sector and Territory (TSP) and Municipal Attractiveness, a new grouping emerges, with Santa Rosa de Cabal, Pereira and Marsella detached from the rest of the department. (See Annex 2, Graphs 1, 2 and 3).

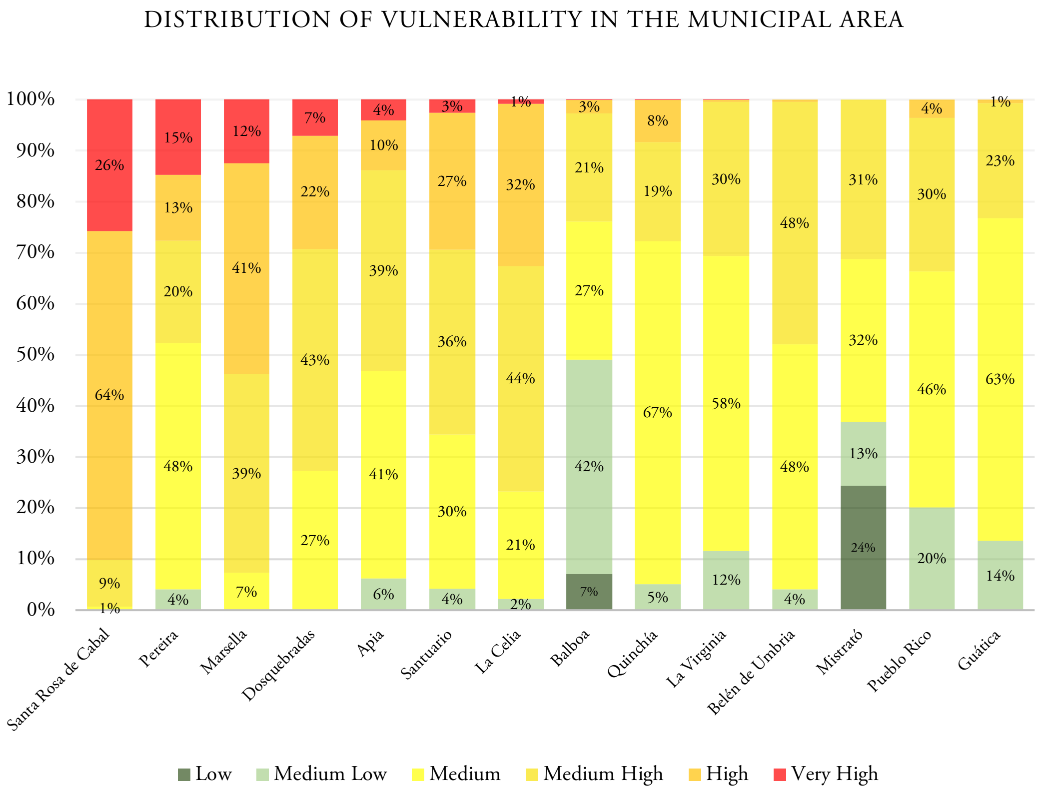
The transformation functions between quantitative coefficients and qualitative levels of vulnerability are presented in Annex 1, Table 4.

FIGURE 8.
Municipal average aggravation coefficients (F)



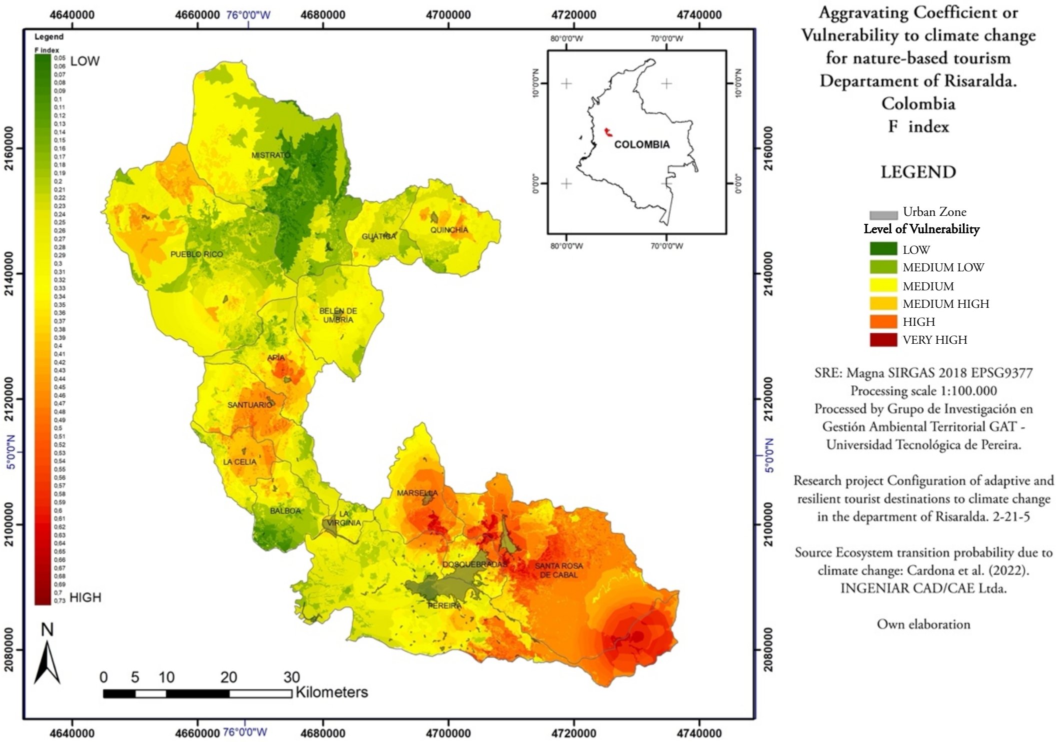
Source: Own elaboration.

FIGURE 9.
Distribution of vulnerability levels in the municipal area



Source: Own elaboration.

Map 5.
Coefficient of aggravation or integral vulnerability to climate change for nature-based tourism in the Department of Risaralda



Source: Own elaboration.

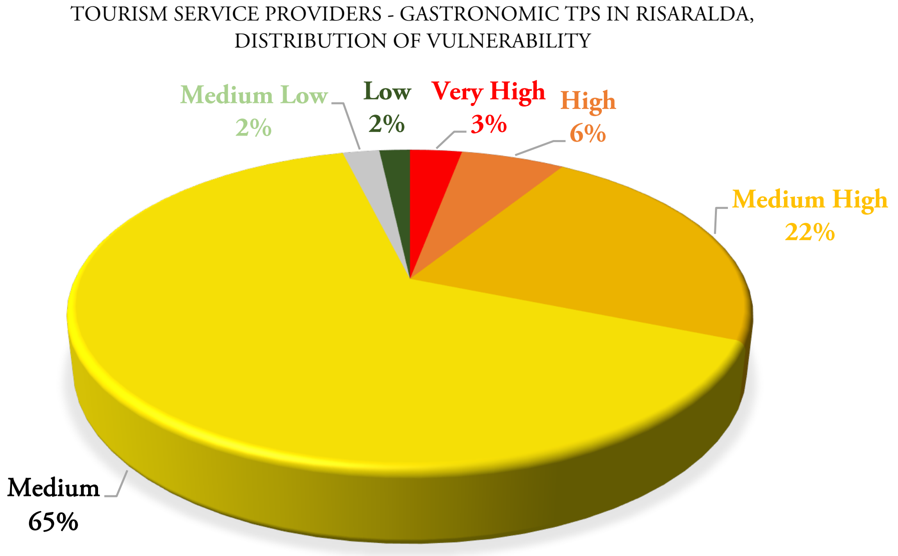
3.3. Vulnerability of tourism supply

Intersections were made between the 798 tourist service providers (72% gastronomic and 28% accommodation), the 148 tourist attractions (73% cultural heritage and 27% natural) and the polygonal results of the integral vulnerability in Risaralda, following the methodological process of spatial analysis previously described.

31% of the assessed gastronomic TSPs show vulnerability levels higher than level F "Medium". This implies a significant aggravation coefficient for the value chain indirectly related to the state of ecosystems (Figure 10).

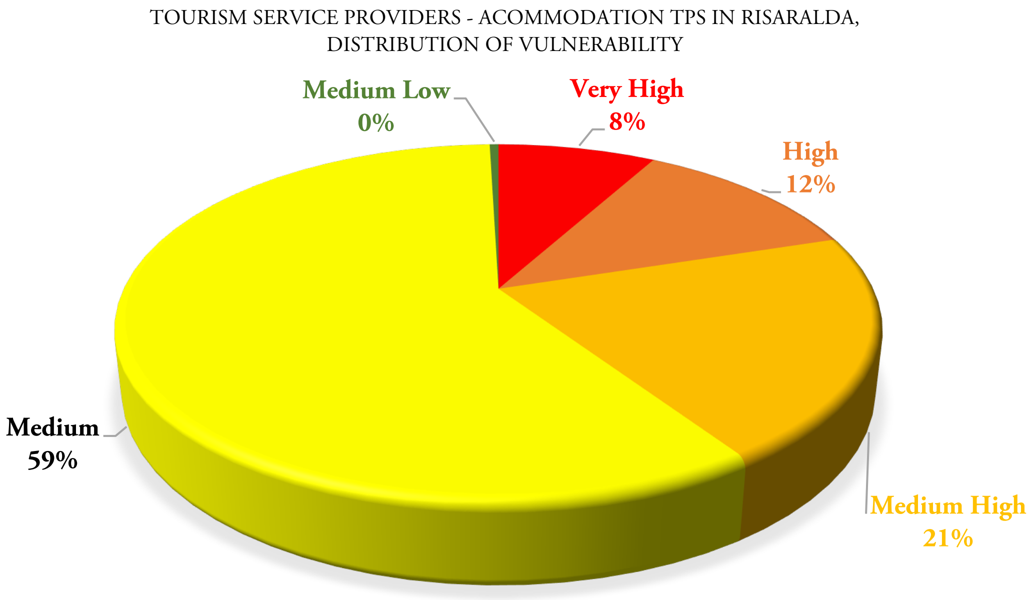
As for the accommodation TSP, a similar behaviour is observed above level F "Medium" in 41% of them (Figure 11).

FIGURE 10.
Levels of vulnerability in the tourism supply value chain - Gastronomic (TPS)



Source: Own elaboration.

FIGURE 11.
Levels of vulnerability in the tourism supply value chain - TPS Accommodation

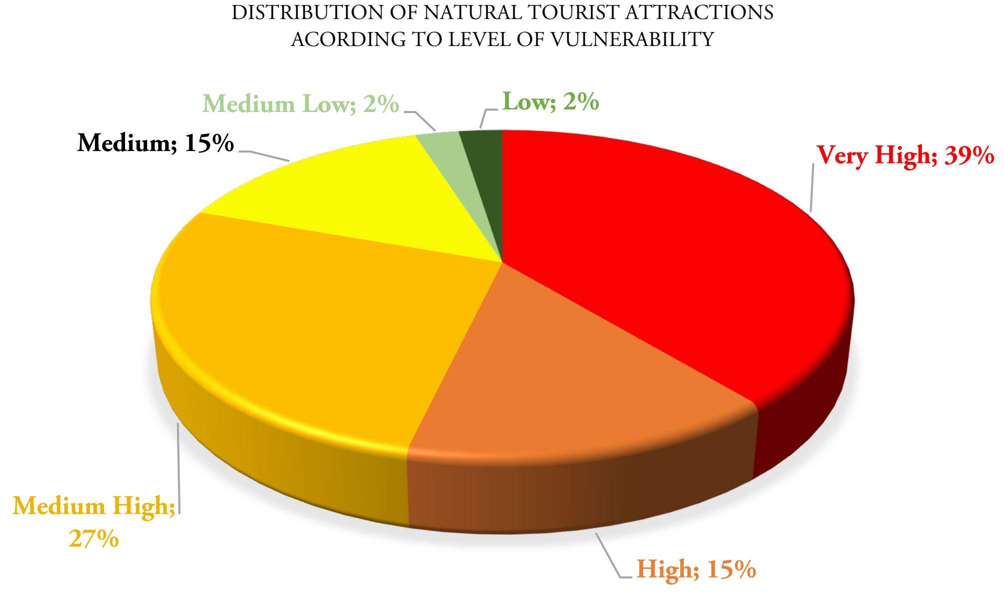


Source: Own elaboration.

The hierarchical clustering of the factors and aggravation coefficient of the TPS identifies two clusters based on their similarity, with the high mountain cabins separated from the rest, a high proximity between hotels, restaurants and campsites (see Annex 2, Graph 5).

On the other hand, 81% of the natural attractions have "high" or "very high" vulnerability, indicating a significant predisposition to their affectation due to ecosystem transition (Figure 12).

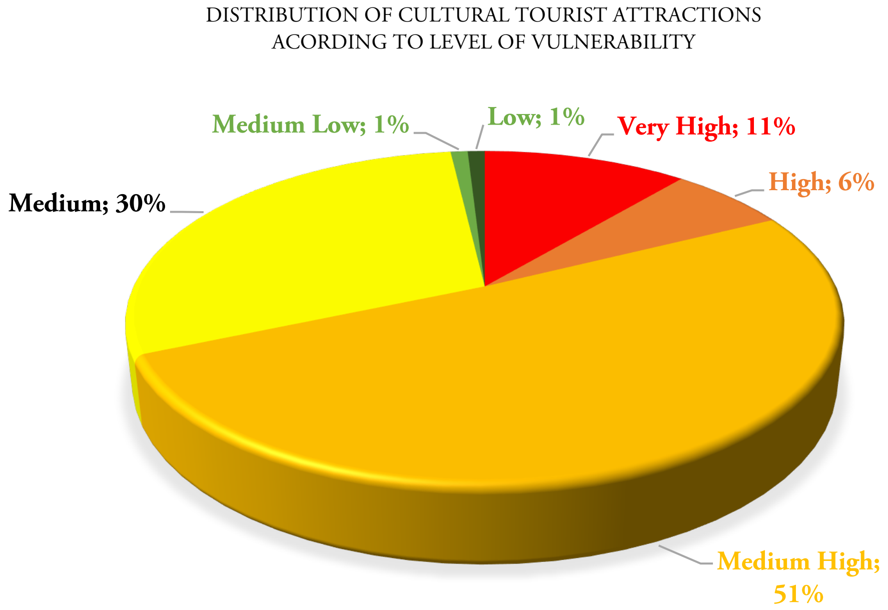
FIGURE 12.
Distribution of natural tourist attractions according to levels of vulnerability



Source: Own elaboration.

68% of cultural attractions have a vulnerability level above "Medium", suggesting a possible indirect impact on non-nature-based tourism, which is complementary to the municipal tourism offer (Figure 13).

FIGURE 13.
Distribution of cultural tourism attractions according to levels of vulnerability



Source: Own elaboration.

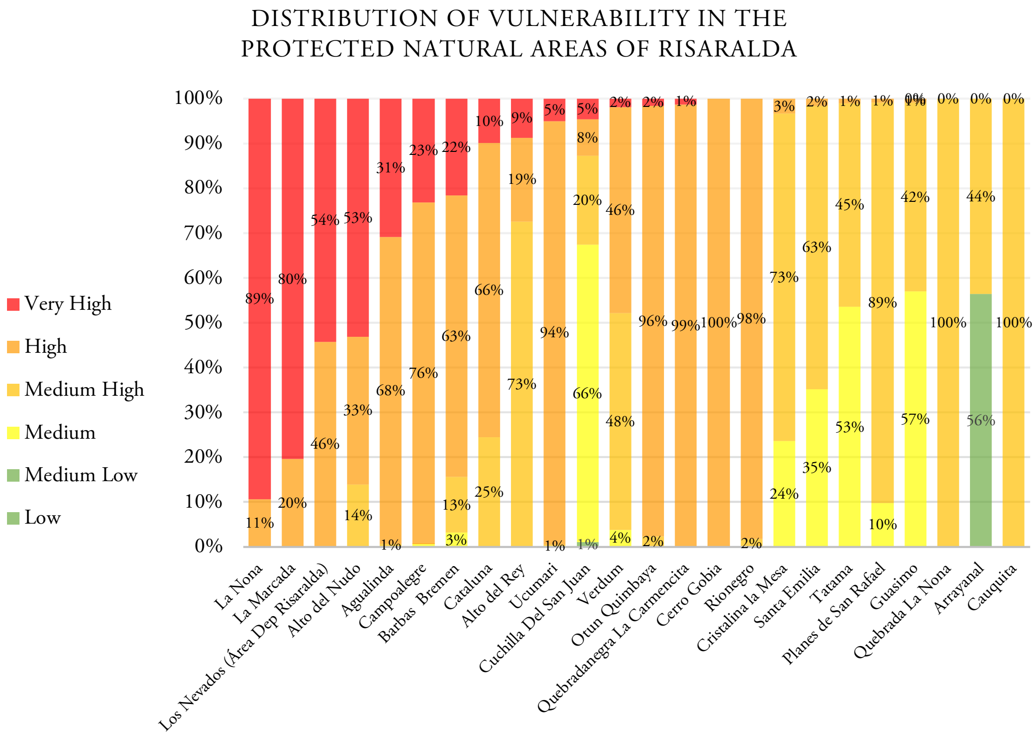
Hierarchical clustering of municipal factors and aggravation coefficient identifies two clusters based on their similarity, with the immovable and intangible cultural heritage in one group, separated from the rest of the attraction typologies (see Annex 2, Graph 6).

3.4. Vulnerability or aggravation coefficient in areas of tourist interest and protected natural areas

Results for Risaralda's Natural Protected Areas (NPAs) show that some, like La Nona (89%), La Marcada (80%), Los Nevados (54%), and Alto del Nudo (53%), have over 50% of their areas at "Very High" vulnerability levels. Others such as Barbas Bremen, Agualinda, Cataluña, Alto del Rey, Campoalegre, Ucumari, Otún Quimbaya, Quebrada la Carmencita, Rionegro, Cerro Gobia, Quebrada la Nona, Cauquita, and Verdum have vulnerability levels at "Medium High" or higher for nearly their entire area, depicted in Figure 14.

Comparing aggravation factors and coefficient (F) identifies NPAs vulnerable to nature-based tourism dynamics. NPAs like Quebrada la Nona, La Nona, La Marcada, Los Nevados, Alto del Nudo, and Agualinda face higher anthropic pressure due to their tourism stress factor (STT). In contrast, NPAs like Cerro Gobia, Rionegro, Verdum, Alto del Rey, Guásimo, and Cauquita, although in tourist areas, show lower average vulnerability levels. This relationship is illustrated in Figure 15 and supported by cluster analysis (Annex 2, Graph 7).

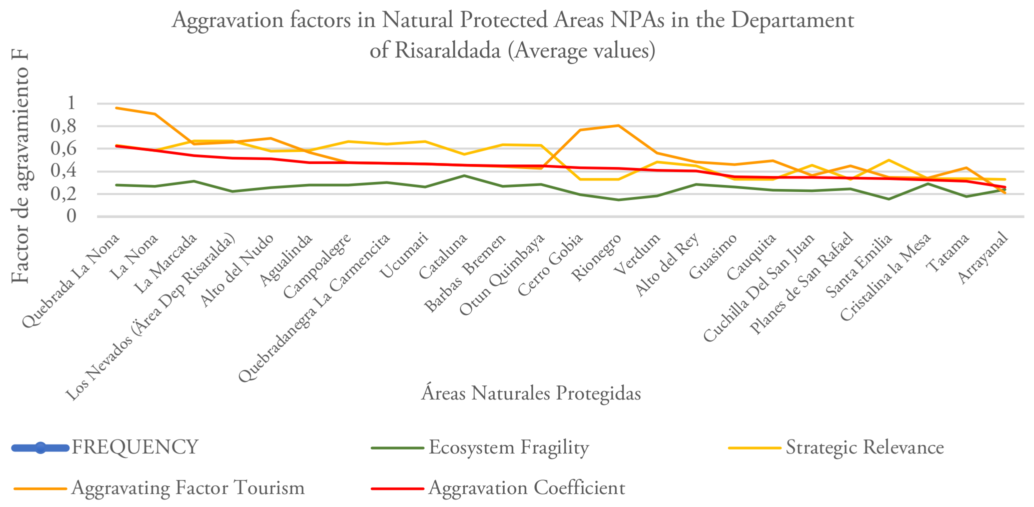
Figure 14.
Distribution of vulnerability levels within the Departmental NPAs



Source: Own elaboration.

Cluster analysis results show three groups of NPAs with similar characteristics, suggesting they could be managed as equal planning units for vulnerability management. The third group exhibits the highest vulnerability levels (Annex 2, Graph 9). Similarities in NPA typologies indicate proximity between those with the highest conservation category designation and Regional Integrated Management districts and Recreation areas (Annex 2, Graph 8)

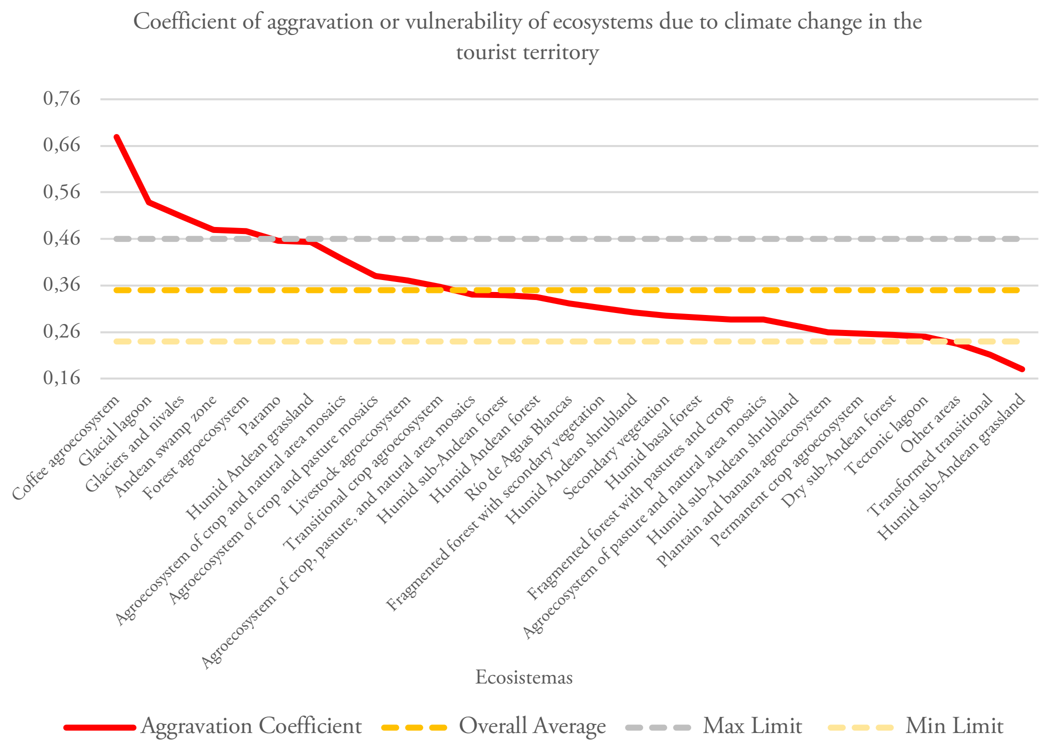
FIGURE 15.
Aggravation factors and coefficient in the NPAs of the Department of Risaralda



Source: Own elaboration.

The aggravation coefficient F in various ecosystems exceeds the departmental average of 0.34, with coffee agroecosystems notably high at F=0.67. Ecosystems such as páramo, forest agro-ecosystem, Andean swamp, glaciers, snowdrifts, and glacial lagoons surpass the departmental maximum limit (with SD = 0.11), as depicted in Figure 16.

FIGURE 16.
Aggravation coefficient in ecosystems and agro-ecosystems of Risaralda



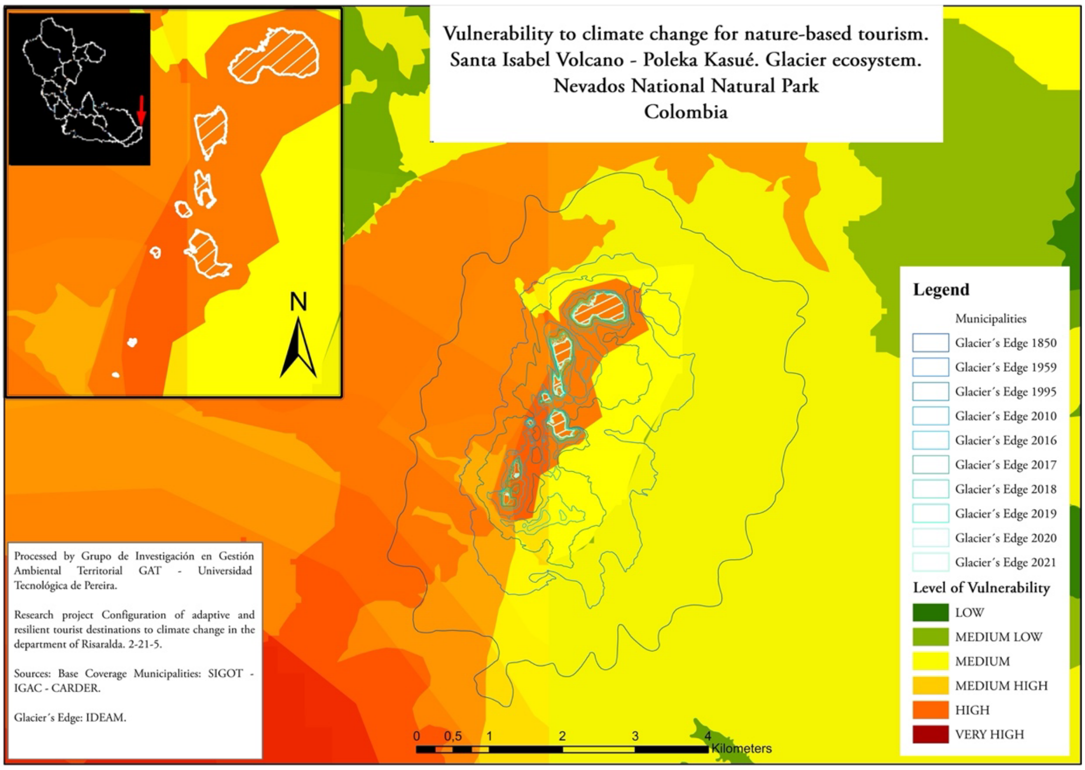
Source: Own elaboration.

The clustering analysis identifies three ecosystem groups with common vulnerability factors suitable for planned tourism adaptation management. Group one includes fragmented forests, moorlands, agro-ecosystems, and rivers, while group two comprises lagoons, swampy areas, glaciers, snow, scrublands, and grasslands. The third group consists of highly intervened ecosystems (see Annex 2, Graph 9 and 10).

In a broader context, vulnerability assessment model data was compared with reality, focusing on Los Nevados National Natural Park. Results for the park revealed average values: STT 0.65, RE 0.67, FE 0.22, and F 0.54. Within the park, the Glacier and Snow ecosystem "Poleka Kasué" displayed RE 0.67, FE 0.32, STT 0.46, and F 0.48, indicating a "High" vulnerability level. Considering LRE B2aiii criteria and RCP scenarios (Map 1), this ecosystem faces a 0.06 to 0.09 probability of transition due to climate change.

Glacial and snow ecosystems in the field exhibit historical retreat, documented by IDEAM (2021), signifying paramo and super-paramo ecosystem transitions from glacier and snow-capped mountain retreat or collapse. This aligns with vulnerability assessments conducted (Figure 17).

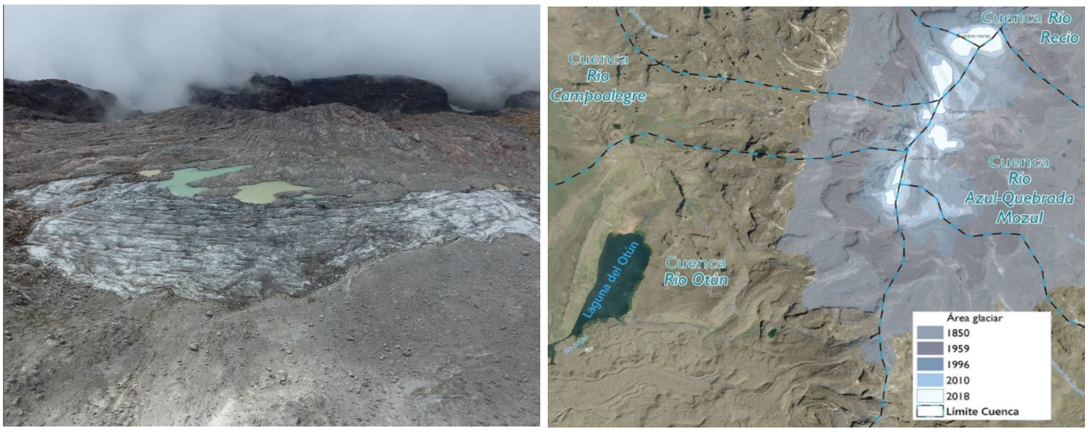
Figure 17.
Vulnerability maps for areas of glacier and snow ecosystem retreat and collapse. Poleka Kasue glacier, PNN Los Nevados



Source: Own elaboration.

By 2022, the Otún Norte and Otún Sur glacial relicts in Risaralda have completely collapsed. The collapse evidence (Figures 17 and 19) and ecosystem transition documentation by IDEAM (2021) underscore the urgency of adopting adaptive and resilient strategies to address climate change impacts in protected natural areas. These areas are not only popular tourist destinations but also highly vulnerable.

Figure 18.
Left, last remnants of glacial ice in the Otún Risaralda River basin. Right, monitoring of glacial retreat (IDEAM)



Source: Jorge Luis Ceballos Lievano (2020).

Figure 19.
Left, Nevado Santa Isabel Glacier - Conejeras sector; Right, advance of super-paramo ecosystems in areas of glacial retreat

Source: Jorge Luis Ceballos Lievano (2023).

4. Discussion

Our conceptual and methodological framework (Figures 3 and 2) differs from conventional approaches in recent tourism vulnerability studies (Álvarez et al., 2022; Aznar et al., 2020) and climate change vulnerability (IPCC, 2014; IDEAM, 2017), yet aligns with the general principle of vulnerability in the literature. This perspective emphasizes exposure, sensitivity, and adaptive capacity as contextual factors independent of hazard behavior.

The adapted methodological approach (Figure 2, equation 3) based on a reference model (Cardona et al., 2022; Government of Colombia, 2021) represents a novel application to the tourism sector. It integrates key elements of exposure related to the interaction between tourism territory and ecosystems, sensitivity, and adaptive capacity. These components are combined through variables considering strategic relevance, ecosystem fragility, and sectoral and territorial aggravation factors for tourism. This approach is applicable to tertiary sectors beyond those addressed in Colombia's Long-term Climate Strategy for the Paris Agreement (E2050).

The aggravation coefficient (Equation 3), indicating the tourism system's vulnerability to ecosystem transition or collapse due to climate change, offers a metric for understanding contextual factors in the society-nature relationship. It addresses the determinants of the relationship between climate change, biodiversity impacts (Ojija & Nicholaus, 2023; Habibullah et al., 2022; Shivanna, 2022; Muluneh, 2021; Shukla et al., 2021; Hemanth et al., 2020), and the provision of cultural ecosystem services supporting nature-based tourism.

The results of ecological fragility calculations show that ecosystems such as rivers (average 0.36, maximum 0.64), agroecosystems (average 0.29, maximum 0.64), and glaciers and snow (average 0.25, maximum 0.32) stand out above the departmental average (0.2) (Figure 4, Map 2). Agroecosystems in Risaralda, linked to cultural ecosystem services from biodiversity associated with crops, are particularly vulnerable. Climate change impacts biodiversity in agricultural areas of ecotourism destinations, especially those near conservation areas (Hanilyn & Hidalgo, 2014), with about 36% of Risaralda's territory under protection.

The strategic relevance of ecosystems highlights the importance of Andean grasslands, glaciers, glacial lakes, wetlands, paramos, and forests for conservation and culture. Agro-ecosystems, especially the coffee ecosystem (0.39) and crop mosaics (0.41), reflect the significance of Colombia's Coffee Cultural Landscape (UNESCO, 2011; MINCULTURA, 2011). The aggravation coefficient for the coffee agroecosystem (0.68), glacial lagoons (0.54), and glaciers (0.51) exceeds the departmental limit (standard deviation 0.11), indicating tourist interest areas and tourism vulnerability to climate change.

Tourism factor (STT) valuation is proportional to the territory's tourism vocation, but some municipalities like Mistrató, Belén de Umbría, Guática, and Apia show high supply segmentation, low STT density, and vulnerability (GRITUS, 2018). Higher vulnerability coefficients (F) are linked to concentrated, non-specialized day trip tourism in the most vulnerable municipalities with high tourism competitiveness (CPTUR, 2020). These municipalities cluster together in vulnerability analyses (Figures 2 and 3).

The calculated density shows urban TSPs concentration (75%) and dispersed rural attractions (47%). For instance, Pereira has higher aggravation coefficients in rural areas and Natural Protected Areas (NPAs) (Map 4).

The F coefficient indicates high vulnerability in Santa Rosa de Cabal, Marsella, and Dosquebradas, which have the largest proportions of vulnerable areas (Figure 9). Despite tourism sustainability certifications (NTS-TS COLOMBIAN SECTORAL STANDARD 001-1), these municipalities form a vulnerable cluster (Graphs 3, 4). This aligns with Scott et al.'s (2019) argument that vulnerability is highest where tourism significantly contributes to GDP and where future tourism growth is projected.

Although this study focuses on natural tourism vulnerability, we recognize its relationship with cultural tourism development (Rivera, 2021). Sixty-eight percent of cultural attractions show high vulnerability (Figure 13), suggesting an indirect impact on both cultural and natural heritage. Clustering analysis reveals similarities between tangible and intangible cultural heritage in their aggravation factors (Graph 6).

Risaralda is experiencing ecosystem transitions and collapses due to climate change, providing an opportunity to discuss the proposed model. Cluster analysis indicates Los Nevados NP has similarities to other tourist areas (Graph 7 and 9). Kevin and Coldrey (2020) note climate change's significant impact on ecosystems in subtropical and tropical areas, potentially reducing national park visitation and posing risks to conservation activities due to decreased tourism income.

The study of paramo and glacier ecosystems, with research authorization from National Natural Parks of Colombia (file: OTRP 008-2021) under the project "Participatory Environmental Monitoring in the High Mountains (MAPAM)" in PNN Los Nevados, allowed us to contrast and discuss the results of our methodological approach with field observations. The potential retreat of the Poleka Kasué (Nevado Santa Isabel) glacier to super-paramo has led tour operators and guides to collaborate with IDEAM, PNNC, and the academic community to implement adaptive responses. These include modifying the NPA tourism management plan, adapting interpretive scripts for scientific tourism, and integrating climate change monitoring into the tourist experience.

In response to the collapse of the Otún Norte, Sur, and Conejeras glaciers, operators have developed resilient strategies. They diversify and specialize high mountain experiences, enforce stricter carrying capacity regulations, and explore opportunities to interpret climate change effects on mountain ecosystems. Cluster analysis shows similarities between grassland, shrubland, swampy area, lagoons, and glaciers ecosystems (Figure 9), which are subjects of interpretation in the area. This includes monitoring glacial retreat and documenting ecosystem collapse within the tourism narrative.

These resilient and adaptive responses align with the potential states of destinations before and after disturbances, as described by Álvarez et al. (2022). Some tourism destinations can identify and reduce vulnerability, becoming "anti-fragile" by recovering and transforming the tourism system post-disruption. These findings address knowledge gaps for South America identified by Scott et al. (2023) regarding integrated impacts and adaptation strategies at the destination scale.

5. Conclusions

Vulnerable Ecosystems: Risaralda's key ecosystems, like agro-ecosystems, glaciers, and rivers, are exceptionally fragile ecologically, making them highly susceptible to climate change.

Strategic Relevance: Andean grasslands, glaciers, glacial lakes, and moorlands are strategically crucial for conservation and regional culture.

Tourism Zoning: Municipalities such as Marsella, Dosquebradas, and Santa Rosa de Cabal share similar patterns in tourism service provider clustering and densities, indicating high vulnerability in tourism offerings.

Rural Area Density: Pereira shows a significant concentration of tourism services in rural areas, expanding tourism beyond urban centres.

Vulnerable Operators: Municipal clusters with high aggravation coefficients (F) and tourism sustainability certifications paradoxically exhibit high competitiveness, necessitating adaptive planning beyond short-term competitiveness.

Impact on Protected Areas: Protected areas like Los Nevados National Park face significant vulnerability due to glacial retreat and ecosystem shifts, impacting tourism and conservation efforts.

Glacier Collapse: Data indicate complete glacier collapse within Risaralda, urging immediate attention to tourism vulnerability.

Responses: Tour operators in protected areas are adopting adaptive measures, diversifying offerings, and monitoring ecosystem transitions to enhance tourism resilience.

Anti-fragile Potential: Resilient responses can make the tourism system "anti-fragile," capable of regeneration despite disruptions.

In summary, Risaralda's vulnerability as a tourism destination underscores the need for adaptive management considering climate impacts on ecosystems. Public policies and strategic planning should integrate proposed zoning and similarity frameworks to enhance sector resilience.

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Annexes

Annex 1. Degrees of association or membership with the aggravation coefficient

Table 1.
Ecological Fragility. Degrees of association or membership for each aggravating factor

GT	FGT	(LRE) Criteria LREA1, LREB1aiii, LREB2aiii, LRED1	FLRE	IPHE	DD	F IPHE, DD
Natural	0	Agroecosystems	0	Very Low	No Susceptibility	0
Semi-transformed	0.5	No Concern (LC)	0.01 - 0.25	Low	Very Low	0.1 - 0.2
		Vulnerable (VU)	0.26 - 0.5	Moderate	Low	0.3 - 0.4
		Endangered (EN)	0.51 - 0.75	High	Moderate	0.5 - 0.6
		Critical	0.76 - 1	Very High	High	0.7 - 0.8
Transformed	1			Critical	Very High	0.9 - 1

Source: Own elaboration.

Table 2.
Strategic Relevance. Degrees of association or membership for each aggravating factor

AIMPOCUL	F	AIMPOCONS	F	Coefficient of Endemic Species (CES)	F
Other areas	0	Other areas	0	CES < 0.16	0
WHS (PCC) buffering zone.	0.75	Strategic ecosystems	0.1 - 0.25	CES >= 0.16	1
WHS (PCC) core zone.	1				
Indigenous Reserves	1	AICAS and Priority Areas 2008	0.26 - 0.5		
Peasant Reserve Zones	1				
Black Community Councils	1	National Protected Areas (RUNAP)	0.6 – 1		

Source: Own elaboration.

Table 3.
Aggravating factor in the tourism sector and territory. Degrees of association or membership for each aggravating factor

SST								CAT			
CTSP (%)	F	ROT (%)	F	OZRD (%)	F	STCNCC	F	ICM	F	CATCNCC	F
0	0	0	0	0	0	0,00	0,00	0	0,00	0	0
1	0,1	2	0,21	11	0,21	0,18	0,41	19	0,43	0,67	0,90
2	0,23	3	0,35	29	0,53	0,20	0,44	20	0,45	0,69	0,94
3	0,35	5	0,49	33	0,62	0,29	0,67	26	0,58	0,71	0,96
4	0,5	6	0,63	36	0,66	0,30	0,68	27	0,60	0,72	0,97

TABLE 3. CONT.
Aggravating factor in the tourism sector and territory. Degrees of association or membership for each aggravating factor

SST								CAT			
CTSP (%)	F	ROT (%)	F	OZRD (%)	F	STCNCC	F	ICM	F	CATCNCC	F
8	0,93	7	0,76	39	0,72	0,31	0,69	29	0,65	0,73	0,98
> 10	1	9	0,99	40	0,74	0,32	0,73	29	0,66	0,74	0,99
		> 10	1	43	0,8	0,33	0,74	35	0,78	>0,74	1,00
				53	0,9	0,34	0,77	36	0,81		
				> 53	1	0,37	0,83	41	0,92		
						0,40	0,90	43	0,97		
						0,43	0,97	> 43	1,00		
						> 43	1,00				

Source: Own elaboration.

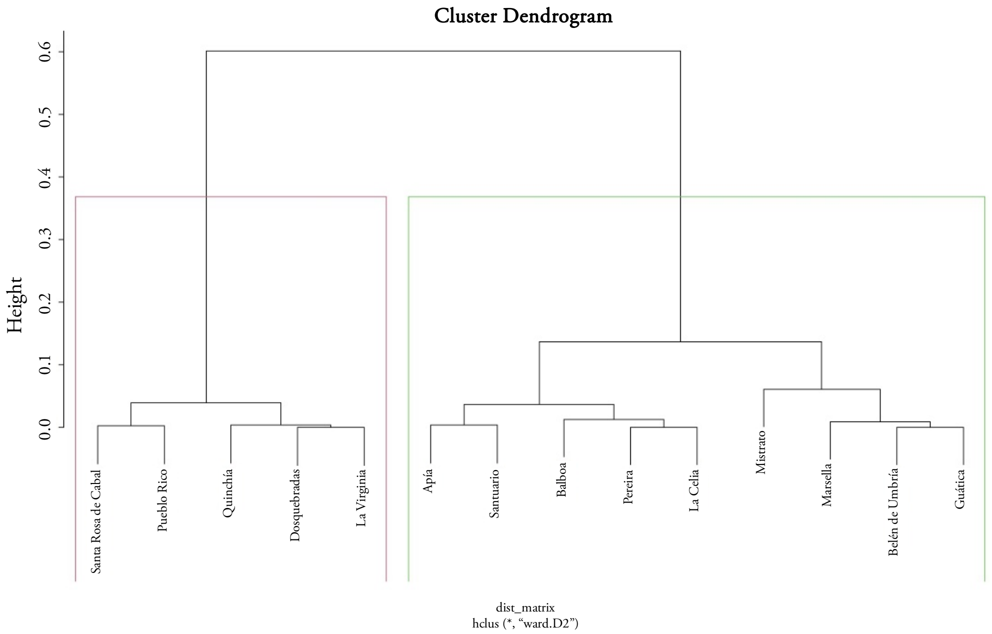
TABLE 4.
Transformation functions from quantitative coefficients to qualitative levels of vulnerability

Aggravation Coefficient F value	Level of Vulnerability
0	No Vulnerability
0.05 – 0.1	LOW
0.11 – 0.19	MEDIUM LOW
0.2 – 0.3	MEDIUM
0.31 – 0.4	MEDIUM HIGH
0.41 – 0.49	HIGH
>0.5	VERY HIGH

Source: Own elaboration.

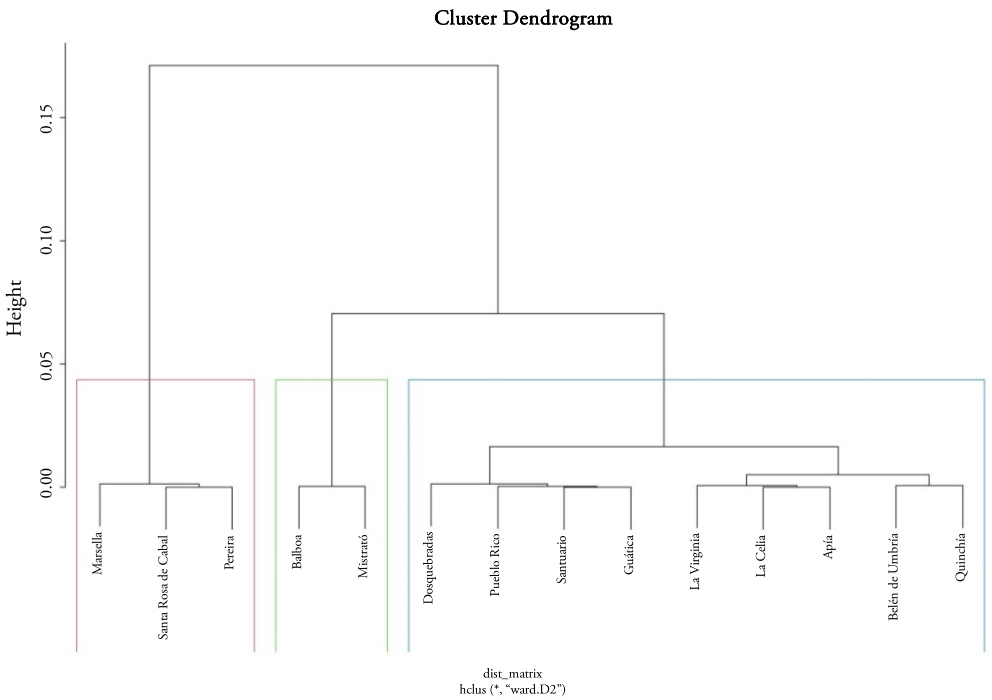
Annex 2. Graphs.

Graph 2.
Cluster Dendrogram factors and aggravation coefficients at the municipal level



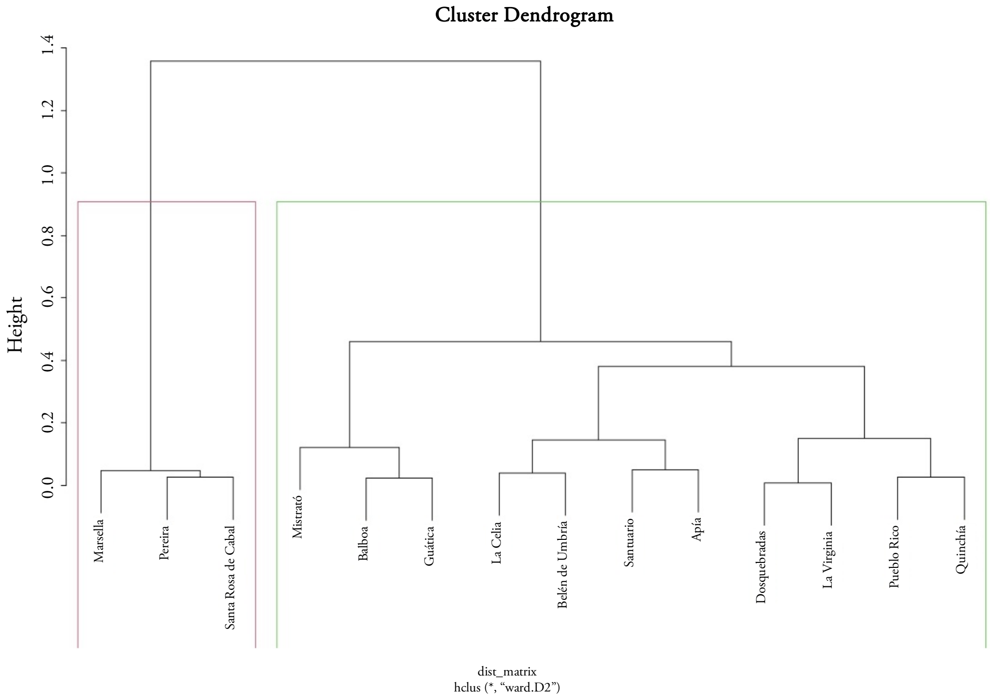
Source: Own elaboration.

Graph 3.
Cluster Dendrogram factors and aggravation coefficients at municipal level for TSPs



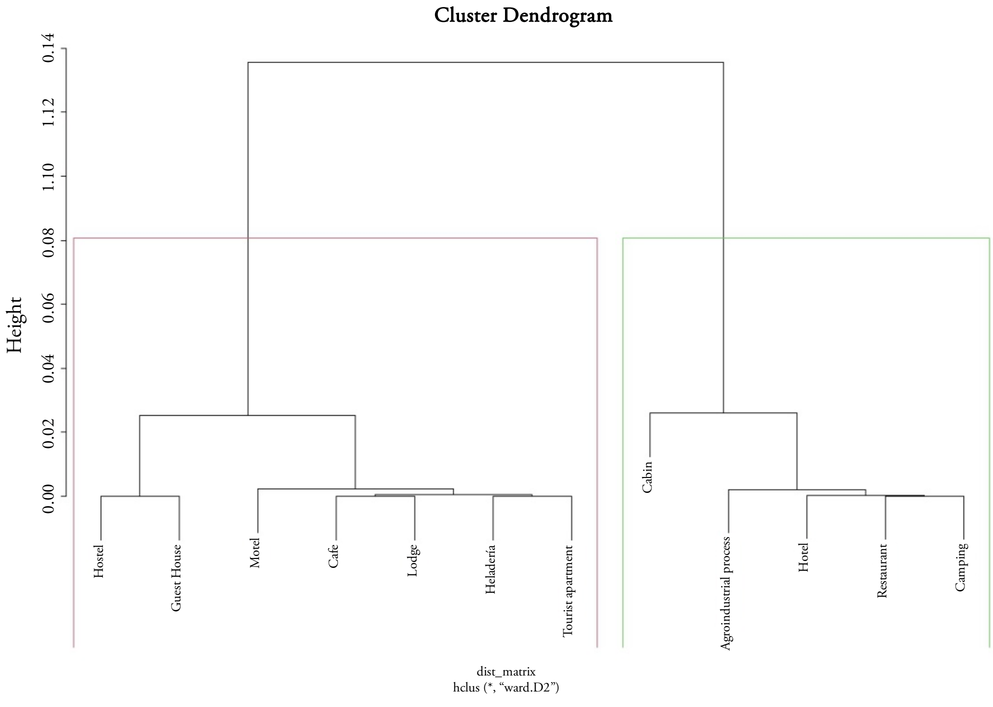
Source: Own elaboration.

Graph 4.
Cluster Dendrogram factors and aggravation coefficients at the municipal scale for Tourist Attractions



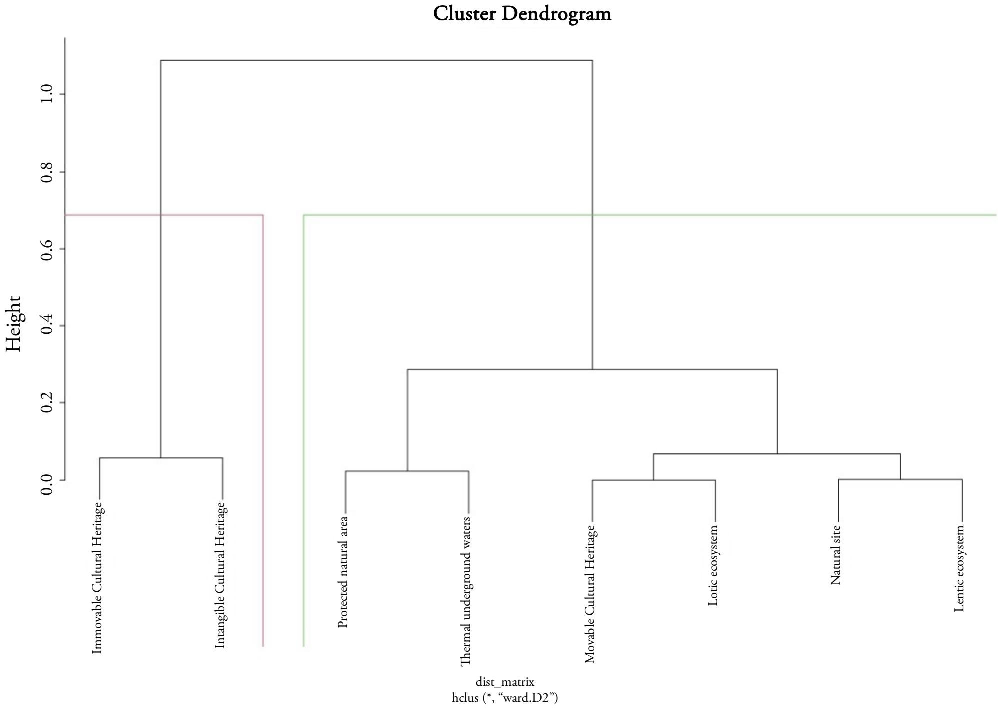
Source: Own elaboration.

Graph 5.
Cluster Dendrogram aggravation factors TSPs typology



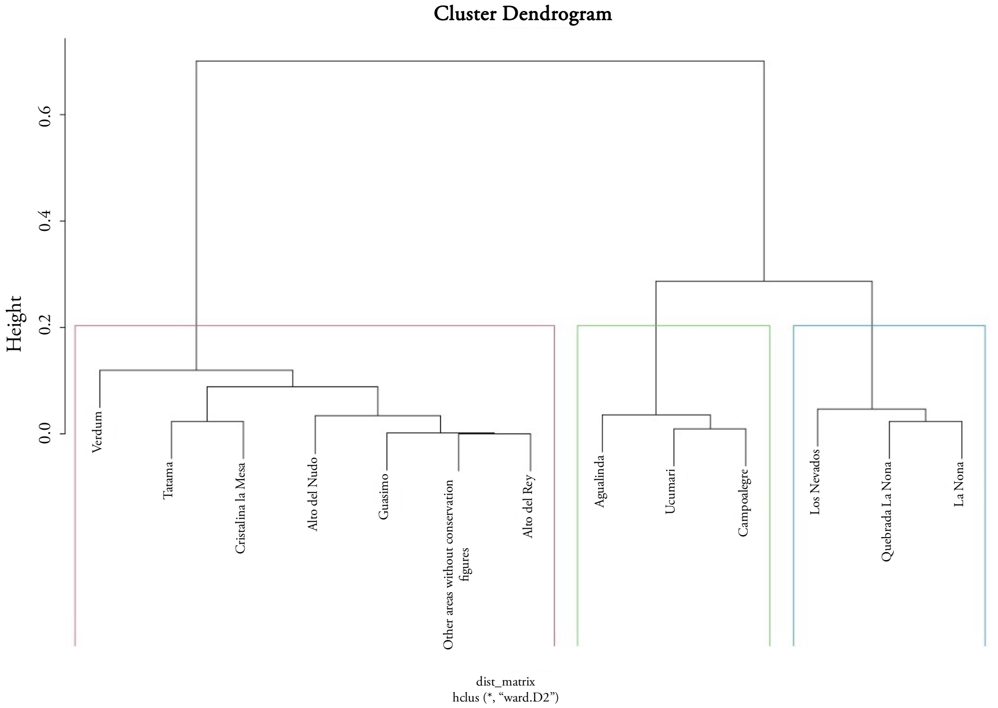
Source: Own elaboration.

Graph 6.
Cluster Dendrogram aggravation factors Tourist Attractions according to heritage typology



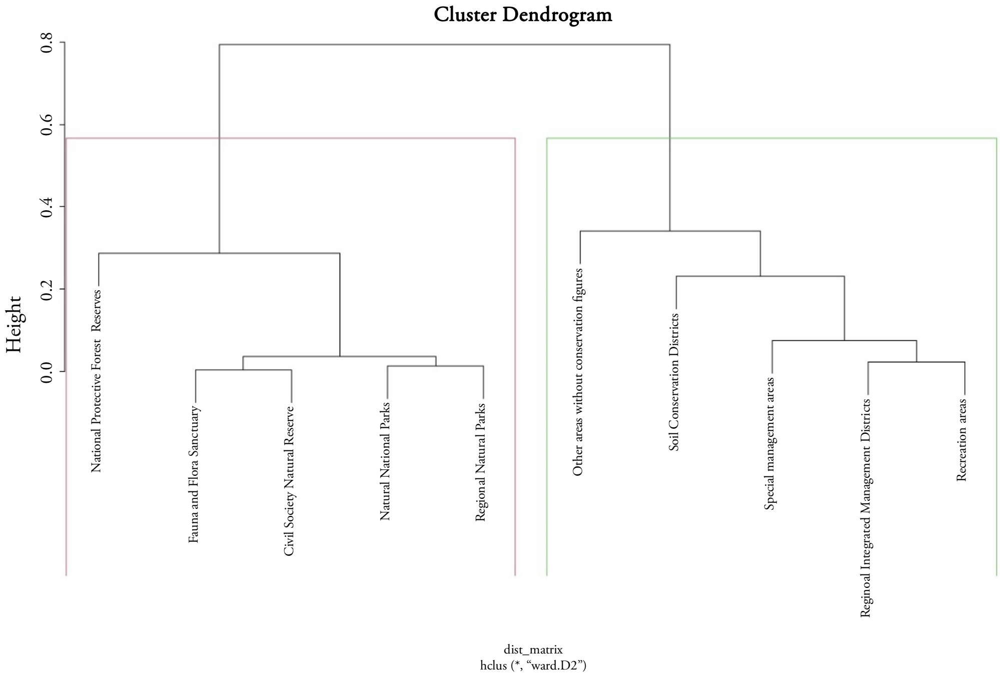
Source: Own elaboration.

Graph 7.
Cluster Dendrogram aggravation factors NPAs according to Tourist Attractions



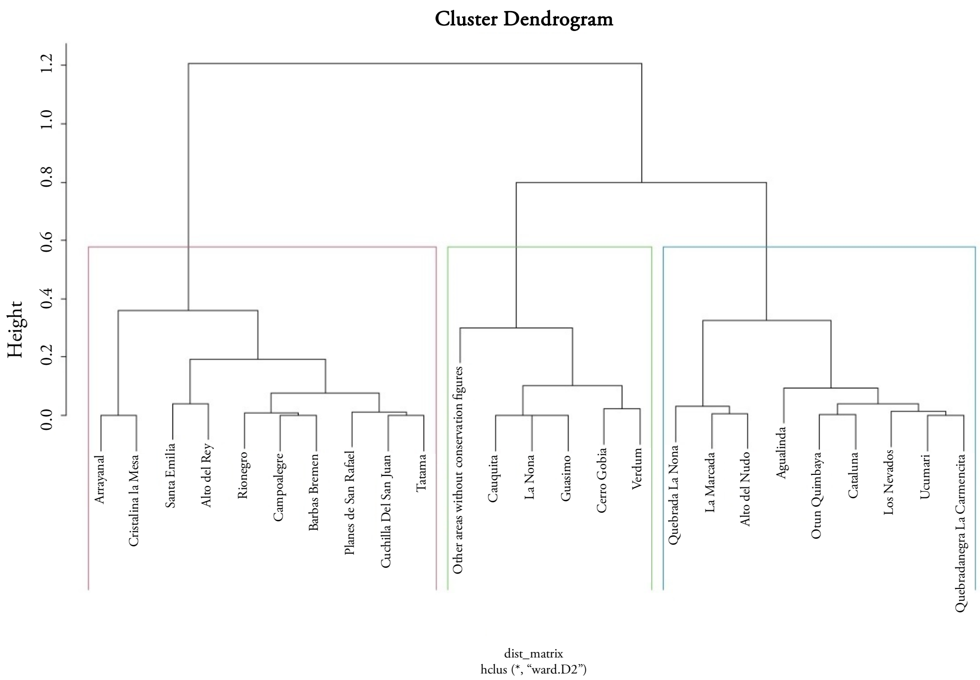
Source: Own elaboration.

GRAPH 8.
Cluster Dendrogram aggravation factors NPAs according to conservation category



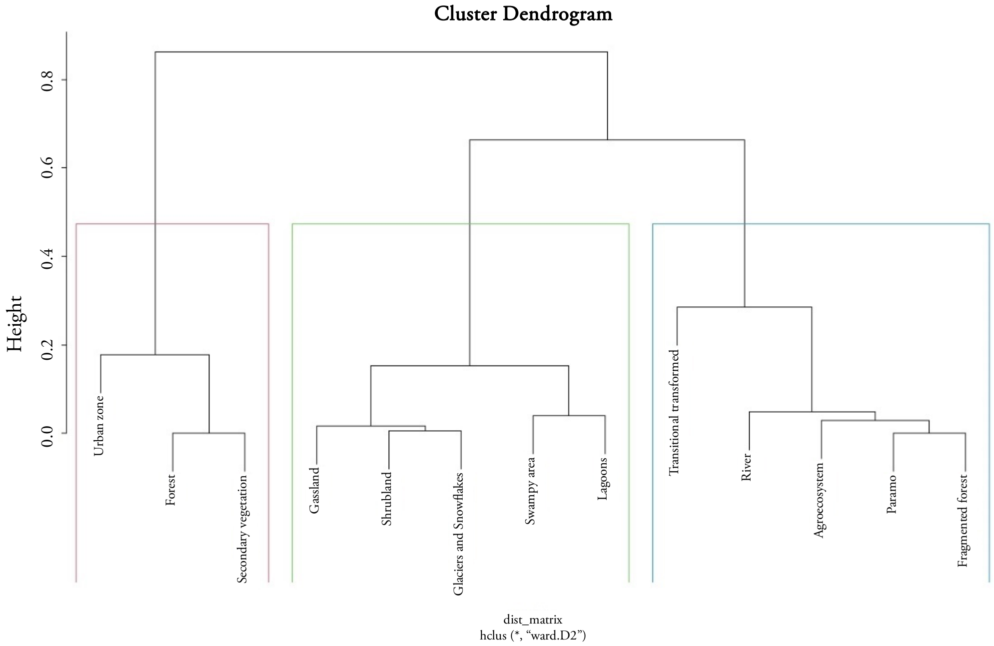
Source: Own elaboration.

GRAPH 9.
Cluster Dendrogram aggravating factors for NPAs



Source: Own elaboration.

Graph 10.
Cluster Dendrogram aggravation factors for ecosystems



Source: Own elaboration.