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Case Report

A Historical Perspective of Landscape and Human Population Dynamics in Guimarães (Northern Portugal): Possible Implications of Rural Fire Risk in a Changing Environment

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Abstract: The occupation of a territory combines a set of variables which affect the development of the mode by which populations have been organized throughout history. How this occupation takes place demonstrates much of a territory's past and shows how the populations managed to make the most out of the available resources. The region of Entre-Douro-e-Minho (Northern Portugal), similarly to what happens in other regions, such as Galicia (Northern Spain), Brittany (Northern France), or Ireland, presents a type of dispersed land use, with an alternation of urban, agriculture, and forest areas. On one hand, this proximity allows urban populations to come into contact with a rural environment. On the other hand, this proximity also causes a set of problems, namely those related to rural fires, which are now enhanced by climate change, and associated phenomena, such as heatwaves and the lack of precipitation. The present work analyzes the evolution of rural fires in 1975–2019, in the municipality of Guimarães (Northern Portugal), to understand how these events have been distributed over time and evolved in a climate change scenario. Based on the results and discussion presented, it can be concluded that there is an increasing trend in the occurrence of rural fires in the territory under study, and that this can also be associated to climate change, in the form of a gradual increment in temperature, particularly in the autumn months, and a decrease in rainfall. This situation is responsible for the increment of the risk caused by the proximity of the populations to forest and agricultural areas because rural fires can jeopardize the safety of people and goods.

Keywords: rural fires; land management; land use; biomass waste; climate change

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1. Introduction

Rural fires affect the interface between natural ecosystems and urban environments, destroying agriculture and forest production capacity and ecosystem services [1–3]. The occurrence of fires, especially in Mediterranean-type regions such as Portugal, has a highly negative impact on several areas, such as the economy, through the destruction of property and heritage, and the environment, through the destruction of natural areas [4–6]. This interface between the urban and rural environments is commonly artificialized and subject to an increasing pressure due to the expansion of urban zones, and it is of great importance [7–9]. It often provides the only point of contact with the natural environment to which urban populations have access [10,11]. In addition to this access facilitated by the proximity, this rural agroforest interface also presents the only possibility for providing a set of ecosystem services, increasingly recognized and valued, that go far beyond the simple provision of an environment for leisure activities or for agricultural and forestry production [12,13].

The ecosystem services most easily identified are, without doubt, the production of oxygen, the protection of water resources, the fixation and protection of soils and biodiversity preservation [14–16]. However, other services can be listed—namely, carbon storage—thus contributing to the mitigation of climate change and the creation of buffer zones that protect urban populations from wind, noise, or even the negative visual impact caused by human activity itself, such as quarries, roads, or industrial parks [17–19]. In places where the land use is of a dispersed type, as is the case of Northern Portugal, as well as other regions, such as Ireland, Brittany (Northern France), or Galicia (Northern Spain), it is challenging to manage the available space to avoid conflicts between different interests—namely, conflicts caused by urban pressure on agricultural and forest areas, which cause changes in the type of land cover and use through urbanization [20–22]. This change creates intricate networks in sparsely populated regions where different land use types are mixed, as can be seen in Figure 1. Thus, the alternation between land for agricultural use and land for urban and forest areas facilitates the proximity between different land covers and brings to the population the problems associated with this proximity, as is the case of rural fires [23–25].

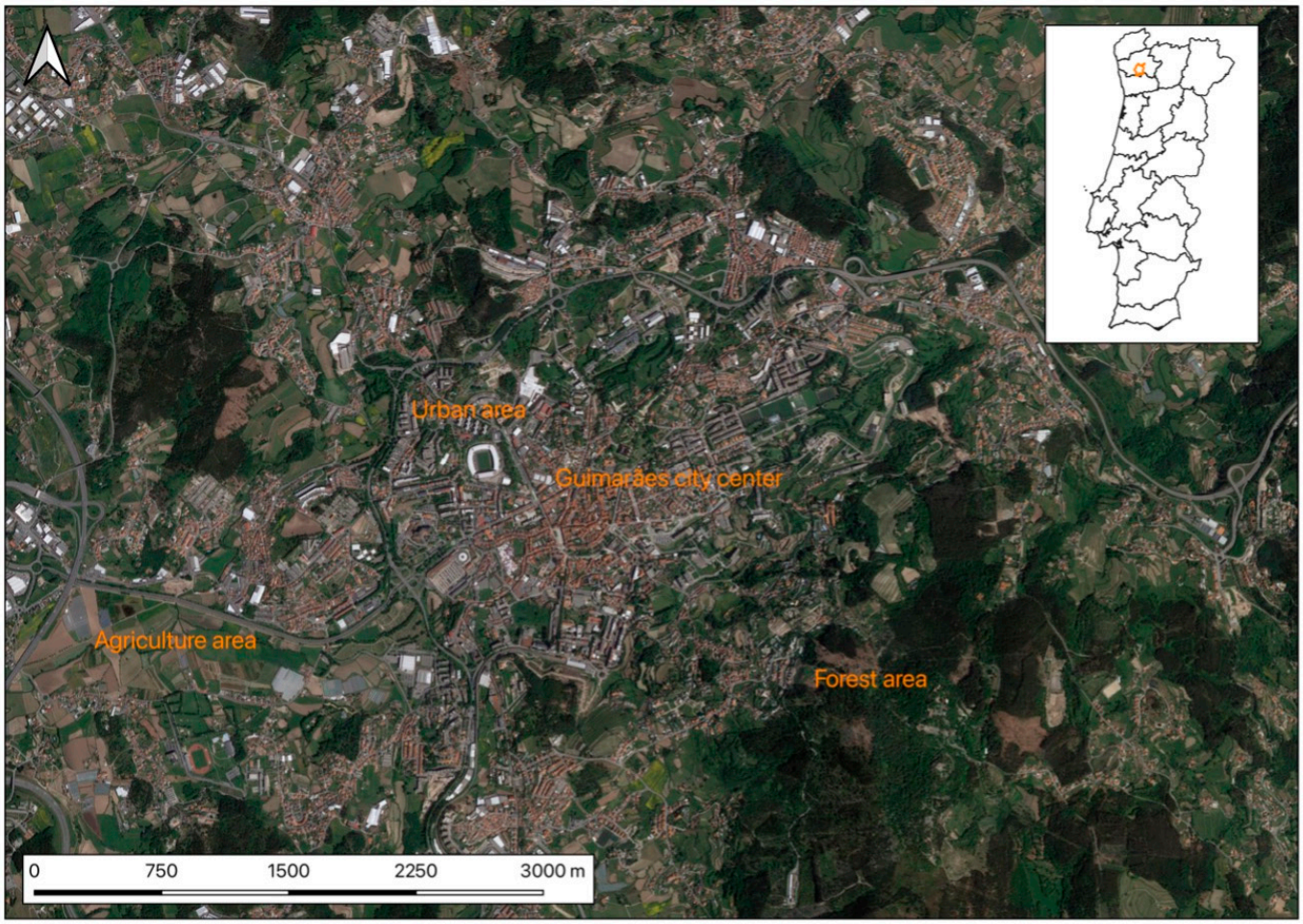

Figure 1. Alternation of different land use types in a region with dispersed population (Guimarães, Portugal).

In Figure 1, where the city center of Guimarães is visible, there is an interweaving of the different types of land use, with an alternation between the urban, forest, and agriculture zones. Usually, urban areas are surrounded by agriculture areas, especially when located near water lines, which are more leveled. Forest areas dominate the most difficult parts of the relief, with urban areas occupying the gentler slopes.

Rural fires, which are a recurring problem due to the proximity of agricultural and forest areas to the urban environment, have received increased attention in recent times, which is mainly justified by the accumulation of a set of variables related to climate change [19,26,27]. Among these variables, the increase in average temperatures, the decrease in precipitation, the decrease in the air relative humidity, and the increased occurrence frequency of some extreme phenomena can be highlighted [27–29]. These phenomena include a succession of heatwaves and the successive breaking of maximum temperature records [29–31]. These variables can be linked to an increased risk of rural fires, especially if there is an accumulation of fuel load caused by the uncontrolled growth of some shrub and tree species, as is the case of species of the genus *Acacia*, among others, partially due to the lack of proper management policies for the rural territory [32–34].

The anthropogenic origin of the phenomenon of rural fires in Portugal is mainly caused by the misuse of fire and negligent attitudes towards it, mainly associated with the burning of leftovers resulting from agricultural activity or forest management operations [19,35–37]. This traditional use of fire, used to eliminate waste materials resulting from agriculture and forestry practices, such as the elimination of leftovers, but as well as a cleaning method to eliminate excess biomass and to control exotic species, is statistically the main cause behind most of the rural fires occurred in Portugal. The data made available by ICNF (Instituto para a Conservação da Natureza e da Floresta) show that up to 27% of fires, of a total of 41% of fires attributed to all negligent causes, were caused by this misuse of fire in the year 2020. This scenario remains in line with the data available for the decade 2010–2019. This number of fires with an anthropogenic cause may indicate that the pattern of these rural fires may in some way be related to the already-mentioned urban pressure in these areas [37–39].

The present study aims to carry out a historical retrospective study of the succession of rural fires in Guimarães (Northern Portugal) from 1975 to 2019. This retrospective is achieved by analyzing the evolution of events over the years, both from the perspective of the location of the occurrences and the development of the land use over this period and the expected future trend. It is also expected to analyze how the population evolved over time to justify why the dispersion model occurred once this distribution can be the base for an increased risk for the populations due to the proximity to forest and agriculture areas. Another aspect that is considered important for the complete analysis is the local climate evolution, as well as the changings observed in the forest cover over the past 150 years and how this cover can contribute to the increment of the risk to the populations.

2. Materials and Methods

2.1. Data Acquisition

The present work was based on prior research and acquired bibliographic references from the digital collections available at the following sources:

- Casa de Sarmento, Centro de Estudos do Património, available at https://www.csarmento.uminho.pt, accessed on 15 February 2021. This is a differentiated unit of the University of Minho (Portugal), founded in 2017, through a protocol signed between Guimarães City Council and the Sociedade Martins Sarmento. One of its main activities is the treatment, cataloguing, digitization, and dissemination of the bibliography, documentary, and museological collection of Sociedade Martins Sarmento, making the inventory already catalogued available to researchers and the public, as described in the introductory note on the aforementioned website.
- The Biblioteca Nacional de Portugal, available at https://www.bnportugal.gov.pt, accessed on 15 February 2021, the most extensive library in Portugal. It makes available, through its digital section, a set of historical documents of undeniable value for obtaining data referring to periods in the history of Portugal, which otherwise would not be accessible to researchers or at least not in such an expeditious and rapid manner.

- Climatic data from Guimarães, obtained through the METEOBLUE platform, available at https://www.meteoblue.com, accessed on 30 May 2021. The data obtained on this platform are based on 30 years of simulations carried out using accurate data obtained from meteorological stations close to the desired point. This platform was used because no actual data were found, and these simulated data were used to analyze the evolution of climatic factors to date.
- ICNF (Instituto da Conservação da Natureza e das Florestas), an organization whose mission is to contribute to the enhancement and conservation of aspects related to forest resources as well as Nature and Biodiversity in Portugal. Data on rural fires, in the form of shapefiles, are available at https://sig.icnf.pt, accessed on 30 May 2021.
- SNIRH (Sistema Nacional de Informação de Recursos Hídricos), na organization that is part of APA (Agência Portuguesa do Ambiente) that has as main objective to collect and manage data about national water resources in Portugal. Data are available at https://snirh.apambiente.pt, accessed on 30 May 2021.

The data collected in the form of literature (books and articles) were analyzed to allow the characterization and comparative analysis of the past situation with the current data, both for the characterization of the climate, as for the characterization of the evolution of the forest and the territorial organization of the area under study. Each one of the bibliographical references analyzed is described in the corresponding section, to facilitate the relationship between the reader and the framework of the reference text.

2.2. Selection of the Area under Study

The area selected for the present study was the municipality of Guimarães, located in the northern region of Portugal. Guimarães is one of the 14 municipalities that make up the district of Braga, in the province of Minho, more specifically in the sub-region of Baixo Minho. The municipality of Guimarães borders Braga and Póvoa de Lanhoso to the north, Famalicão to the west, Fafe to the east, and Vizela to the south, all belonging to the same sub-region, and Santo Tirso and Felgueiras, both belonging to the district of Porto, in the province of Douro Litoral also border to the south. Figure 2 shows the location of the municipality of Guimarães in the national and regional framework. According to the data presented in the last census of 2011, the municipality of Guimarães occupies 240.96 km^2. In this area, there are 158,124 inhabitants, 54,097 of whom live in the city. The municipality is divided into 48 parishes, of which Brito, Lordelo, Moreira de Cónegos, Pevidém, Ponte, Ronfe, Taipas, Serzedelo, and S. Torcato stand out as being secondary urban centers. The dispersed character of the population is repeated throughout the northern coastal region of Portugal.

2.3. Biophysical Characterization of the Municipality of Guimarães

2.3.1. Geology, Geomorphology and Hydrography

In the municipality of Guimarães, granitic and granodioritic geological formations are predominantly found. Structurally, these formations have NE/SW and NW/SE fractures. In the NW region of the municipality, extending to the SE area, there are also metamorphic rocks, specifically mica schists. In the areas corresponding to the water lines, modern cover sedimentary deposits are observed, mainly sand and alluvial gravel. The territory is surrounded by the mountains of Outeiro and Penedice, Sameiro, and Falperra on the NW side, Senhora do Monte on the N side, and Santa Marinha and Santa Catarina on the SE side. The central region corresponds to the path of the Ave and Selho rivers and their tributaries, creating an extensive flattened alluvial area. The lowest point is found in the south of the municipality in the river Vizela, at a 77 m altitude. Its highest point is in Santa Catarina (Penha), at a 613 m altitude. The municipality of Guimarães includes a significant part of the hydrographic basin of the Ave River, which originates in Serra da Cabreira, located in Vieira Minho. It flows into the municipality of Vila do Conde in the district of Porto. This river, about 100 km long, is the main water line that runs through the territory. However, other smaller water lines, as do the Selho and Vizela rivers and their tributaries,

contribute to the formation of areas with long periods of waterlogging, associated with the gentle slopes that occur relatively frequently.

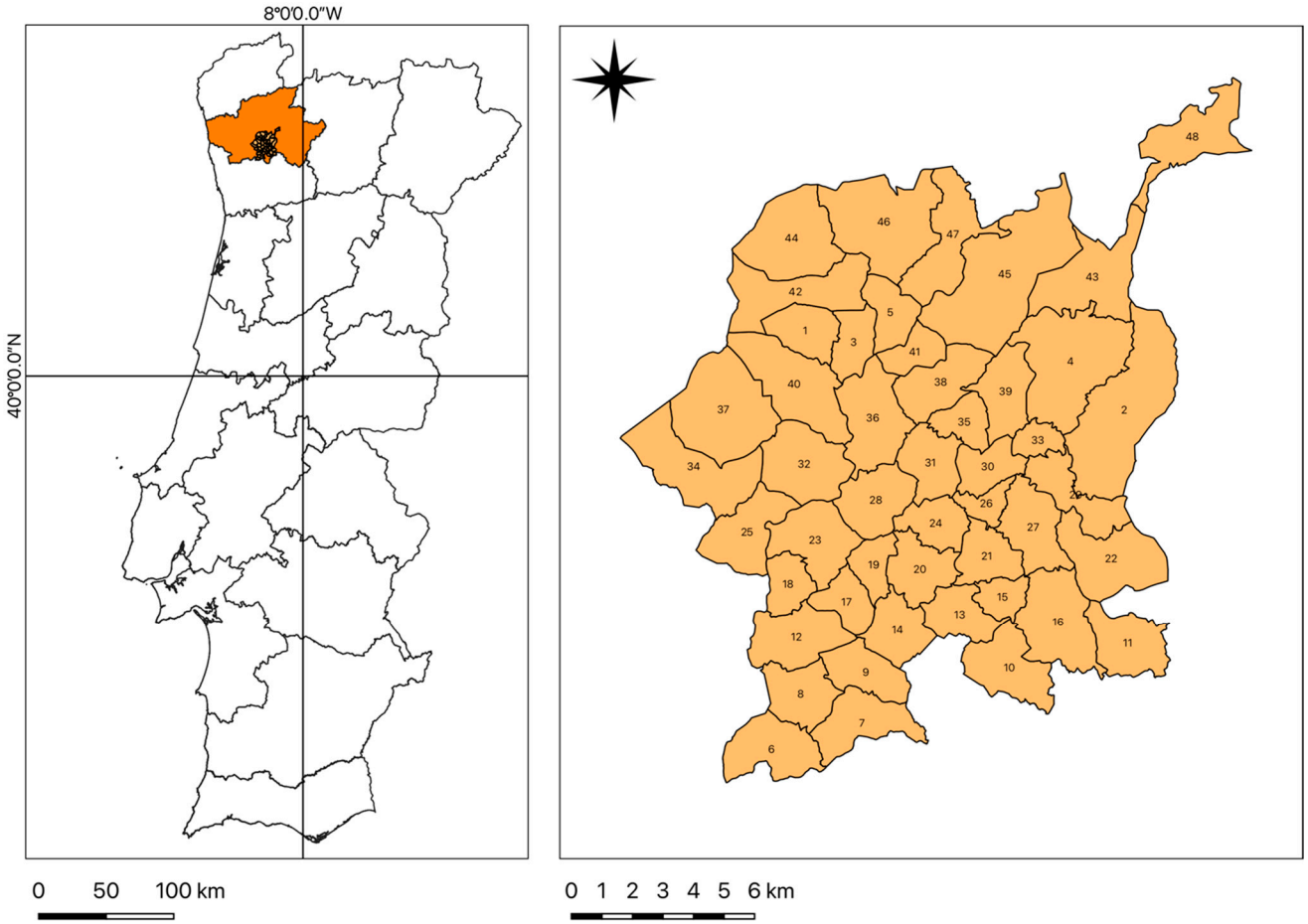

Figure 2. The municipality of Guimarães is located in Northern Portugal, in the district of Braga, also known as the Baixo Minho region. Guimarães is divided into 48 parishes, presented in the right side of the figure as follow: 1—Sande (São Martinho); 2—União das freguesias de Atães e Rendufe; 3—Caldelas; 4—São Torcato; 5—Barco; 6—Lordelo; 7—Moreira de Cónegos; 8—Guardizela; 9—União das freguesias de Conde e Gandarela; 10—União das freguesias de Tabuadelo e São Faustino; 11—União das freguesias de Serzedo e Calvos; 12—Serzedelo; 13—Polvoreira; 14—Nespereira; 15—Pinheiro; 16—União das freguesias de Abação e Gémeos; 17—Selho (São Cristóvão); 18—Gondar; 19—Candoso (São Martinho); 20—União das freguesias de Candoso São Tiago e Mascotelos; 21—Urgezes; 22—Infantas; 23- Selho (São Jorge); 24—Creixomil; 25—Ronfe; 26—União das freguesias de Oliveira, São Paio e São Sebastião; 27—Costa; 28—Silvares; 29—Mesão Frio; 30—Azurém; 31—Fermentões; 32—Brito; 33—Aldão; 34—União das freguesias de Airão Santa Maria, Airão São João e Vermil; 35—Penselo; 36—Ponte; 37—União das freguesias de Leitões, Oleiros e Figueiredo: 38—União das freguesias de Prazins Santo Tirso e Corvite; 39—União das freguesias de Selho São Lourenço e Gominhães; 40—União das freguesias de Sande Vila Nova e Sande São Clemente; 41—Prazins (Santa Eufémia); 42—União das freguesias de Sande São Lourenço e Balazar; 43—Gonça; 44—Longos; 45—União das freguesias de Souto Santa Maria, Souto São Salvador e Gondomar; 46—União das freguesias de Briteiros São Salvador e Briteiros Santa Leocádia; 47—União das freguesias de Briteiros Santo Estêvão e Donim; 48—União das freguesias de Arosa e Castelões.

2.3.2. Climate

The region of Guimarães has a strong Atlantic influence, given its location less than 40 km in a straight line from the ocean and the mountainous environment that limits the province of Minho and Trás-os-Montes. Figure 3 shows the thermopluviometric diagram for the decade from 2010 to 2019, projected with the climatic data obtained on the METEOBLUE

platform (available at www.meteoblue.com, accessed on 30 May 2021). The data derived from the NEMS meteorological model have a resolution of approximately 30 km.

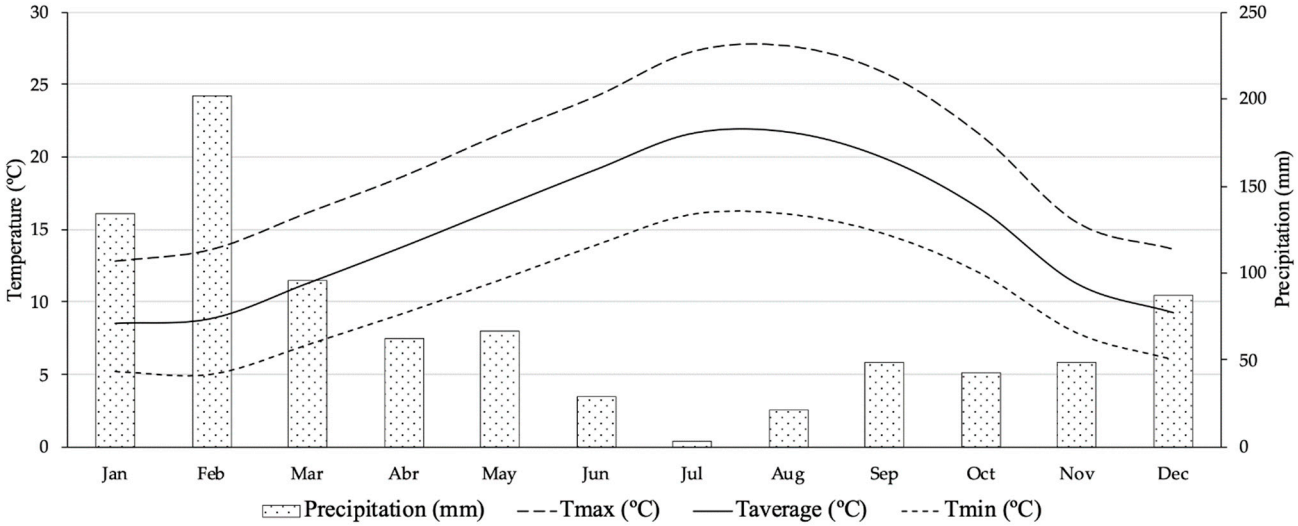

Figure 3. Thermopluviometric diagram designed with data obtained using the METEOBLUE platform for the decade 2010–2019 with the precipitation values corrected in accordance with the data available in the SNIRH website (available in https://snirh.apambiente.pt, accessed on 30 June 2021) for the meteorological station of MOREIRA DO REI (05I/04G), located in the municipality of Fafe (distancing approximately 15 km from the city center Guimarães).

As can be seen, the climatic results indicate a significant change in the usual pattern for a climate of strong Atlantic influence, which would typically have high rainfall. However, the results presented show that the decade received an extreme lack of precipitation. Table 1 presents the comparative analysis between the climatologic normal values for the period 1971–2000 and the precipitation values for the decade 2010–2019.

Table 1. Comparative analysis between the monthly precipitation presented in Figure 3 and the climatic normal values for the period 1971–2000 (data for the normal period 1971–2000 available on https://www.ipma.pt/pt/oclima/normais.clima/1971-2000/#23, accessed on 9 July 2021).

	Jan	Feb	Mar	Abr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010–2019	134.2	201.9	95.8	62.2	66.7	29.2	2.9	21.6	48.3	42.4	48.6	86.9
1971–2000	192.7	161	102.3	122.5	118.5	62.5	24.1	29.8	79	166.8	175.4	231.4
Diference	−58.5	40.9	−6.5	−60.3	−51.8	−33.3	−21.2	−8.2	−30.7	−124.4	−126.8	−144.5

As can be seen in Table 1, there is a significative reduction in the precipitation in the decade 2010–2019, here represented by the difference between the two periods. This way confirms that the referred period was dryer then the usual, with a total precipitation of 840.7 mm, instead of the average 1466 mm verified in 1971–2000.

2.3.3. Forests

The Regional Forest Management Plan of the Baixo Minho characterizes the Cávado-Ave sub-region as having a high soil potential for forest use, mainly for the species *Pinus pinaster* and *Eucalyptus globulus*. The presence of these species occurs in the same proportion in Guimarães, as shown in the Municipal Plan for the Defense of the Forest Against Fire. In addition to these dominant species, there are also abundant stands of woody invasive species. The species of the genus *Acacia* stand out, such as *Acacia dealbata* and *Acacia melanoxylon*. In addition, there are *Ailanthus altissima* or *Robinia pseudoacacia* in areas where the fire eliminated the vegetation cover in disturbed areas with higher organic loads. Concerning shrub species, *Hakea sericea* has also begun to be a cause for concern in

the northern mountains of the municipality, as are as well the occurrences of *Phytolacca americana*, which are gaining space and competing directly with native species (Figure 4). The main native species, such as *Quercus suber*, *Quercus robur*, and *Quercus pyrenaica*, still constitute patches with some importance but are threatened by the advance of the previously mentioned invasive species and eucalyptus, which is slowly beginning to dominate the landscape. Other hardwood species, such as elm trees, willows, alders, and poplars, occur close to the water lines, constituting areas with high ecological potential.

Figure 4. *Phytolacca americana* (**left side**) and *Ailanthus altissima* (**right side**).

The distribution of forest areas by the territory follows the reverse model of the distribution of urbanized areas, with the forest areas being concentrated more in the parishes of the northern part of the municipality. At the same time, the main urban centers can be found in the southern region of the municipality. However, in the South, it is also possible to find a very significant forest spot, which corresponds to the mountain of Santa Catarina, locally known as Penha. Concerning the distribution of the species *Eucalyptus globulus* and *Pinus pinaster*, those are mainly associated with the most significant continuous forests located in the parishes bordering the municipality, specifically Gonça, São Torcato, Donim, São Salvador de Briteiros, Santa Leocádia de Briteiros, Longos, Leitões, and Oleiros. In the South, are mainly distributed in Costa, Pinheiro, Abação, and Mesão Frio, where the mountain of Santa Catarina (Penha) is located. As would be expected, the risk of rural fires is higher in these parishes, and these are also where can be found a higher incidence of fires in the past four decades. With the industrialization of the municipality, one of the leading production centers of the national textile industry, the labor associated with the agricultural sector is often shared with other sectors, on a production basis for self-consumption, with the loss of a set of traditional practices, such as the collection of scrub for manure production and soil fertilization. The proliferation of scrubs in uncultivated land became a reality, which was enhanced by the arrival of invasive species such as those

of the genus *Acacia* [40]. This also contributes significantly to increase the risk of rural fires occurrence [41].

2.3.4. Territorial Organization

As already mentioned, the settlement in the municipality of Guimarães is of a dispersed type, with an alternation of different kinds of land use, which is common in the region of Baixo Minho. This alternation is characterized by a lack of defined limits for the end of urban areas, often with a mixture of agriculture and forest areas, as shown in the example presented in Figure 5. This dispersion of different forms of land use has some advantages [42]. It allows populations to enjoy close contact with resources. On the other hand, it presents disadvantages as well, such as the risk of being close to rural fires when those occur [43]. As far as forest areas are concerned, this dispersion creates difficulties in the management and in the creation of economies of scale due to permanent loss of continuity and increasing the cost of some maintenance operations, such as excess biomass cleaning [44].

Figure 5. An example of part of the municipality of Guimarães where urban areas surrounded by forest and agriculture areas can be seen.

The populations in this dispersed model originated in the primitive communities of the Bronze and Iron ages that inhabited this territory, occupying the top of the hills in the Castros or Citânias [45]. Later, these communities were forced to abandon the top of the mountains and high hills due to the arrival of the Roman conquerors [46]. Thus, these communities began to inhabit the valleys, which were more accessible for the new rulers to control, giving rise to the formation of nuclei dedicated to agriculture practice in detriment of the pastoralism practiced as the main activity until then [47]. These nuclei, the Villae, continued as the organizational base after the fall of the Roman Empire and persisted until today, with the transformation of the Villae into parishes, which evolved to urban agglomerations [48]. In Guimarães, there is a great pressure on forest and agriculture areas

due to the intense growth of urban areas, mainly due to the development of industrial parks, which seek locations further away from inhabited areas to minimize the negative impacts on populations. However, people migrated closer to these industrial areas to reduce the distance between their homes and workplaces, once again creating pressure on the territory by forcing the alteration of the land use to develop new urban areas.

Currently, land use in the municipality is distributed as shown in Figure 6.

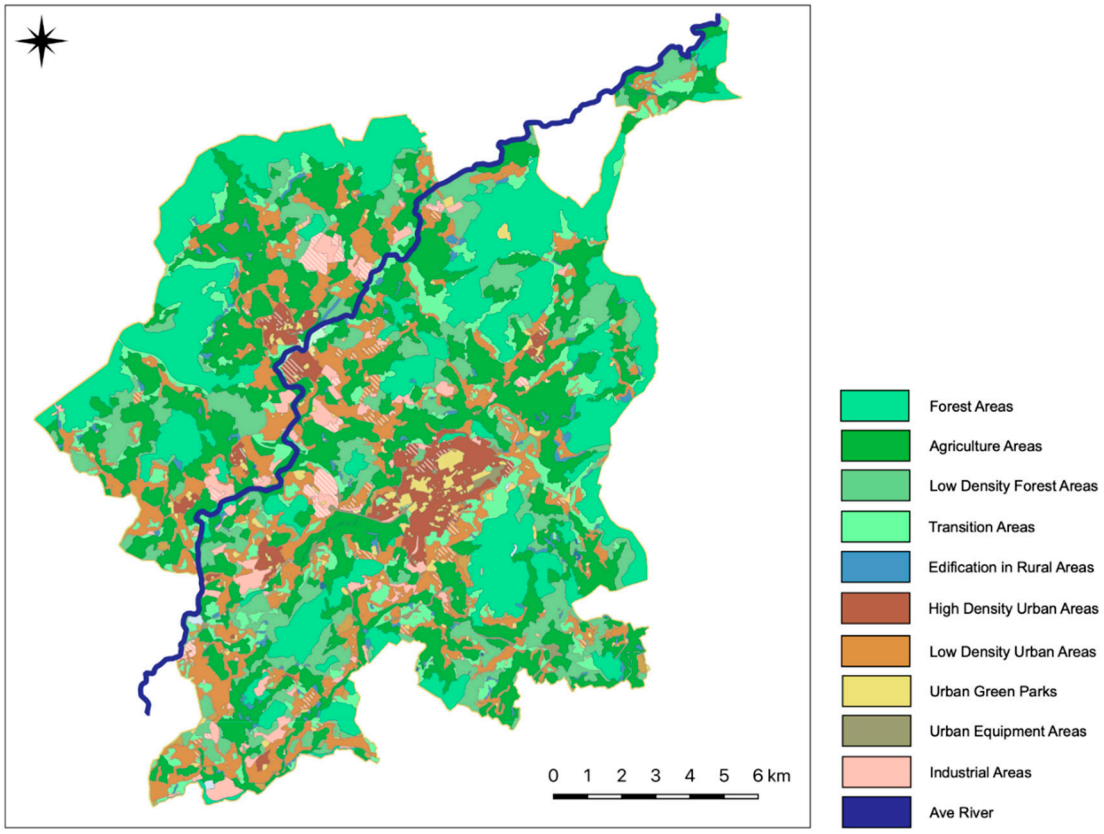

Figure 6. Land Use and Land Cover (LULC) map, highlighting the rural and urban areas of the municipality of Guimarães (adapted from the data collected at https://snig.dgterritorio.gov.pt, accessed on 30 June 2021).

In the Land Use and Land Cover (LULC) map for the region under study, can be seen a predominance of forest areas in the northern part of the municipality, while the urban areas preferentially occupy the southernmost area of the municipality, with the presence of high-density urban areas, such as the city itself, and some of the more relevant secondary urban centers. There is also an alignment of the dispersed settlement with the course of the Ave River, which divides the territory into two parts, confirming a search for the flatter areas of the territory, both for the settlement of populations, as well as for the development of the agriculture activity.

According to the Inventário Florestal Nacional 6 (IFN6), made available in 2019, for the Ave region (NUT III) presenting average values for its municipalities and where Guimarães is located, there is a trend towards a decrease in the areas occupied by forests, although in the period from 2010 to 2015 was verified a slight increase of approximately 1%. However, comparatively to the year 1995, in the year of 2015 (the year to which the last IFN6 reports) there is a decrease in the forest area of about 9%. The same is true for agriculture areas, which saw their areas reduced by approximately 16%. However, urban areas presented a growth of around 36%, compared to the situation verified in 1995.

3. Results and Discussion

3.1. Evolution of the Local Climate

In 1907, João Monteiro de Meyra presented his inaugural dissertation to the Medical-Chirurgical School of Oporto, entitled "O Concelho de Guimarães: Estudo de Demographia e Nosographia", in which described, in detail, several aspects of the municipality of Guimarães, dedicating a significant number of paragraphs to the characterization of the local climate [49]. This document is essential since there is little information regarding this region. The fact that the author received a higher academic education, albeit not in natural sciences or geography, gives some relevance to the data and analysis presented in the study. The climatology section mentions that "there is no observatory in Guimarães that could provide the necessary meteorological data for this study". The author used information collected by J. Kempf, a professor of the Colégio do Espírito Santo in Braga, who collected continuous meteorological data and justified the data transposition from Braga to Guimarães writing that it was inspired by "the extreme proximity of the two cities (...) and the analogy of their geographical situation". He also considered that "the error that may exist must be insignificant". This same methodology was also used by Paul Choffat in his Report on Water Supply to the City of Guimarães, presented in 1904, writing that "having no knowledge of meteorological observations in the city, I had to address J. Kempf, professor at the College do Espírito Santo, in Braga, who has been making these observations in that city since 1888 (...), and given the proximity of the two locations, the climates may be similar, if not identical" [50].

Figure 7 shows a comparison between the results obtained by J. Kempf for the decade 1886–1905 and the results obtained through the METEOBLUE platform for the decade 2010–2019. As can be seen, there is a significant difference, mainly concerning precipitation, as evidenced by the various news articles published by the media, including the need to supply water to the population. This difference is more problematic if compared with the average values for the decade 1886–1905, which reached 1286 mm. This value, which may seem high, is in line with the precipitation values also collected by J. Kempf for the decade 1888–1899 and later used by P. Choffat (1904) in his report on solving a water supply problem in the city of Guimarães [50]. This decade had an average value of 1317 mm, registering the highest value, 1682 mm, in 1895, and the lowest value, 885 mm, in 1898, which triggered the problem with the water supply occurred in the last years of the 19th century [50].

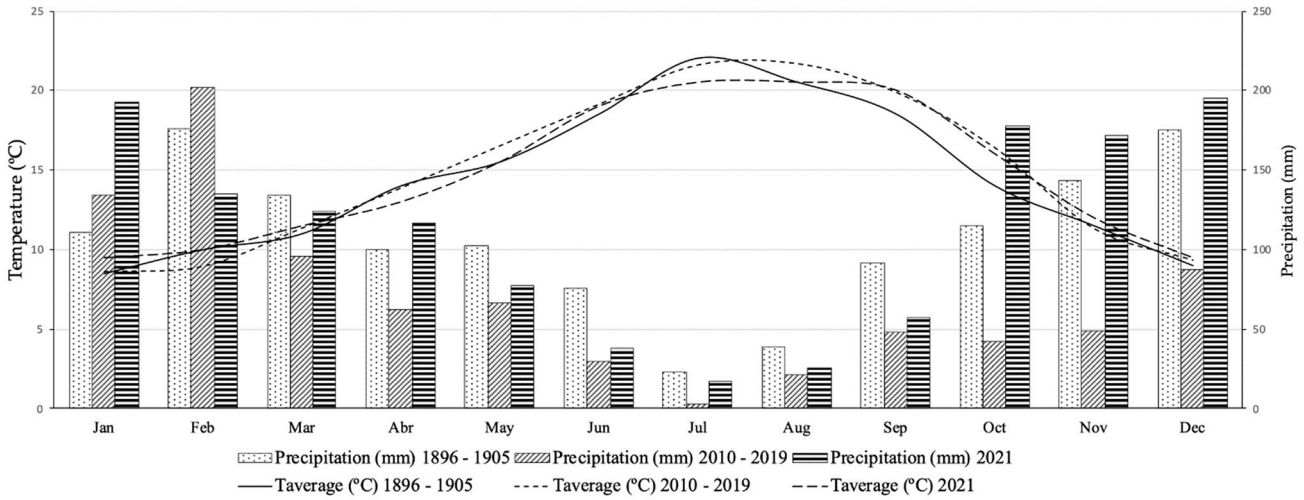

Figure 7. Comparison between the results obtained by J. Kempf for the decade 1896–1905, the results obtained through the METEOBLUE platform for the decade 2010–2019 with the data available in the SNIRH website (available in https://snirh.apambiente.pt, accessed on 30 June 2021) for the meteorological station of MOREIRA DO REI (05I/04G), located in the municipality of Fafe (distancing approximately 15 km from the Guimarães city center), and the modelled data for the year 2021 with the results obtained on the METEOBLUE platform.

In addition, there was a change in the average monthly temperatures, mainly in months of the second half of the decade. From January to July, there is an almost perfect overlap between the curves of the decade 1896–1905 and the decade 2010–2019. However, during August, September, and October, there is an increase in temperature of, respectively, 1.2, 1.4, and 2.4 °C, which seem to indicate a trend towards the extension of the typical summer weather conditions practically until winter. In November and December, the temperatures are again equivalent. Apparently, for the modelled and observed results for the year 2021, the precipitation seems to be following a trend considered normal for the region of Minho, with the total precipitation value reaching 1328 mm. However, concerning temperature, the values follow a trend of prolonged higher temperatures during autumn, as observed in 2010–2019. Figure 7 presents the modelled data as well for the year 2021 with the results obtained on the METEOBLUE platform and is possible to observe a recovering of precipitation values for the year 2021 comparatively to the previous decade. This way, the values predicted for 2021, and confirmed until now, are more in consonance with the historical register analyzed for the decade 1896–1905, as presented in Figure 7. However, and considering the recent register of the past 10 years, the year 2021 can be considered as an out-of-range year, because the results are contrary to the actual trend.

The region in question has been studied by several authors, such as Salvati (2014), since it is a region in which climate change has manifested itself in different ways, namely through the recurrence of rural fires [51]. This author, in addition to analyzing the occurrence of rural fires, also analyzes the relationship established with the urbanization of the territory and the possible conflicts between the coexistence of different types of land use. In fact, this proximity, if related to other factors that may be enhanced by climate change, could lead to situations in which the proximity of populations could create a permanent risk situation during the traditionally driest and hottest months, which, as before, may have their period of occurrence prolonged two more months than would be expected in a period prior to the manifestation of climate change.

De Dios et al. (2007) analyzed the effects of climate change on Mediterranean forests and presented a set of preventive measures [52]. As measures for the restoration of different environments, the authors, based on a review of the literature on the effects of climate change on Mediterranean systems, resorted to a set of techniques and methodologies to restore the structure and resilience of spaces. They also referred to the fact that the existence of a mosaic in the landscape, with different occupations and land uses, may also contribute to a certain type of event, such as the occurrence of rural fires, but also the proliferation of exotic species can be detected and controlled due to the presence of urban agglomerations. On the other hand, this presence of people dispersed throughout the territory also entails a huge concern, since the presence of people closer to places where there is a greater risk of fires also increases the probability of the occurrence of victims. Precisely, this aspect of victims associated with the occurrence of rural fires in Mediterranean regions was analyzed by Badia et al. (2002), which used Catalonia (Northeast Spain) as a case study [53]. In this research work, the authors attribute a growing occurrence of rural fires and their impacts, not to climate change, or even individual misbehavior, but rather to the decline of the traditional landscape mosaic that historically characterized the Mediterranean rural areas. Recent socio-economic changes resulted in an uncontrolled growth of the forest masses in turn enabling the propagation of large fires.

If these facts are associated with climate change, especially if they are seen from a local and regional perspective, such as the one described here, and which demonstrates an increase in temperature, which, although not very significant, with the framed rise in the range of 1.2–2.4 °C, but mainly because this rise occurs in the autumn months (September and October), extending the summer by two months more. Together with this situation, the reduction in precipitation, which is significant, contributes to an increase in the risk associated with the occurrence of rural fires, as was also presented in the works by Fried et al. (2004) Loepfe et al. (2012), Lindner et al. (2010) or Calheiros et al. (2021) [54–57].

3.2. Evolution of Forest Cover

Several references go back to a somewhat distant past and refer to and describe the mode of occupation and use of the land in the territory of Guimarães. The most reliable document in which it is possible to obtain a characterization and description of the rural environment, mainly the space occupied by scrub, pasture, crops, and forest, dates back to 1868, entitled "Relatório Ácerca da Arborização Geral do Paiz" [58]. It was prepared by the Instituto Geographico, under the guidance of its Director, Filippe Folque, and printed by the Typographia da Academia Real das Sciencias, by request of the Minister of Public Works, Commerce and Industry, Sebastião Lopes Calheiros de Menezes. In that report, several descriptions and references are made to the municipality of Guimarães and its neighbors, which allow to get an image, albeit sometimes romanticized, of the landscape and its constituent elements, making possible to compare it with the current state and the verified evolution over about 150 years. For example, on page 32, concerning the type of settlement, which, contrary to what happens in the valleys, "almost always has a pleasant landscape, especially when opened in granites, the central part of the province (Entre-Douro-e-Minho) must preferably be mentioned as one of the most beautiful treatments in the country, which stretches from Ponte de Lima to Penafiel, covering Braga, Barcelos, Santo Tirso, and Guimarães, and the southwest corner of Porto to Póvoa de Varzim". On the contrary, the mountain massifs of Peneda, Serra Amarela, Gerês, Cabreira, and much of Marão are almost deserted, and agriculture is enchanted in them at the lowest points and sheltered from streams and slopes". This reference compares the population density, which was already high, as mentioned in the report on page 315, with population densities of 164 inhabitants.km^{-2}, 114 inhabitants.km^{-2}, and 85 inhabitants.km^{-2}, respectively, for Porto, Braga, and Viana do Castelo, according to the reference census for January 1, 1864. Although these districts lost the lead for the metropolitan area of Lisbon, continue to show high population densities.

Regarding the characterization of the forest species that most attracted the attention of the author, the vegetation existing on the route between Vila Nova Famalicão and Guimarães is reported on page 290, with emphasis on "the oaks in association with many other trees, among which there is no lack of olive trees, which form thick forests, while at the edge of properties and on the banks of streams, the vine becomes entangled in these trees". The existence of pine forests is also referenced, but in a way that does not indicate a great abundance of them; they occur in areas of higher altitude, where "thickets, cliffs and some small forest or pine forest" can be seen, highlighting the fact that many of these elevations are found "in bare parts of trees", while others are "only populated by some oaks and pine forests". The references continue to indicate profound differences from the current reality. For example, there is a reference to the high productivity of soils near the city of Guimarães. Additionally, "the slopes of the hills adjacent to this city are covered with diverse cultures and groves up to half of the elevation, while upwards it is rare, until it disappears completely, leaving the soil at its top uncovered". This is not the case currently, and the hills are completely covered with arboreal vegetation. With the slopes, many times having been occupied by the expansion of the urban limits, observable even in the most emblematic green space of the county, the Serra de Santa Catarina, being described as "covered with bushes, with some thickets of pines or oaks, or with uncultivated parts and with the ridge formed by rounded masses of porphyry granite" (Figure 8). The references to forest species remain the same throughout the text, always highlighting oaks and chestnut trees, especially on the slopes, with occurrences of other species, mainly pines, cork oaks, willows, olive trees, and other unidentified trees. There are plantations of corn, millet, and vegetables in the valleys. In contrast, meadows of rye, clover, vegetable gardens, and orchards are planted along the streams and on the slopes with less accentuated slopes. However, one reference is consistent throughout the report, as stated on page 292: "the crowns of the granitic boulders are unguarded between Guimarães and the Vizela River valley, but also downstream from Fafe", denoting the lack of large vegetation in significant parts of the mountains, contrary to what happens today (Figure 9).

Figure 8. View of the Church of S. Gualter in Largo da República do Brasil, known locally as Campo da Feira, with the Serra de Santa Catarina (Penha) backdrop, at the beginning of the 20th century. As can be seen, a highly significant part of the hill is devoid of vegetation, with the chaos of blocks being evident (image obtained from a postcard from the private collection of the author).

Figure 9. View of the surroundings of Vizela, with the mountains devoid of large vegetation (image obtained from a postcard from the private collection of the author).

Later, in 1874, the book "Fair Lusitania", presented by Lady Catherine Charlotte Jackson, describes a long trip to Portugal taken by the author. Chapter XXIV, entitled "A Ramble in Minho", describes several parts of the region, with a brief paragraph dedicated to Guimarães, which focuses mainly on the landscape surrounding the city [59]. Similarly to what happened in the report analyzed above, references are made to green landscapes, with abundant orchards, vineyards, and gardens. The text highlights that "evergreens cover the slopes, and there are avenues of magnificent chestnuts and oaks. Many pretty villas are dotted about over which [cork trees] spread their leafy houghs". In this case, the reference to forest species comprises oaks, chestnut trees, and cork oaks, with no reference to pine forests or other types of trees. However, the fact that the author is on a tourist trip and that the knowledge degree about local species is unknown may only suggest that probably pine trees are not abundant. This observation can be confirmed by analyzing the "Carta Xylographica de Portugal", commonly called the "Carta dos Arvoredos", found in "Cartas Elementares de Portugal para Uso das Escolas", by B. Barros Gomes, printed by Lallemant Fréres Typ., Lisbon, in 1878, which places the limit of occurrence of *Pinus pinaster* in the northwest, respectively, in Vila Nova de Famalicão and Braga, and in the south in Santo Tirso and Felgueiras, with Guimarães being marked as preferential for *Quercus robur* and other deciduous oaks [60]. The occurrence of *Pinus pinaster* in the municipality would be acceptable, as well as other types of pine, namely, *Pinus pinea*. Moreover, some centuries-old specimens, such as the one found in the recently created "Rotunda do Pinheiro Manso" on the road EN206, connecting Guimarães to Vila Nova de Famalicão, which has been recognized in Guimarães as the Tree of the Year 2021.

As presented in this section, the development of the forest in this region went through different phases, mainly due to the influence of the development of populations and the way in which they were organized over time in the region. More recently, as verified through documentary analysis, the forest evolved in a very significant way, with a profound change in terms of species, but also in terms of occupied areas, with a growth in the forest national area of more than three million hectares from the beginning of the 20th century to the present, as demonstrated in the work by Nunes et al. (2019) [61].

Palahi et al. (2008) presented a study with an analysis of the vulnerability of Mediterranean forests to fires, indicating that this vulnerability will be greater as greater are the weakening agents that act on the forests, namely over-exploitation, deforestation, and degradation, which are now accentuated by the context of climate change and land use changes [62]. In this way, the growing pressure of urbanization on the forest space, together with the conversion also into new agriculture areas, led to the weakening of the resilience of the forests, also enhanced by the introduction of exotic species, which are replacing native species, less capable of react quickly to the effects of climate change. This replacement of species, in addition to the highly negative impact related to the loss of biodiversity, also contributes to these disordered forests to accumulate large amounts of fuel load, and with this, increasing the risk of occurrence of rural fires [13,63].

3.3. Evolution of Land Use and Occupation

Land use underwent profound changes over time regarding how the land is valued and exploited [64–66]. Understandably, soils in lower and alluvial areas are more fertile and abundant in organic matter where agriculture is facilitated [67]. However, the land with the highest slopes, with thinner soils and where the rock emerges, hindering plant production and growth, is more difficult to valorize [68]. These areas suffer from a process of changing needs since these soils and the materials that grow on them have allowed for other soils, the so-called fertile ones, to be used for centuries, even millennia, which is why people from Minho can still work on these lands.

The occupation of the territory that today is the municipality of Guimarães comes from the most remote prehistoric times, but the kind of practices to which the populations dedicated themselves to ensure their subsistence, given the lack of archaeological records, cannot be determined with certainty [69–71]. In the period corresponding to the Bronze Age, the archaeological records are much more detailed, indicating complex and organized settlements, such as the one identified at the archaeological station of Penha [72]. These populations, most likely, would include more shepherds than farmers, and it is argued that they inhabited the summit of the hills, far from the most fertile fields, at the bottom of the valleys [73]. The same reasoning can be applied to Iron Age settlements, which must have also engaged in subsistence practices dedicated to pastoralism, taking advantage of the low wooded mountains and the ridges occupied by herbaceous shrub species serving as feed for livestock, mainly goats [74]. With the arrival of the Romans, these populations were forced to descend from the hills and establish new settlements in the valleys, giving rise to a dispersed organization, with new settlements next to the water lines [75,76]. These populations changed their means of subsistence, with agriculture becoming the means by which the livelihood of the populations was guaranteed [77]. However, the available area, with fertile soils, was, and still is, in fact, small, so they quickly found themselves exhausted after a few generations, making it challenging to ensure the supply of a growing population [78]. This fact led the farmers to look for bushes as a source of organic matter incorporated into the soil, perpetuating its fertility [79]. For centuries, this practice was carried out, guaranteeing that forests were collected in the mountains, controlled, and prevented from growing in an uncontrolled manner [80].

This practice, which has lasted until very recent times, has spread to such an extent that no farmer has surrendered his land to produce scrub. Alberto Sampaio, in 1886, in his work entitled "Estudos de Economia Rural do Minho", dedicated an entire chapter to the culture of the bushes, where demonstrates the importance that this practice had for agriculture productivity [81]. The author mentions "one of the most precise productions with which nature perhaps wanted to compensate for the initial poverty of these lands (...)", referring to the abundance of forests, which the populations learned to use for their benefit as a fertilizer for soil improvement. The author continues, using other regions as examples where this occurred, writing that "it is so in all granitic countries, from Minho to Brittany", since "in all agriculture, those plants use the forests as one of the main fertilizer elements (...)". Alberto Sampaio even goes so far as to say that, if these forests had disappeared, agriculture production in Minho would be deficient.

However, this traditional method of using existing resources has declined, mainly due to the persistent abandonment of agriculture as the main activity of the current population, which, over the past four decades, has given up working on the land and set out in search of new opportunities, both in industry and in civil construction, which had its great advent after Portugal entered the European Union in 1986 [82–84]. This change in practices led to a lack of control of the underbrush, creating an extensive accumulation of biomass and increasing the risk of rural fires, which has been enhanced by the reduction in precipitation in recent decades, associated with the gradual increase in temperature [63]. In other words, the more significant available fuel load (which is also drier in an environment with high temperatures) led to an increased risk of rural fires. In addition to this accumulation of problems, there is also the issue of the arrival and proliferation of exotic species with invasive behavior, commonly found in these abandoned territories, since those are usually highly resilient species adapted to callous edaphoclimatic conditions. An example of these species is *Acacia dealbata*, which occupies extensive areas, mainly stony slopes and peaks, where there is no competition from tree species that can hinder direct access to sunlight, as these species are heliophiles [85].

In the current climate change scenario, the risks associated with the occurrence of rural fires, more specifically with the negative impacts they may have on populations, have been the object of several studies, where the different parameters presented here are related. The relationship between the occurrence of rural fires and climate change, even if on a local or regional scale, is relatively easy to justify, with several works presented on the subject, as for example, by Pereira et al. (2013), where the effects of regional climate change on the occurrence of rural fires in Portugal are analyzed [19]. In this study, the methodology used the Burnt Area Model (BAM), based on multiple regression analysis, and was able to explain 63% of the variance observed in the period 1980–2011, using data simulated by a Global Climate Model (GCM) for the current climate and for two 30-year periods (2051–2080 and 2071–2100), with the conditions foreseen by the Intergovernmental Panel for Climate Change (IPCC) for emissions in a B1 scenario. The results obtained point in the direction of an increase in the risk of occurrence of rural fires in view of the predictions of changes in climate conditions in the future, with a forecast also for an increase in burnt areas, but also in the severity of fires. This aspect is extremely important, since, as seen in the present study, the dispersion of populations across the landscape, and the intercalation of different types of land occupation, will increase the probability of populations remaining in direct contact with the occurrences of rural fires, and with that, increase the level of risk for these same populations.

This relationship between how populations are distributed in the landscape, especially in the Mediterranean regions, was also studied by Gauquelin et al. (2018), adding to the existing threat analysis also the human component, developing a link between the "*hard sciences*" and the social sciences, in order to understand the full scope of these complex systems from a perspective of understanding how these shared and interspersed environments, in spite of specific climatic constraints, can also be healthy and productive, and play a major ecological and social role [86]. In that study, the impact of human activity on the landscape and on the evolution and alteration of the types of land use is also analyzed. These are important themes for the definition of the risk to which populations are subject, mainly in a climate change scenario, forest alteration through changing interests in resources and services, and the introduction of exotic species, which alter the traditional form of development and accumulation of biomass.

Several other studies, such as those presented by D'Antonio and Vitousak (1992), Pausas and Vallejo (1999), Hill et al. (2008), Syphard et al. (2009) or Bajocco et al. (2012), already warned to the problems related to changes in land use and the impacts associated with risk for populations, albeit indirectly, as it can easily be inferred, that the proximity of populations in a type of dispersed settlement creates a permanent proximity, increasing, as mentioned above, the probability of being closer to an occurrence of rural fire [87–91].

3.4. Historical Analysis of the Occurrence of Rural Fires in Guimarães

There are few references to the occurrence of rural fires in the territory of Guimarães before 1975, and this is precisely the year of the first record of burnt areas in mainland Portugal provided by the ICNF, followed by another record corresponding to the year 1978. The references to fires that are known to have occurred in periods before these dates are not very reliable and depend on older local inhabitants who remember the occurrences, but who often do not know the dates or, less often, the areas affected by the fires. There is an important question related to the location of the fires, since in many cases, although the inhabitants were aware of the occurrence, they did not witness it personally. Based on the available data, it can be inferred that these were much less frequent phenomena. Figure 10 shows the overlap of occurrences from 1970 to 2019, divided by decades, as follows: 1970–1979, 1980–1989, 1990–1999, 2000–2009, and 2010–2019.

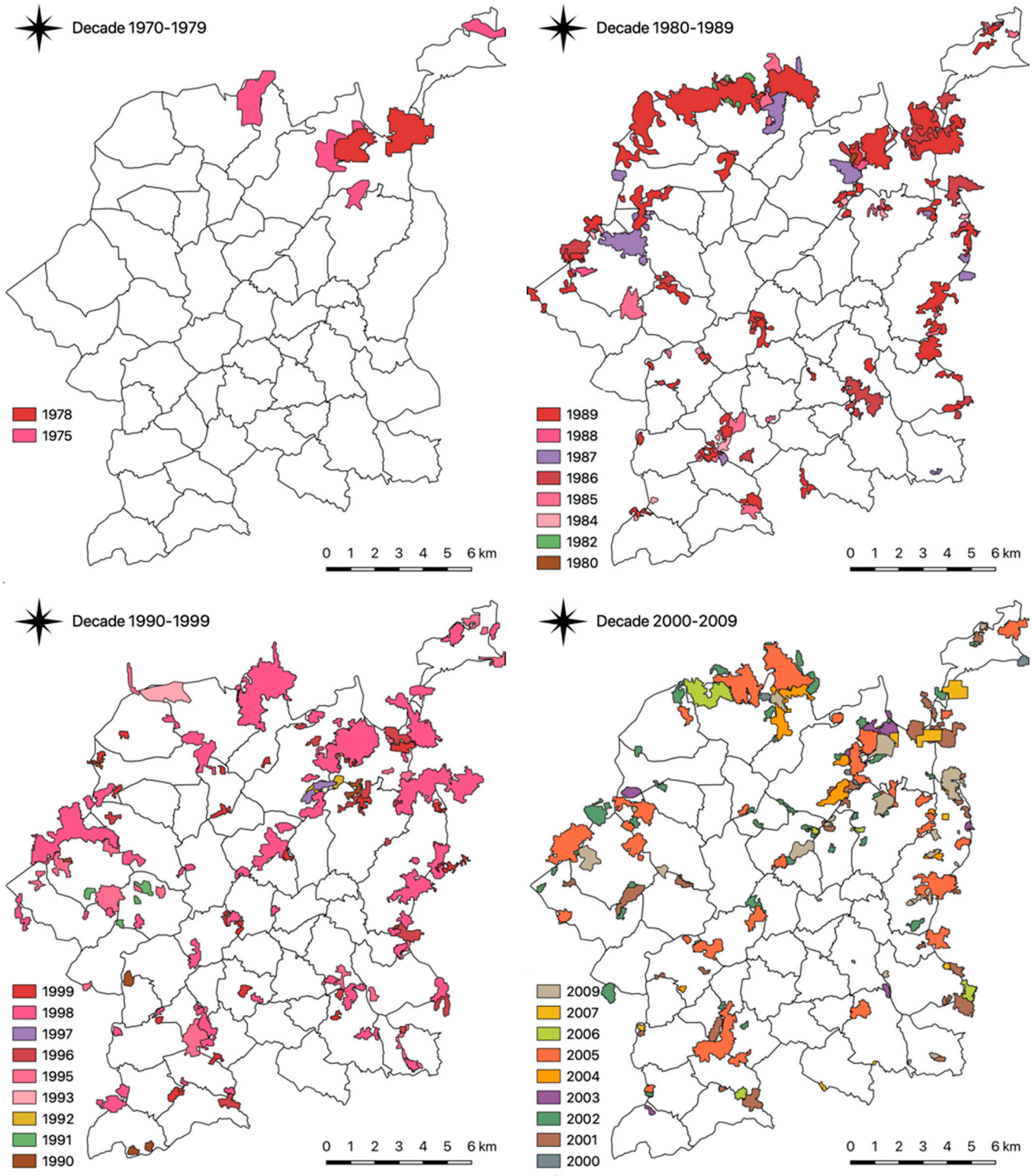

Figure 10. *Cont*.

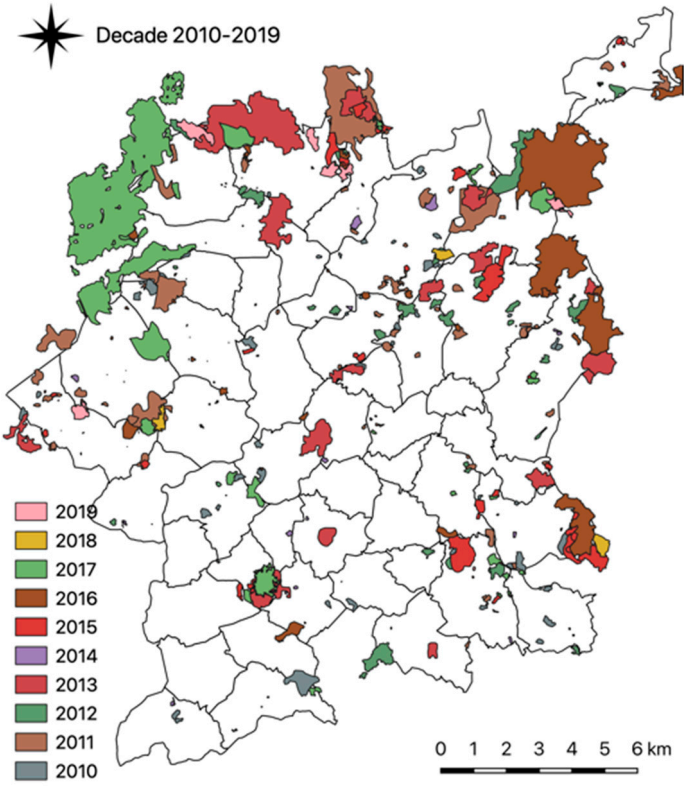

Figure 10. Rural fires occurred in Guimarães from 1970 to 2019 (adapted from data available at the ICNF website).

If all the occurrences of rural fires in the municipality of Guimarães for the decade 1970–1979 are duly registered, it appears that there was a very significant increase in the number of fires and burnt areas in the following decade, 1980–1989. As can be seen, the fires continued to affect parishes in the northern part of the municipality, which are more mountainous and where continuous forest areas led to larger fires. However, there were also fires in other forest areas of the municipality, mainly in the Serra de Santa Catarina (Penha). In 1990–1999, fires in the northern parishes and several minor occurrences in the southern part, which continued to persist. There were also fires in the Serra de Santa Catarina, which became more frequent. It has also been verified that the arrangement of the burnt areas followed the alignment of the main watercourse that crosses the municipality, in a NE/SW direction. This evidence may indicate a trend towards the need to free up forest area to develop new urban or agriculture areas that seek proximity to the Ave River. Still, it might also indicate a greater density of vegetation, enhanced by the proximity to water. In 2000–2009, the trend observed in the previous decades ceased, with the largest burned areas occurring in the northern parishes of the municipality and with a higher number of fires also occurring in parallel to the Ave River, delineating the burnt areas with its margins. There was also a continuous occurrence of fires in the Serra de Santa Catarina. The 2010–2019 decade was the worst period for rural fires, given the high number that occurred. The trend for large fires in the north and their alignment with the Ave River margins persisted. The only explanation for this trend has been the urban pressure in some specific river sections. Fires in the Serra de Santa Catarina also became a reality in this decade. Figure 11 presents the relation between the number of occurrences and area burnt for each decade, where the continuous growth is visible both for the number of occurrences and for the area burnt, with a particularly clear increase in the latter case. In the decade 2010–2019, the number of occurrences in more than the double that of the previous decade, and it is possible to see an increment in the burnt area as well.

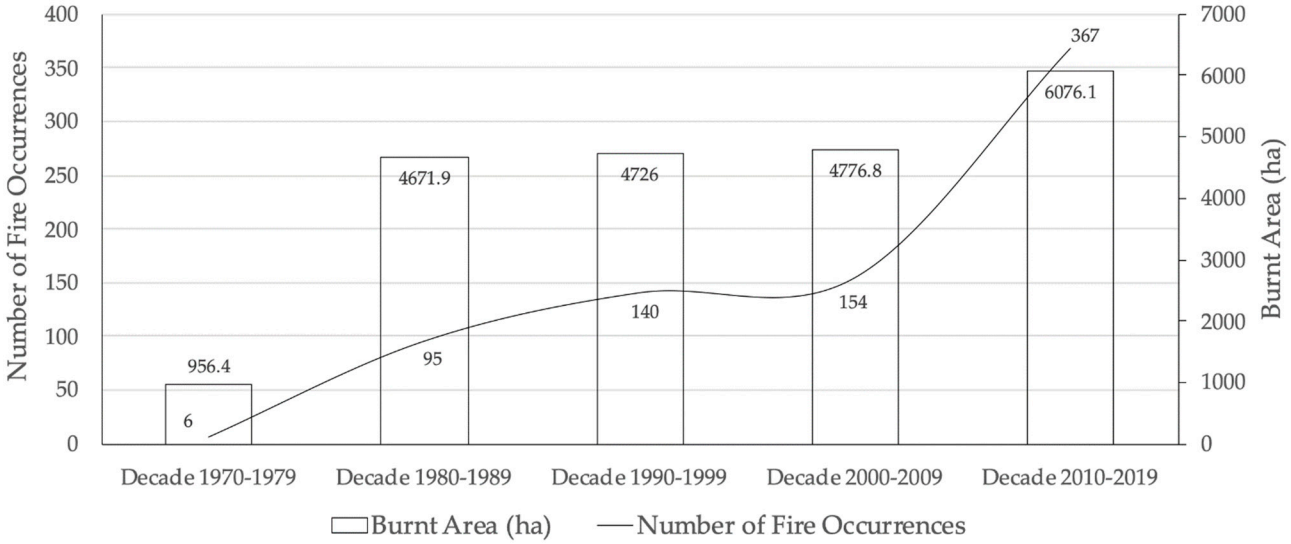

Figure 11. Evolution of the number of occurrences and area burnt during the past five decades in the municipality of Guimarães.

The assessment of the risk associated with the occurrence of rural fires in this region has not been the object of significant studies. However, there are some previous approaches, namely the work on the disruption of the rural world in mountain areas and the risk of fire, presented by Bento-Gonçalves et al. (2010) [92]. In this work, the authors treated the Serra da Cabreira (Vieira do Minho, Portugal) as a case study, and they concluded that the disruption of the rural world led to a strong increase in the number of outbreaks of rural fires. This situation is in line with what is seen in the territory of the municipality of Guimarães, as it was precisely this disruption of the rural world that led to the current state, with the abandonment of traditional practices, namely due to the abandonment of fields. Moreover, the collection of bushes that were previously referred to were later converted into fertilizers for agriculture fields. This ancestral practice, in addition to increasing the fertility of the soils, also reduced the fuel load and, thus, reduced the risk of rural fires, or at least their severity and capacity to spread. The vulnerability of the territory of Minho was the subject of another study, conducted by Bento-Gonçalves et al. (2014) [93], once again concluding that the disruption of the rural world would be the main cause of the increase in the occurrence of fires, and that it had already been addressed in this perspective, in a previous study by Leite et al. (2013), where the authors list the great forest fires in mainland Portugal as a result of disturbances in fire regimes in the Mediterranean [94]. In this work, the authors point to industrial development, and rural-urban conversion, associated with the depopulation of agriculture work in the last half of the 20th century, as the main reason for the increase in the number of occurrences of rural fires. This perspective supports the hypothesis of increased risk for populations, now urbanized, but which maintain a very close proximity to the rural environment, although, for the most part, no longer have the capacity to intervene in these areas, and are much less prepared to protect themselves in the event of a rural fire.

The increase in the average temperatures, which extends the hot and dry period to the autumn months, as observed in Section 3.2, significantly increased the risk of rural fires. This has forced authorities to review the period where there is a risk for rural fire occurrence and to extend it to October 15 instead of September 15. Figure 12 shows the projection of the number of rural fires and the burnt area between 1975 and 2019.

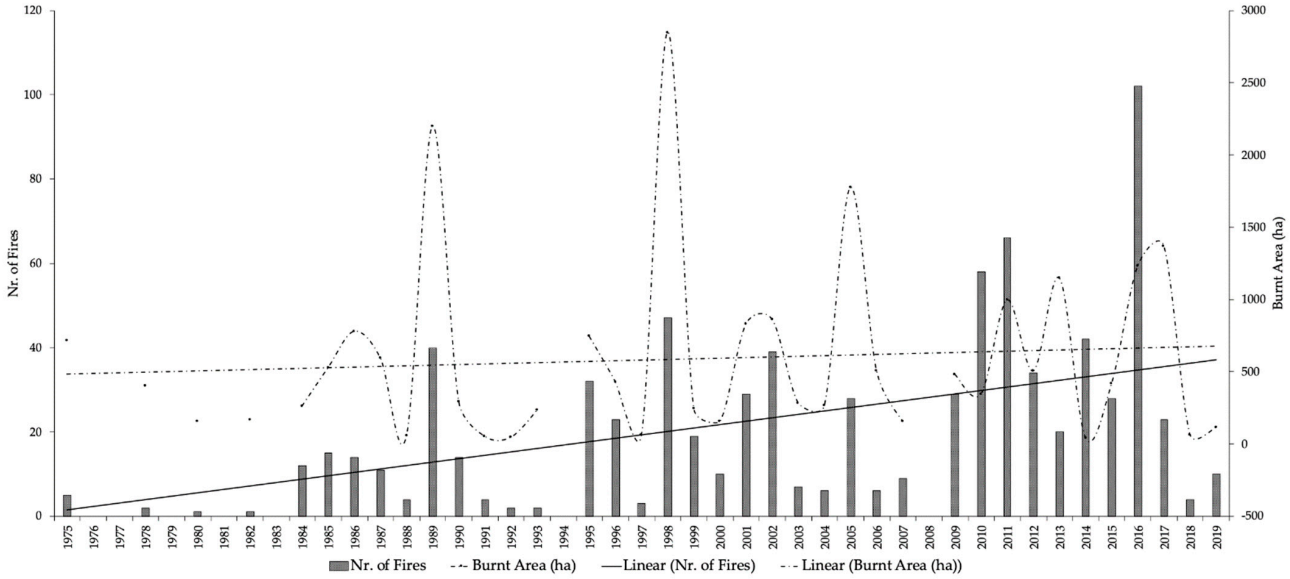

Figure 12. Occurrences of rural fires and burnt areas in 1975 to 2019.

As can be seen, there is a trend towards an increase in the number of occurrences. This increase is highly significant given the slope of the trend line projected for the history of rural fires. The burnt area trend seems to have somewhat stabilized. However, the trend line shows a slight upward slope, indicating the probability of an increase in the area burnt annually, depending this possibility on the development of the climate [95]. Additionally, the evolution of the management and spatial planning of these areas and the increase in urban pressure (related to the abandonment of secular practices of rural area management, mainly concerning the management of scrub and residual biomass, contributing to the accumulation of these fuel loads) significantly increase the risk of rural fires [96]. Their recurrence and increased severity are expected in the territory under consideration in this case study.

Nunes (2012), presented a study addressing the regional variability and the causes behind rural fires in Portugal, in the period between 1980 and 2009 [38]. This work analyzed the evolution and regional distribution of the number of ignitions and burnt areas for each one of the districts of mainland Portugal, having confirmed the existence of a positive trend in the number of fires and in the areas burnt by fires since 1980, detecting a regional distribution of ignitions and burnt areas, highlighting some regions particularly vulnerable to the outbreak of fires and others particularly susceptible to the spread of fire. As previously mentioned, supported by the work of Nunes et al. (2020) or Raposo et al. (2020) [13,63], the main cause of fires in Portugal is the misuse of fire, mainly associated with negligence during the processes of burning agriculture and forestry remnants, and which was once again confirmed by the work of Nunes (2012), in which it is stated that the population density was the primary determining variable in the outbreak of fires, with the burnt areas being influenced by the effects of topography, changes in land use, and changes in the type of vegetation cover [38].

4. Conclusions

The occurrence of rural fires is an issue that must be addressed from an integrated perspective to analyze all the aspects involved, whether they are of an environmental or economic nature, or a sociological or demographic nature. The occurrence of rural fires directly affects the dynamics of the evolution of territories. However, they also directly affect how the territory interacts with space, concerning its organization and the distribution of land use. The dispersal of populations and their interaction with the countryside leads to profound difficulties concerning their organization, raising questions about exposure to the growing risk of rural fires and their proximity to urban areas. Guimarães, similarly to what

occasionally happens throughout the country, is currently changing its forestry/agriculture matrix, which is evolving towards adapting to climate change and incorporating new exotic species with invasive behavior, as is the case of acacias. The evolution of land management practices that has led to the abandonment of traditional practices, such as forests for the fertilization of soils and the accommodation and feeding of animals, has contributed to the accumulation of combustible loads in these lands. The increase in average temperature and the significant reduction in precipitation led to the increased risk of rural fires, which have intensified in the last two decades. The analysis of historical data indicates an increase in the probability of the occurrence of this type of event, which, in addition to the usual environmental damage, entails a set of concerns related to the growing urban pressure on the rural space, further enhancing the danger associated with this type of event due to the land use and dispersed population observed in the region.

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