A Work Project, presented as part of the requirements for the Award of a Master's degree in Economics from the Nova School of Business and Economics.

MAPPING SOCIOECONOMIC VULNERABILITIES OF THE CENTRO REGION'S PORTUGUESE POPULATION TO LAND USE

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26/01/2024

Abstract

This analysis maps the vulnerability of Portugal's Centro region population to land use, exploring the relationship between land use patterns, socioeconomic indicators, and environmental hazards. It reveals concentrations of wealth and education in coastal and urban areas, contrasting with heightened vulnerability in forested inland regions. The study highlights intensified flood risks in coastal territories, underlining amplified vulnerability due to economic activity and human presence. Additionally, it emphasizes the correlation between forested areas and fire risks, impacting the resilience of vulnerable communities. The findings underscore the necessity for tailored policies, informed by local dynamics, to enhance community resilience against environmental risks.

Keywords: Land use, Land cover, Socioeconomic vulnerability, Spatial analysis

This work used infrastructure and resources funded by Fundação para a Ciência e a Tecnologia (UID/ECO/00124/2013, UID/ECO/00124/2019 and Social Sciences DataLab, Project 22209), POR Lisboa (LISBOA-01-0145-FEDER-007722 and Social Sciences DataLab, Project 22209) and POR Norte (Social Sciences DataLab, Project 22209).

I. Introduction

The relationship between land use patterns and socioeconomic indicators can highlight disparities in the distribution of environmental amenities. Furthermore, it helps identify if certain socioeconomically vulnerable communities have limited access to the provision of key ecosystem services. This thesis aims to delve into this topic within the specific context of Portugal's Centro region, contributing to the ongoing discussion about the interplay between environmental characteristics and social vulnerability.

Coastal regions face degradation due to human pressure that is contributing to erosion, habitat deterioration, and the threat of rising sea levels in the context of climate change. Forests are central for economic development, job generation, and environmental balance. Urban green spaces are essential to the fabric of urban living. In contrast, the development pressure that leads to the expansion of urbanized areas, namely at the Wildland-Urban-Interface (WUI) in the vicinity of cities where forests intermingle with houses, increasing the fire risk, require a comprehensive investigation to identify the main forces driving those events, and how they interact with socioeconomics indicators.

This thesis focuses on the Centro region of Portugal, conducting a municipality-level analysis that allows for a better identification of the vulnerabilities specific to this area. The focus on the Centro region resulted from its distinctive features in terms of diverse landscapes, which include coastal areas, forests, and urban spaces. This diversity allows for a comprehensive analysis of the different land uses, the ecosystem services provided and their connections to socioeconomic indicators. The study investigates the correlations between socioeconomic variables, land use patterns and environmental hazards. In first place, the different land covers, such as wetlands, water bodies, forest cover, urban green areas, are identified. Then, the vulnerabilities of the populations residing in areas characterized by those distinct land uses are assessed. Finally, the analysis incorporates environmental hazards, specifically flood risk and fire risk, by examining their correlation with land uses to understand how these different land utilizations can influence susceptibility to these risks. The findings reveal that communities facing higher vulnerabilities are predominantly located in proximity to forests, where this land use heightens the risk of fires, exacerbating the challenges faced by these populations. Conversely, territories near the coast and urbanized areas exhibit lower vulnerability, despite confronting significant risks associated with flooding, where the potential severity of consequences is intensified by the economic importance and the high population density characterizing these areas.

Ultimately, the results obtained aim at offering insights that can guide policymakers in formulating targeted and effective public policies. By understanding the socioeconomic dynamics of different land uses, policymakers can tailor interventions to address specific vulnerabilities and enhance the overall resilience of communities.

II. Literature review

In the existing literature, numerous examples show how interconnections between land and socioeconomic indicators have been investigated. Coastal areas, forests, green urban areas, are the primary land uses extensively examined in the literature.

1. Coastal areas

One of the most pressing issues in Portugal is coastal vulnerability. Coastal regions all over the world face issues such as coastal erosion, deterioration of marine habitats, pollution, and the threat of rising sea levels. Their extensive development poses a serious challenge to their natural self-regulation (Martins et al. 2011). Moreover, the central Portuguese coast is acknowledged as the area in Portugal most susceptible to coastal erosion (Alves et al. 2009). Furthermore, around 75 % of the population in Portugal live close to coastlines, where also political decision-making centers, commercial and industrial hubs, and employment opportunities are located, generating significant human pressure on these areas (refer to Figure A1 for the distribution of population density in Portugal). Activities including tourism, boating, fishing, aquaculture, saliculture, and mineral and energy pursuits, collectively contribute to approximately 85% of the national Gross Domestic Product (GDP), hence being strategic for the country (Rocha, C. et al. 2019). These activities and the monetary streams that they allow are linked to the ecosystem services provided by wetlands and water bodies.

Given the significant human pressure and economic activities concentrated along Portugal's coastlines, understanding the vulnerabilities of the population living in these areas becomes important. This dimension is crucial when evaluating the population's capacity to deal with risk management, adaptation and mitigation measures. Assessing the vulnerabilities plays a central role in advising policymakers to develop sustainable public policies which are suited to address population´s wellbeing.

In Alves et al. (2007), the authors establish the connection between socioeconomic aspects and the Central Portugal coastal region's environment in the context of the Coastal Zone Management Plan. The authors emphasize the role of demographic pressures, economic opportunities, challenges posed by tourism, and the importance of aligning development with sustainable principles. More specifically, they identify a rapid development in the central coastal zone since the mid-20th century, which is associated with significant socioeconomic opportunities. Moreover, they highlight the demographic pressure on the coastal regions, which raises challenges to sustainable development and increases the vulnerability of coastal populations.

When we look more specifically at the potential implications of accelerated sea-level rise in Portugal, Ferreira, O' et al. (2008) show that the areas that will be most affected will be those close to estuaries and coastal lagoons where there is a significant human occupation, specifically, in the Centro Region, where the Ria de Aveiro coastal lagoon will suffer important socioeconomic effects. In this area, the increased risk of flooding and overwash will negatively impact economic activities, such as navigation, tourism, recreation, fisheries and shellfish farming (Ferreira, O' et al. 2008). Rocha C. et al. (2019) focus on the same issue to assess coastal vulnerability to sea-level rise. According to this study, inland waters will be the areas with the highest exposure for people and buildings, in particular when compared to the districts characterized by extensive estuaries, such as Faro and Aveiro. Four examples of cities in the Central Region that have important infrastructure in vulnerable zones are identified, in particular, the Peniche Peninsula, the municipalities of Alcobaça, Figueira da Foz and Espinho. Considering these challenges, when implementing adaptation strategies, the role of wetlands and water bodies in providing ecosystem services such as flood protection (refer to *Table 1*) should be taken into account. Enhancing their presence by investing in nature-based solutions to improve their conditions could be an effective way to mitigate issues connected to coastal vulnerabilities. In conclusion, the vulnerability of Portugal's central coastal regions raises complex challenges, intertwining demographic pressures, economic dependencies, and environmental risks. As the nation heavily relies on coastal activities, addressing these vulnerabilities is crucial for sustainable development. Adequate policies must emerge, considering the socioeconomic interplay and specific vulnerabilities identified.

This research adds a valuable contribution to existing studies by specifically focusing on the Centro Region, mapping and analyzing socioeconomic characteristics associated with various land uses to reveal distinct patterns of wealth and vulnerability. Moreover, it offers an initial understanding of how different land uses in the Centro Region contribute to or mitigate coastal vulnerabilities.

2. Forest cover

Besides the issue of coastal vulnerabilities, a second distinction should be made between green areas and gray areas. In the context of green areas, the existing literature presents numerous studies aiming to explore the correlation between these areas and various socioeconomic indicators. For instance, some papers delve into the interconnection between forests and the characteristics of the populations they provide services to. An illustrative example is found in Nunes et al. (2019). This study comprehensively reviews the historical development of Portuguese forests, with a particular focus on the three primary species covering approximately 72% of the total forested areas. These key species are maritime pine (Pinus pinaster), cork oak (Quercus suber), and eucalyptus (Eucalyptus globulus). The economic importance of forests is highlighted, generating jobs and contributing significantly to the local and national economies. Forest-based industries, including sawmills, pulp and paper, and cork play crucial roles. The potential for further development of the forest value chain in Portugal is also emphasized. The Common Agricultural Policy (CAP) 2021–2027 is seen as an opportunity for forest-targeted policies. A clear and cohesive stake in the forest, combining public and private investment, is considered very important for increasing social benefits, including increasing water availability, strengthening rural economy, increasing exports, and climate change mitigation.

The impact that forests have on socioeconomic development is analyzed by Ribeiro et al. (2007). This study focuses on Portugal, examining the relationships between indicators of socioeconomic development, landscape metrics, and forest conditions. The analysis considers national and regional scales, using data on forest and socioeconomic characteristics. The research reveals strong negative correlation between socioeconomic development and forest conditions at the regional scale, for data at the municipality level of the North Region. This suggests that in this region, areas more developed (mainly near the coast) are more likely to present degraded forest conditions. Different socioeconomic groups seem to be associated to different forest characteristics, reflecting pre-industrial, industrial, and post-industrial forestry stages, which can illustrate the different stages of forest transition from native Portuguese broadleaf forest to more productive tree species. In the paper, the concept of “virtuous circles” is enhanced, suggesting that reinforcing linkages between socioeconomic and environmental aspects is crucial in all types of landscapes. Their conclusion emphasizes the need to integrate socioeconomic and environmental dimensions, encouraging such virtuous circles. Policymakers should take them into account when implementing sustainable forest management strategies, in order to be successful regarding both socioeconomics dimensions and sustainability at the landscape scale, thus contributing to build social capital.

3. Urban Green Areas

Furthermore, the literature also focuses on the role that urban green areas play and on how they are linked to socioeconomic variables. In Pinto et al. (2021) the authors examine how socioeconomic indicators are related to urban green areas. The study is based on an on-site quantitative survey that was conducted on five urban green spaces (UGS) in the Coimbra municipality. The paper provides insights into the interplay between sociodemographic factors, user preferences, and UGS characteristics. The results show that in three out of the five parks wealthier older individuals are more prone to use these parks. The paper emphasizes the importance of taking this finding into consideration in park planning and management to address the concern of social equity in park availability and accessibility.

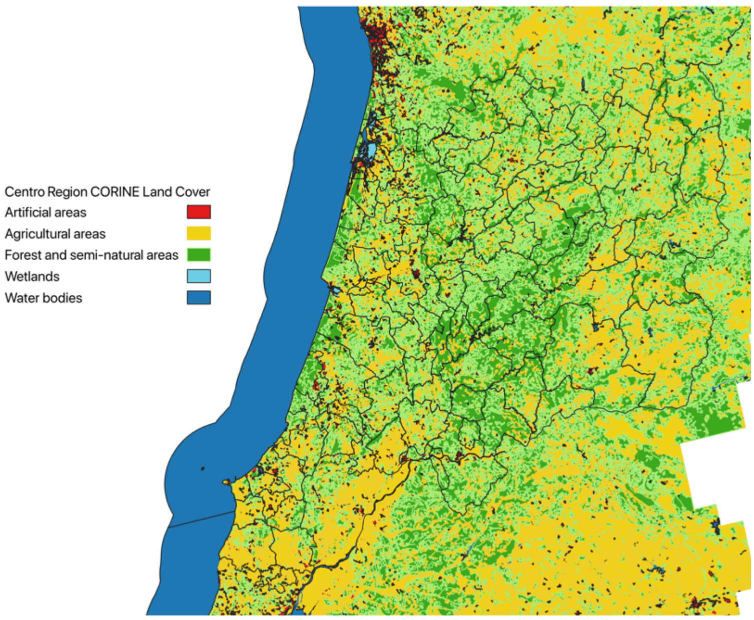
Also Hoffimann et al. (2017) examined whether there are socioeconomic differences in the accessibility and quality of green spaces among different neighborhoods in Porto. The results showed important socioeconomic inequalities in urban green areas provision in Porto, with large differences across quintiles of neighborhood socioeconomic deprivation with regards to geographic accessibility to green spaces. Furthermore, the research demonstrated that wealthier neighborhoods exhibited higher green space quality. Highlighting the importance of incorporating both quality and proximity metrics to effectively address inequality in the planning of green space provision. Additionally, the paper also mentions that in the literature the provision of green space has effects on population's health indicators, showing that a lack of green space leads to physical inactivity, obesity, poor quality of life, and higher mortality risk. These findings have important consequences for urban planning and design because the allocation of green spaces must be based on the principle of equity.

This study contributes to the discussion by mapping socioeconomic indicators with the existence of green urban areas in the Centro region, illustrating how the distribution of wealth and vulnerabilities correlates with the spatial presence of these areas.

III. Centro Region (study area)

The focus of this study is the Centro Region (see the geographical position in *Figure A2*). Administratively, it comprises 100 municipalities grouped into eight sub-regions, which correspond to the NUTS III level. These are Aveiro, Coimbra, Leiria, Viseu Dão Lafões, Beiras and Serra da Estrela, Beira Baixa, Oeste, and Médio Tejo (see the distribution of the Intermunicipal Communities in the Centro Region in *Figure A3*) (CCDRC n.d.). This region features an extensive forest cover, accounting for 38.8% of the territory. The prevalent types include eucalyptus (40.2%) and maritime pine (42.1%) as of 2015 (Pordata n.d.). Following closely is agricultural land use, constituting 22.4% of the coverage. The distribution of land uses across the Centro region is displayed in *Figure 1*.

Figure 1: Centro region CORINE Land Cover



Furthermore, as illustrated in the literature, the region features an important coastal lagoon known as Ria de Aveiro, located in the Aveiro sub-region. Moreover, among the many rivers present, the region is crossed by the Mondego River, which is the longest river running entirely in the Portuguese territory, having its source in Serra da Estrela and its estuary close to the city of Figueira da Foz (Universidade de Évora n.d.). These variety of land uses provide very different ecosystem services, that will be further analyzed in the next paragraph.

Moreover, the region presents a population of 2.227.239 according to the 2021 Census, with an average population density of 79 individuals per km^2. This falls below the national average of 112.2 and ranks as the second lowest in Portugal, surpassed only by the Alentejo Region (INE Statistics Portugal n.d.). *Figure 2* illustrates the distribution of population density in the region, highlighting a significant human concentration along coastal areas, while inland regions exhibit very low population density. Regarding education, the average percentage of residents with completed higher education stands at 18.59%, while for the whole country this percentage rises to 21.20%. Once again, a higher percentage is observed in proximity to coastal areas (*Figure 3*). Similarly, income distribution follows these patterns, with wealthier individuals predominantly residing along the coast (*Figure 4*). For a comprehensive view of the spatial distribution of other socioeconomic indicators in Centro Portugal, refer to Figure A4/A10 in the Appendix.

Figure 2: Population density

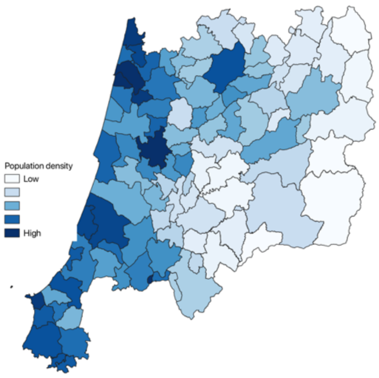


Figure 3: Education

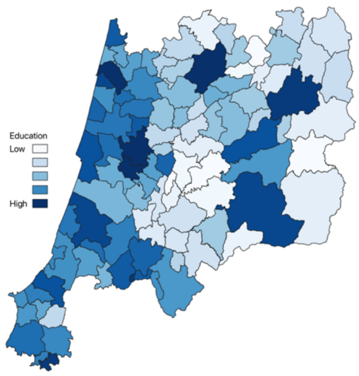
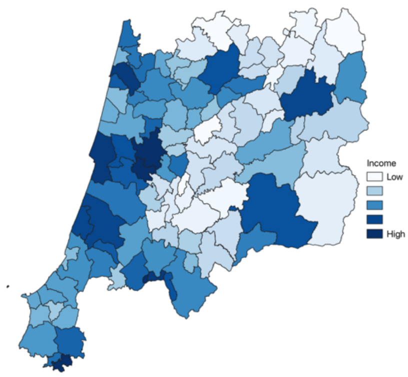


Figure 4: Income



IV. Land uses and Ecosystem Services

This analysis considers 44 classes of land use from the CORINE land cover dataset, which will be further explained in the next section. These can be categorized in ecosystem types. This classification was conducted by the working group on Mapping and Assessment of Ecosystems and their Services (MAES) which was established by the European Commission (Maes et al., 2020) (for the correspondence between CORINE land cover (CLC) classes and MAES ecosystem types see *Table A1*). These ecosystem types categorize and describe the variety of ecosystems found across landscapes, including urban ecosystems, forests, wetlands, grasslands, and more. Finally, for each type of ecosystem the corresponding ecosystem services are defined, which are 'the direct and indirect contributions of ecosystems to human well-being' (TEEB. 2010). These services include provisional services, regulating services, cultural services and supporting ones (TEEB. 2010). The variety of ecosystem services provided by the various classes analyzed in this study are shown in *Table 1.* Furthermore, a more detailed analysis of the services provided by each one of the 44 classes of land use can be found in *Table A2* (Burkhard, Kroll and Windhorst 2009).

Table 1: Provision of ecosystem services per land use

	Ecological integrity	Provisioning services	Regulating services	Cultural services
Aggregated forests and semi-natural areas	Exergy capture (Radiation) Reduction of Nutrient loss Storage capacity (SOM) Biodiversity	Wild foods Timber Wood fuel Biochemicals/Medicine	Erosion Regulation Nutrient regulation Water purification Air Quality Regulation Local climate regulation Pollination	Recreation & Aesthetic Values Intrinsic Value of Biodiversity
Green urban areas	Exergy capture (Radiation)	-	-	Recreation & Aesthetic Values
Beaches, dunes and sand plains	Abiotic heterogeneity Biodiversity	-	Flood protection	Recreation & Aesthetic Values
Aggregated wetlands	Storage capacity (SOM) Biotic waterflows Metabolic efficiency Exergy Capture (Radiations)	Fodder Energy (Biomass)	Flood protection Global climate regulation	Recreation & Aesthetic Values
Aggregated water bodies	Metabolic efficiency Exergy Capture (Radiations)	Capture Fisheries Acquaculture Wild Foods Freshwater	Flood protection	Recreation & Aesthetic Values Intrinsic Value of Biodiversity
Sea and Ocean	Reduction of Nutrient loss	Capture Fisheries Acquaculture	Glocal climate regulation Nutrient regulation	Recreation & Aesthetic Values

Reference: Burkhard, Kroll and Windhorst 2009

Moreover, specific land uses provide ecosystem services such as flood protection and erosion regulation, which can mitigate environmental hazards like floods.

To summarize, the connection lies in understanding how specific land uses influence the characteristics of ecosystems and, in turn, how these ecosystems provide various services to the population. Specific ecosystem services can accentuate or mitigate environmental hazards such as floods and fires, alleviating or worsening the consequences of these events on the population facing those risks.

V. Methodology and Data

1. General Methodology

To assess the vulnerability of the population to specific land use categories, a correlation analysis was undertaken. Firstly, the study investigates the correlations between socioeconomic variables and land uses, followed by an analysis of the relationships between land uses and environmental hazards. This approach was selected first to explore the possible relationships among variables, laying the foundation for a more in-depth investigation in subsequent studies using more advanced techniques. It is important to emphasize that correlation does not establish causality, therefore, the results shown in the next paragraphs should be interpreted with caution.

2. Land use data

With regards to the land use variables, the dataset used was the Corine Land-Cover (CLC). This dataset is part of the Copernicus program, which was financed by the European Commission to provide information services based on satellite Earth observation and in-situ (non-spatial) data (Copernicus n.d.). More specifically, the Corine dataset focused on collecting satellite data for the European Continent, categorizing the soil in 44 classes of land use and land cover (CORINE Land Cover n.d.). The data are collected every six years and for the purpose of this study we considered the most recent dataset, which referred to 2018.

First, the classes were aggregated in 5 main categories; artificialized areas, agricultural areas, forest and semi-natural areas, wetlands and water bodies, which coincide with the 5 major subclasses of the dataset. Subsequentially, a more specific focus was directed to subclasses of the dataset, such as green urban areas (141), and beaches, dunes and sand plains (331). The data in the CLC were expressed in terms of km^2 and, to be able to interpret the data, they were transformed in percentage of the territory. The focus of the analysis is the municipality level, hence, in the end, the CLC measured the percentage of territory of a specific municipality that was allocated to a specific land cover.

3. Socioeconomic data

In addition to the land use variables, data regarding socioeconomic variables is also needed. The different indicators were mostly retrieved from the Portuguese Census of 2021, which contains statistical information regarding economic, social and demographic characteristics at the municipality level (INE Statistics Portugal n.d.). Other indicators were taken from the INE Statistics Portugal website. The purpose of collecting socioeconomic data is to include data which can help assessing the social vulnerability of the population. According to Ogie and Pradhan (2019) "social vulnerability can be defined as those socioeconomic and demographic characteristics of a population that influence both the sensitivity of the population to natural hazards and its ability to prepare for, respond to, and recover from the impacts of hazards". The importance of assessing vulnerabilities has major political implications. In Bergstrand, et al. (2015) the potential relationship between community resilience and social vulnerability across U.S. counties was assessed, revealing a correlation between high vulnerability and low resilience (Pearson's correlation was 0.386 ($p <. 001$), and Spearman's correlation was 0.554 ($p <.001$)). The findings support the use of community vulnerability maps to guide emergency planners and policymakers in disaster prevention. Recognizing areas in need allows for proactive programs to prepare and mitigate harm before disasters, as well as target aid afterwards. Overall, assessing both social vulnerability and community resilience informs emergency planners and authorities, enabling them to address weaknesses and enhance communities' ability to withstand hazards. Moreover, given that resources are scarce, it may also contribute to allocating them to the most vulnerable areas.

The selection of key socioeconomic indicators for the analysis was guided by two distinct sources. First, the variables considered were similar to those in Raimi et al. (2022) where the vulnerability of populations to the US Energy transition was assessed and mapped. Furthermore, the variables picked also result from comparing this analysis with the paper from Frigeiro (2016). This study uses a GIS-based approach to identify the spatial variability of social vulnerability to seismic hazard in Italy to capture social vulnerability by looking at six classes of indicators, namely age, employment, education, anthrophization, quality of residential construction and ethnicity.

In the end, the variables considered include eight key characteristics of the population, namely population density, vulnerability, which accounts for elderly and younger people, minority representation, educational attainment, income, inequality, unemployment, and housing conditions. These indicators are illustrated in *Table 2*.

Table 2: Socioeconomic indicators

	Indicator description	Source
Population density	Measures the intensity of settlement expressed as the total population per square kilometer	2021 Census
Total dependency ratio	Compute the shares of the population over 65 years old and those younger than 15 years old in the total working-age population	Annual estimates of the resident population in Portugal
Old-age dependency ratio	Computes the ratio between the elderly and the working-age population	Annual estimates of the resident population in Portugal
Share of minorities	Share of resident population with foreign nationality on the total population in a specific municipality	2021 Census
Education	Share of the resident population with higher education completed on the total population	2021 Census
Income	Median value of gross reported income net of taxes per household	Ministry of Finance in 2021
Inequality	Gini coefficient as a proxy to measure inequality, which was computed based on the net reported income (after taxes) per household (%)	Ministry of Finance in 2021
Unemployment	Unemployment rate (%)	2021 Census
Housing with repair needed	Percentage of buildings needing repair	2021 Census
Buildings built before 1981	Percentage of building that were constructed before 1981	2021 Census

With regards to the income variable, the decision to consider the median value instead of the average is because the median is considered a robust statistic as it is not influenced by extreme values. If the data has a few extremely high or low values that may not be representative of the overall pattern, the median can provide a more robust measure. The income was decided to be considered after taxes, to account for the disposable income, which is key for assessing the actual purchasing power of individuals. This measure reflects the resources available for consumption, savings, and investment. Additionally, the measurement was chosen per household instead of per individual following Trapeznikova (2019). This author argues in favor of considering the household instead of the individual when assessing inequality because the household provides an implicit form of insurance against risk and it also allows for income pooling. The same reasoning was also followed for the variable measuring inequality.

4. Complementary data

In addition to land use and socioeconomic data, this analysis incorporates a third set of data. The study aims to explore the relationship between the characteristics of the population and the diverse ecosystem services associated with different land uses. However, measuring ecosystem services directly poses challenges. Therefore, land use is considered as a proxy to indirectly represent these services. To strengthen the analysis, data on the structural risk of fires and floods are introduced, which are indirectly related to ecosystem services. These indicators measure the percentage of a municipality's territory exposed to a very high, high, medium, low and insignificant risk (very low for the risk of fire dataset). Flood risk data are sourced from the open platform for public Portuguese data, while fire risk data are obtained from the Instituto da Conservação da Natureza e das Florestas (Dados.gov.pt n.d.) (ICNF n.d.).

VI. Results

1. Correlations between land use and socioeconomic indicators

1.1 Correlation between artificialized areas and socioeconomic indicators

The first correlation conducted was between the socioeconomic indicators illustrated before and the aggregated artificial areas, which correspond to the first class of the CLC dataset. The results from this first analysis are shown in *Table 2* and they suggest that areas with more artificial structures tend to be associated with higher educational levels, which may be explained by the fact that urban or developed areas often host education institutions and facilities. Furthermore, artificial areas show a strong positive correlation with population density, possibly because urban and developed regions typically have higher population concentrations. The positive correlation with the percentage of foreign population may suggest that urban regions may attract a more diverse population, as typically these areas have better infrastructure and services, in general. Additionally, income inequality is positively correlated with artificial areas, suggesting that more developed regions tend to have higher income inequality. The positive correlation with income suggests that areas with more artificial structures tend to have higher median incomes. Regarding the negative correlation with the percentage of buildings built before 1981, it may be explained by the fact that newer buildings could be associated with artificial areas. Lastly, artificial areas show an inverse correlation with the total dependency rate and the old dependency rate, indicating that regions with more artificial structures may have a lower dependency rates.

After analyzing in general the correlation with artificialized areas it is interesting to delve into it more in detail. The correlation between socioeconomic indicators and green urban areas, which is measured by the CLC variable 141, was performed and results can be seen in *Table 2*.

Table 2: Correlation between artificialized areas and socioeconomic indicators

	Artificial areas	Green urban areas
Population density	0.9216 (0.0000)***	0.2642 (0.0079)**
Total dependency ratio	-0.5625 (0.0000)***	-0.1795 (0.0740)
Old-age dependency ratio	-0.5820 (0.0000)***	-0.1743 (0.0828)
Share of minorities	0.2831 (0.0043)**	0.0459 (0.6501)
Education	0.5782 (0.0000)***	0.5501 (0.0000)***
Income	0.6102 (0.0000)***	0.4204 (0.0000)***
Inequality	0.4888 (0.0000)***	0.3932 (0.0001)***
Unemployment	-0.0504 (0.6186)	0.0450 (0.6565)
Housing with repair needed	0.0064 (0.9494)	0.0948 (0.3482)
Buildings built before 1981	-0.3759 (0.0001)***	-0.0503 (0.6191)

The positive correlation with education and income suggests that areas with more green urban spaces tend to have a population with higher educational levels and income. These findings are supported by hedonic price models' studies, which show that residents in higher-income neighborhoods, likely possessing higher education levels, may place a premium on living in areas with more green spaces and other amenities, contributing to the positive correlation observed in both income and education. In the paper by Franco and Macdonald (2018), a hedonic framework was employed to assess how tree canopy coverage and urban greenness influence the local housing market in Lisbon, with results showing that proximity to smaller neighborhood parks and larger forests positively impacts housing prices. The positive correlation with population density indicates that green urban areas are more prevalent in densely populated regions. This could be due to urban planning efforts to incorporate green spaces in areas with higher population concentrations. The positive correlation with the Gini coefficient suggests that there is a connection between income inequality and the presence of green urban areas. It may imply that more affluent or economically unequal areas are more likely to have green spaces. These claims may support a broad understanding of the relationships observed in the correlation analysis. However, to draw more concrete conclusions and understand the specific dynamics, additional specific information and in-depth analysis would be needed. Overall, these findings reinforce the importance of considering socioeconomic factors in the planning and management of green spaces, as highlighted by Hoffimann et al. (2017), where the socioeconomic disparities in the accessibility and quality of green spaces in Porto is discussed. The emphasis on the need for equitable distribution and quality of green spaces to promote community well-being and health aligns with the implications drawn from this correlation analysis.

1.2 Correlation between forests and semi-natural areas and socioeconomic indicators

The second aggregated class analyzed was class three, which includes forest and semi-natural areas. A correlation analysis was performed to explore the relationships between this class and the socioeconomic indicators that were illustrated before. The results are displayed in *Table 3*, and they show that the correlations reveal that areas classified as forest and semi-natural are associated with older housing, higher dependency indices (total and old), lower education levels, lower population density, lower shares of foreign population, lower income inequality (as indicated by the Gini coefficient), and lower income levels. Together, these results point out to lower-income uniform neighborhoods. These coefficients are the contrary to those obtained for the aggregated artificial areas, showing different or even opposite realities in these two areas. These results are interesting, highlighting the fact that ecosystem types classified as forests show the highest capacity to provide ecosystem services to the population, as illustrated in *Table 1*. Most of land uses in this class show the highest possible values regarding the provision of ecosystem goods and services to the populations. The presence in these areas of lower-income uniform neighborhoods may suggest that these services are not monetizable by the population living in that area, implying that they do not need to pay for them in order to enjoy them. This reflects the underlying market failures due to their public goods features implicitly assuming that the opportunity cost of using them is zero. This aligns with the existing literature, which shows that only a limited number of consumptive ecosystem services, specifically the direct use values of provisioning services, are assigned market prices (TEEB 2010).

Table 3: Correlation between artificialized areas, forests and seminatural areas and socioeconomic indicators

	Artificial areas	Forests and seminatural areas	Beaches, dunes and sand plains
Population density	0.9216 (0.0000)***	-0.4801 (0.0000)***	0.2406 (0.0159)*
Total dependency ratio	-0.5625 (0.0000)***	0.4566 (0.0000)***	-0.2168 (0.0303)*
Old-age dependency ratio	-0.5820 (0.0000)***	0.5001 (0.0000)***	-0.2410 (0.0157)*
Share of minorities	0.2831 (0.0043)**	-0.2286 (0.0221)*	0.1143 (0.2576)
Education	0.5782 (0.0000)***	-0.4715 (0.0000)***	0.1826 (0.0690)
Income	0.6102 (0.0000)***	-0.4207 (0.0000)***	0.1074 (0.2873)
Inequality	0.4888 (0.0000)***	-0.6180 (0.0000)***	0.3419 (0.0005)***
Unemployment	-0.0504 (0.6186)	-0.0138 (0.8920)	0.0967 (0.3384)
Housing with repair needed	0.0064 (0.9494)	0.0342 (0.7353)	-0.1003 (0.3209)
Buildings built before 1981	-0.3759 (0.0001)***	0.3044 (0.0021)**	-0.2786 (0.0050)**

When disaggregating the data in this class, it is interesting to investigate the component of beaches, dunes and sand plains (331). The correlations, displayed in *Table 3*, suggest that the regions with a larger presence of beaches, dunes, and sand plains are associated with higher population density and income inequality. Conversely, they may have lower percentages of older houses, lower total dependency rates, and lower old dependency rates.

With regard to forests, it is interesting to differentiate the different forest species in Portugal to understand how each of them correlates with socioeconomic indicators. In particular, as it was shown by Ribeiro et al. (2007) the three major forest species of Portugal, that is, pine, cork oaks and eucalyptus should be considered separately. Unfortunately, in the CLC dataset it is only possible to differentiate between coniferous and broad-leaved forests, which include both cork, oaks and eucalyptus. When performing the correlation considering these two different classes, the only significant coefficient is that of the unemployment rate with respect to broad-leaved forests ($r = -0.3458$, $p < 0.001$), showing a negative correlation consistent with the literature's findings related to the economic importance of forests, in particular, their role in creating jobs (Nunes, 2019).

1.3 Correlation between wetlands, water bodies and socioeconomic indicators

Lastly, conducting the correlations between wetlands, water bodies and socioeconomic indicators produces interesting results. These classes contribute to the provision of ecosystem services to the population living in the close surroundings, as shown in *Table 1,* generating large values for all four services' dimensions. As previously mentioned, consumptive ecosystem services are the only to which market prices are assigned, and, with this respect, water bodies including coastal lagoons, estuaries and sea and ocean are recognized for their value with regards to provision services, such as capture fisheries and aquaculture (TEEB 2010). Firstly, the correlation between socioeconomic indicators and the fifth class, which includes water bodies, both inland and marine, was conducted, and subsequently the correlation with the fourth class, which identifies wetlands, both inland and coastal, was performed.

The results displayed in *Table 4* show that the correlation with water bodies is significant only in the case of the Gini coefficient that measures inequality. In contrast, the correlation with wetlands showed a higher number of significant coefficients. These findings suggest that areas with wetlands tend to have higher educational levels, population density, income, and income inequality, while exhibiting lower dependency rates, particularly among older populations. The positive correlations found in wetland areas may suggest higher human activity and development in these regions. The two classes were subsequently broken down based on the MAES ecosystem types outlined by Maes et al. (2020) (*Table A1*). Variables representing inland wetlands, rivers and lakes, marine inlets and transitional waters, as well as coastal, shelves, and open ocean ecosystems were considered. When considering rivers and lakes, which in the CLC classification would correspond to inland waters, the results show that the only significative coefficient found is the Gini coefficient, displaying similar results to the ones obtained by considering water bodies. Marine inlets and transitional waters consist of coastal wetlands, coastal lagoons and estuaries When analyzing each single indicator, results show that coastal lagoons only show a significant coefficient with regards to the Gini coefficient ($r = 0.2986$, $p < 0.01$), while for estuaries no significant coefficients were found. About coastal wetlands, instead, the coefficients found significant are the same as for the aggregated wetlands and do not differ much from those values, also influencing the correlation's results regarding the aggregated class of marine inlets and transitional waters. Similar results are also found for inland wetlands. Lastly, the variable coastal, shelves and open ocean, corresponding to sea and ocean in the CLC classification, shows a positive correlation with population density and the Gini coefficient, while it exhibits negative coefficients for the percentage of houses build before 1981, the total dependency rate and the old dependency rate. This indicates areas characterized by higher human presence, newer buildings, lower dependency rates, and higher income inequality.

Table 4: Correlation between waterbodies, wetlands and socioeconomic indicators

	Water bodies	Wetlands	Inland wetlands	Marine inlets and transitional waters	Rivers and lakes	Coastal, shelves and open ocean
Population density	0.1629 (0.1054)	0.2788 (0.0050)**	0.2261 (0.0237)*	0.2608 (0.0088)**	-0.0603 (0.5510)	0.2455 (0.0138)*
Total dependency ratio	-0.1286 (0.2024)	-0.2460 (0.0136)*	-0.2526 (0.0112)*	-0.2398 (0.0163)*	0.1449 (0.1502)	-0.2024 (0.0434)*
Old-age dependency ratio	-0.1366 (0.1754)	-0.2453 (0.0139)*	-0.2592 (0.0092)**	-0.2420 (0.0153)*	0.1436 (0.1542)	-0.2301 (0.0213)*
Share of minorities	0.0380 (0.7076)	0.1025 (0.3103)	0.1763 (0.0794)	0.0751 (0.4574)	-0.0092 (0.9277)	0.1706 (0.0897)
Education	0.1229 (0.2231)	0.3484 (0.0004)***	0.3293 (0.0008)***	0.2920 (0.0032)**	-0.0987 (0.3331)	0.1511 (0.1334)
Income	0.0872 (0.3883)	0.2496 (0.0123)*	0.2642 (0.0079)**	0.1981 (0.0481)*	-0.0101 (0.9208)	0.0454 (0.6534)
Inequality	0.2182 (0.0292)*	0.3372 (0.0006)***	0.2776 (0.0052)**	0.3550 (0.0003)***	-0.2141 (0.0324)*	0.3168 (0.0013)**
Unemployment	-0.0900 (0.3733)	-0.0132 (0.8962)	-0.0630 (0.5337)	-0.0328 (0.7463)	-0.1281 (0.2041)	0.0932 (0.3565)
Housing with repair needed	-0.1491 (0.1388)	-0.0385 (0.7035)	0.0944 (0.3503)	-0.0759 (0.4526)	-0.1395 (0.1662)	-0.0793 (0.4331)
Buildings built before 1981	-0.0513 (0.6121)	-0.1565 (0.1200)	-0.1939 (0.0532)	-0.1343 (0.1827)	0.1399 (0.1650)	-0.3791 (0.0001)***

2. Correlations between environmental risks and land use

In the analysis descripted above, when correlating socioeconomic vulnerabilities with ecosystem services, the variables utilized as proxy for these services are the various types of land cover. However, the challenge arises from the fact that the relation between land cover and ecosystem services is not straightforward, making land cover an indirect indicator of ecosystem service provision. To enhance this analysis, a potential approach is to introduce additional variables, such as flood risk and fire risk, which are indirectly related to ecosystem services. Incorporating these data improves the understanding of how specific land use patterns influence susceptibility to environmental hazards and identify the communities most impacted. Performing correlations between flood and fire risk and distinct land uses could indirectly inform on the contribution of these land covers to specific ecosystem services related to flood control or fire prevention.

In general, aligning with the findings from the literature review, areas proximate to wetlands and inland waters are more susceptible to floodings. This is supported by the results indicating a significant correlation between flood risk and the presence of wetlands and water bodies (refer to *Table A3* in the Appendix). What is nevertheless interesting to observe is that outcomes also reveal a strong and positive correlation between wetlands and low flood risk ($r = 0.8282$, $p < 0.001$), with a larger coefficient than that observed for high flood risk. This could be explained by the role wetlands play in provisioning ecosystem services, particularly flood protection, underscoring their contribution to mitigate the elevated risks associated with this territory (refer to *Table 1*). Moreover, in the correlation analysis between regions prone to high flood risk and socioeconomic indicators, the population in these areas appears to be wealthier, more educated and presents lower dependency indexes and higher inequalities (see *Table A4*). This pattern mirrors the correlations observed between wetlands and socioeconomic indicators, underscoring the interconnectedness of wetlands and flood-prone areas. These socioeconomic characteristics signal higher human activity in these zones, and considering the concentrated distribution of the population and the large economic relevance of these areas, the potential threats and vulnerabilities to human settlements and infrastructure are heightened, contributing to the overall vulnerability of the territory.

Additionally, an analysis of the correlation between aggregated classes of land use and structural fire risk was conducted (refer to Table A6). The findings reveal that areas with a significant presence of forests and semi-natural areas show a positive correlation with very high fire risk. Furthermore, when exploring the correlation between fire risk and socioeconomic indicators, the findings indicate that residents in areas facing a high level of fire risk tend to have lower income, lower education levels, higher dependency ratios, a greater proportion of buildings constructed before 1981, less inequality in wealth distribution, and lower population density (refer to Table A6). These outcomes align with the correlation patterns observed for forests and semi-natural areas, underscoring the interconnection between forests and regions with elevated fire risk. These results show a heightened vulnerability of the population in such areas, attributed to both the increased risk of fires and the prevailing socioeconomic conditions.

To conclude, these findings aim at contributing to better understand the relationship between land use types and socioeconomic indicators, mediated by structural floods and fires risks They can provide guidance to further investigations regarding the specific mechanisms influencing vulnerability and resilience in different environmental contexts.

3. Case study: Aveiro and Beira-Baixa sub-regions

The analysis conducted show broad patterns with regards to the whole Centro region. However, it is interesting to disaggregate these at the sub-region level to see how the correlations behave. When looking at the distribution of wetlands in the Centro region (Figure A11) the map shows a concentration primarily in the Aveiro sub-region, where the Ria de Aveiro lagoon is located. The literature previously analyzed showed how the Aveiro lagoon's area is more prone to be subject to floodings, hence being more vulnerable. For this reason, it is interesting to focus on it. Results from the correlation between socioeconomic indicators and land uses support our previous findings, showing that wetlands are positively correlated with education, income and inequality. Moreover, wetlands areas are again highly correlated with low risk of flood, highlighting the role of wetlands as flood buffers.

Additionally, specific attention is directed towards the sub-region of Beira Baixa, driven by the distinctive characteristics of its population. The population density in this area is notably low at 17.5 individuals per km², significantly lower than the Centro Region's density of 79.0 (Pordata, n.d.). Moreover, Beira Baixa is characterized by the highest percentage of individuals over 65 years in the Centro region, averaging 33.5%, compared to the regional average of 27.0% (Pordata, n.d.). What is interesting to highlight are the unique traits of the population, especially the elderly residing in abandoned rural areas. Despite potential low disposable income, these people often own assets like houses, land, trees, and cattle, contributing to their overall wealth and reflecting a subsistence household economy. Recognizing these characteristics is essential, as conclusions solely based on disposable income estimates may inadequately represent their economic status. These distinctive features are closely tied to the population's vulnerability to extreme events like fires, where the impact on their wealth, in terms of property and animals, outweighs the influence on disposable income, like retirement pensions. This heightened vulnerability exposes them to the severe consequences of such events, impacting their resilience capacity. Unfortunately, our current analysis faces limitations in capturing this phenomenon due to data constraints. Nevertheless, it underscores an interesting area for further exploration in subsequent studies.

VII. Discussion

The findings indicate that individuals with higher wealth and education levels tend to reside in proximity to coastal areas and artificial zones. Conversely, those considered more vulnerable are concentrated in the inland areas of the Centro region, where the territory exhibits a higher prevalence of forestry coverage. Moreover, the analysis showed how the coastal territory is more prone to be subject to floodings, highlighting the vulnerability of this area. These results relate to the literature's findings highlighted by Ferreira, O' et al. (2008) and Rocha C. et al. (2019), which show that regions with significant human occupation are more prone to the risks associated with floodings. In this sense, the intensified economic activity and human presence in these areas amplifies the potential impacts of flood and overwash events. Therefore, this emphasizes the vulnerability of these regions to the adverse effects of sea-level rise and flooding, underlining the need for comprehensive strategies that balance sustainable development with effective risk management and adaptation measures. Policy makers should support policies that foster the implementation and restoration of nature-based solutions for wetlands and water bodies, to enhance community resilience in face of environmental challenges. The 'Investing in nature-based solutions' report by the European Investment Bank suggests two primary ways in which the EU can support nature-based solutions: financial guidance and policy guidance (European Investment Bank 2023). More specifically on policy guidance, it points out at the role that the EU legislation could play in mainstreaming nature-based solutions. One example suggested, among many, is for the European Commission to recommend prioritizing nature-based alternatives over exclusively grey infrastructure solutions in legislative frameworks like the Floods Directive.

Another finding of this study underscores the correlation between forest and semi-natural areas and the risk of fires. The presence of vulnerable population in these areas worsen the consequences of these events, with implications on the resilience capacity of the communities living in those areas. These outcomes align with existing literature on the relationship between fire risk and socioeconomic indicators. Amil et al., (2022) conducted a study to explore the spatial relationship between social vulnerability and wildfire risk for Galicia, Spain, at the municipality level. Their findings reveal that, while municipalities with a higher proportion of the Wildland-Urban Interface (WUI) generally have lower social vulnerability, areas with both high social vulnerability and high wildfire risk, concentrated in the south, are characterized by low population density, remote locations, and a relatively high percentage of elderly residents. The study advocates for targeted policy actions addressing financial resources, social isolation of the elderly, and weak healthcare infrastructure in these vulnerable rural areas. Furthermore, the analysis suggests that land use planning, infrastructure design, and housing development considerations can mitigate the impacts of catastrophic wildfires. The spatial linkages identified underscore the need for a diverse, location-specific range of actions to effectively address wildfire-related socioeconomic concerns in socially vulnerable communities.

VIII. Conclusion

The purpose of this study was to map the vulnerabilities of the Portuguese Centro region's population, by exploring correlations between socioeconomic indicators and land use patterns, which identify the many ecosystem services offered by different land covers. Additionally, the analysis focused on the relationship between land uses, vulnerabilities of the population and environmental hazards such as flood and risk. This study has revealed significant patterns in the distribution of wealth, education, and other metrics across the Centro region of Portugal, highlighting the role of land use in shaping these dynamics. Coastal and urban areas attract wealthier and more educated populations, while inland regions with higher forest coverage exhibit greater vulnerability. The analysis underscores the heightened susceptibility of coastal territories to flooding, emphasizing the need for comprehensive strategies balancing sustainable development with effective risk management. Additionally, the correlation between forested areas and fire risk emphasizes the importance of targeted policies addressing vulnerabilities in socially susceptible communities.

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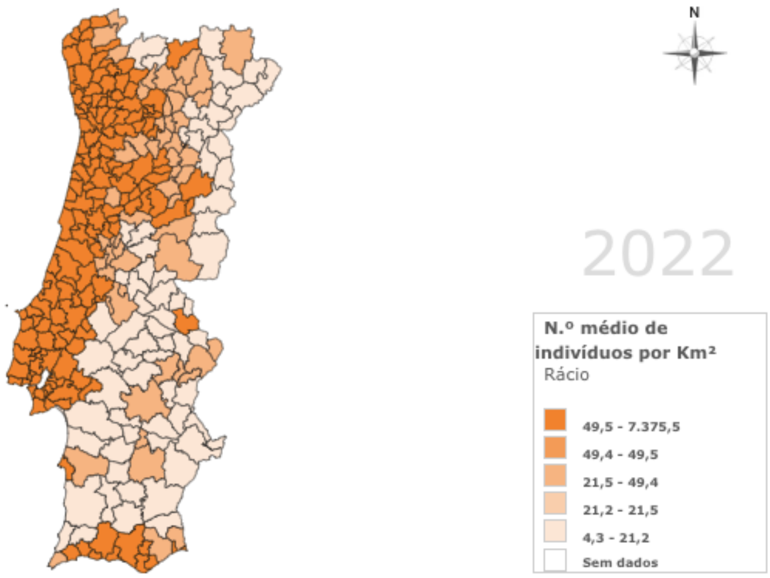
Appendix

Figure A1: Densidade populacional



Reference: Pordata

Figure A2: Geographical position of the Centro Region in Portugal

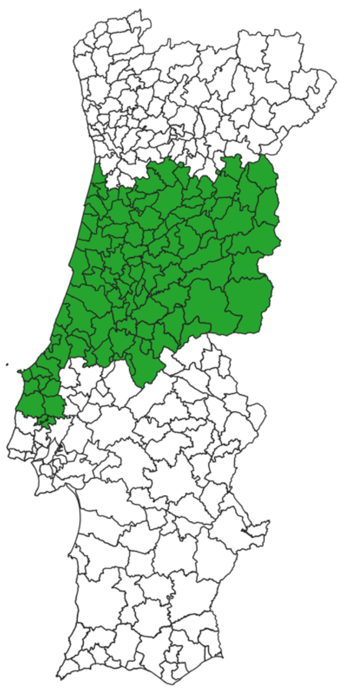


Figure A3: Distribution of the Intermunicipal Communities in the Centro Region

Reference: CCDRC

Figure A4: Inequality

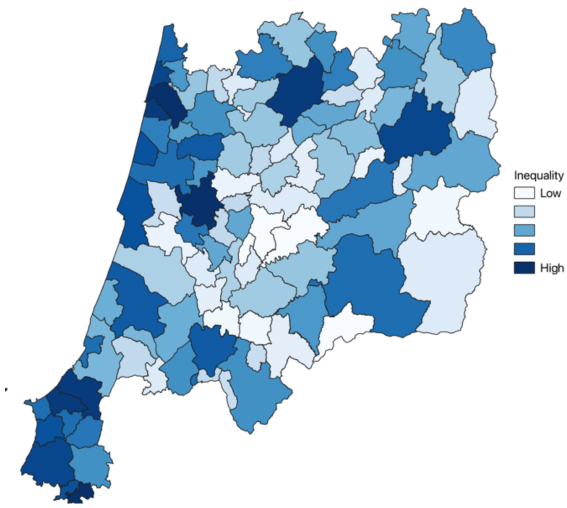


Figure A5: Share of minorities

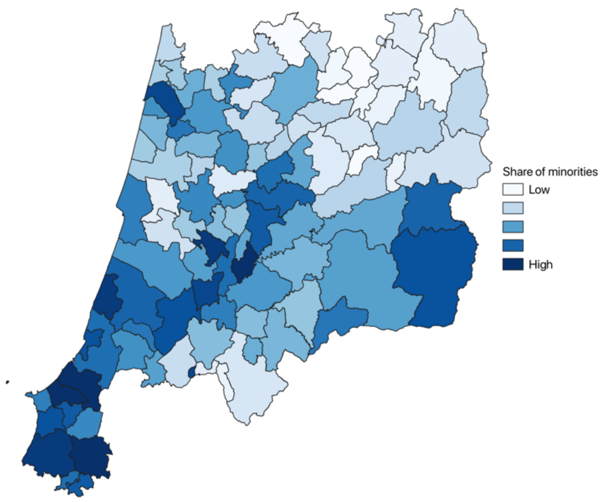


Figure A6: Unemployment

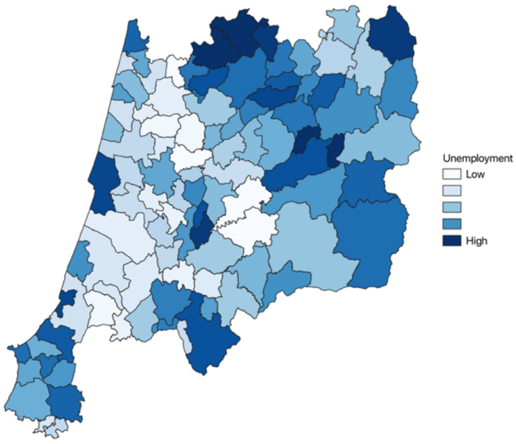


Figure A7: Old dependency rate

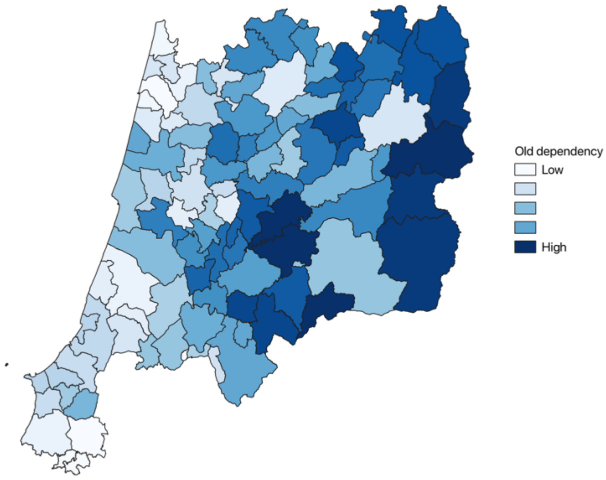


Figure A8: Total dependency rate

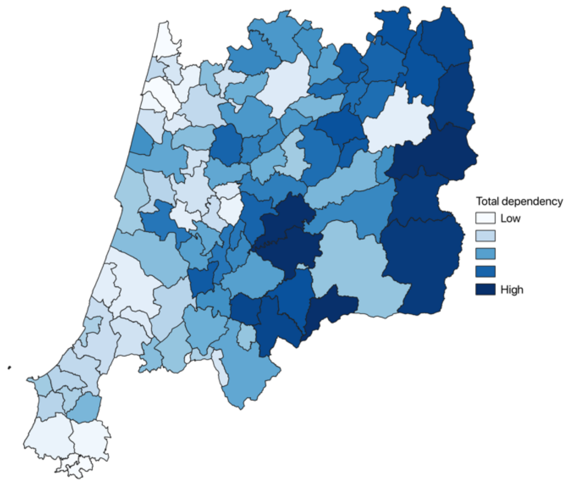


Figure A9: Buildings built before 1981

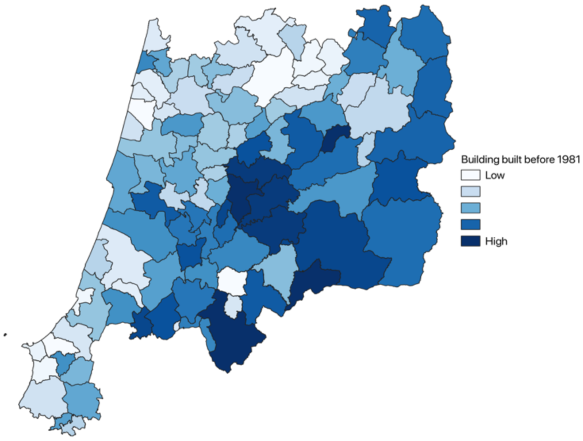


Figure A10: Buildings with repair need

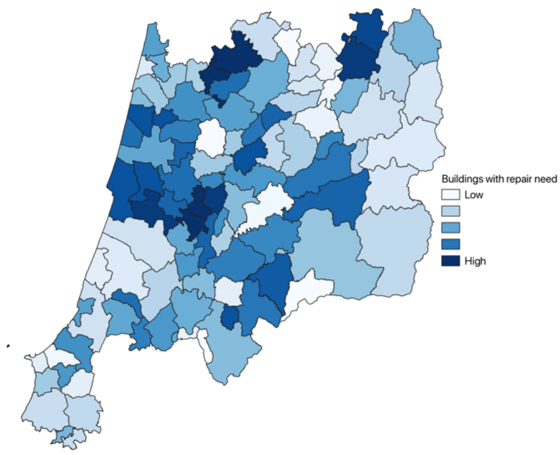


Table A1: Correspondence between CORINE land cover (CLC) classes and MAES ecosystem types

CLC level 1	CLC level 2	CLC level 3	MAES Level 1	MAES Level 2
Artificial surfaces	Urban fabric	Continuous urban fabric	Terrestrial	Urban ecosystems
		Discontinuous urban fabric		
	Industrial, commercial and transport units	Industrial or commercial units		
		Road and rail networks and associated land		
		Port areas		
		Airports		
	Mine, dump and construction sites	Mineral extraction sites		
		Dump sites		
		Construction sites		
	Artificial, non-agricultural vegetated areas	Green urban areas		
		Sport and leisure facilities		
Agricultural areas	Arable land	Non-irrigated arable land		Cropland
		Permanently irrigated land		
		Rice fields		
	Permanent crops	Vineyards		
		Fruit trees and berry plantations		
		Olive groves		
	Pastures	Pastures		Grassland
	Heterogeneous agricultural areas	Annual crops associated with permanent crops		Cropland
		Complex cultivation patterns		
		Land principally occupied by agriculture, with significant areas of natural vegetation		
		Agro-forestry areas		
Forest and semi natural areas	Forests	Broad-leaved forest		Forest
		Coniferous forest		
		Mixed forest		
	Scrub and/or herbaceous vegetation associations	Natural grasslands		Grassland
		Moors and heathland		Heathland and shrub
		Sclerophyllous vegetation		
		Transitional woodland-shrub		Forest
	Open spaces with little or no vegetation	Beaches, dunes, sands		Sparsely vegetated land
		Bare rocks		
		Sparsely vegetated areas		
		Burnt areas		
		Glaciers and perpetual snow		
Wetlands	Inland wetlands	Inland marshes		Inland wetlands
		Peat bogs		
	Maritime wetlands	Salt marshes	Marine	Marine inlets and transitional water
		Salines		
		Intertidal flats		
Water bodies	Inland waters	Water courses	Freshwater	Rivers and lakes
		Water bodies		
	Marine waters	Coastal lagoons	Marine	Marine inlets and transitional water
		Estuaries		
		Sea and ocean		Coastal, shelf and open ocean

Reference: Maes et al., 2020

Table A2: Matrix for the assessment of the different land cover types' capacities to provide selected ecosystem goods and services. The assessment scale reaches from 0 = rosy colour = no relevant capacity of the land cover type to provide this particular ecosystem service, 1 = grey green = low relevant capacity, 2 = light green = relevant capacity, 3 = yellow green = medium relevant capacity, 4 = blue green = high relevant capacity and 5 = dark green = very *high relevant capacity. In the rows between the assessments (yellow colour), sums for the individual ecosystem services groups were calculated. In the table, ecological integrity is similar to the component of supporting services.*

	Ecological Integrity Σ	Abiotic heterogeneity	Biodiversity	Biotic waterflows	Metabolic efficiency	Exergy Capture (Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	Provisioning services Σ	Crops	Livestock	Fodder	Capture Fisheries	Acquaculture	Wild Foods	Timber	Wood Fuel	Energy (Biomass)	Biochemicals / Medicine	Freshwater
Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discontinuous urban fabric	7	1	1	1	1	1	1	1	3	1	0	1	0	0	1	0	0	0	0	0
Industrial or commercial units	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Road and rail networks	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port areas	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Airports	7	1	1	1	1	1	2	0	1	0	0	1	0	0	0	0	0	0	0	0
Mineral extraction sites	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dump sites	8	2	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Construction sites	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green urban areas	18	3	3	2	1	4	3	2	2	0	0	0	0	0	1	0	1	0	0	0
Sport and leasure facilities	16	2	2	2	1	4	3	2	0	0	0	0	0	0	0	0	0	0	0	0
Non-irrigated arable land	22	3	2	3	4	5	1	4	21	5	5	5	0	0	0	0	0	5	1	0
Permanently irrigated land	21	3	2	5	2	5	1	3	18	5	5	2	0	0	0	0	0	5	1	0
Ricefields	20	3	2	5	1	5	1	3	7	5	0	2	0	0	0	0	0	0	0	0
Vineyards	14	3	2	3	1	3	0	2	5	4	0	0	0	0	0	0	1	0	0	0
Fruit trees and berries	21	4	3	4	2	3	2	3	13	5	0	0	0	0	0	4	4	0	0	0
Olive groves	17	3	2	3	2	3	1	3	12	4	0	0	0	0	0	4	4	0	0	0
Pastures	24	2	2	4	5	5	2	4	10	0	5	5	0	0	0	0	0	0	0	0
Annual and permanent crops	18	2	2	3	2	4	2	3	20	5	5	5	0	0	0	0	0	5	1	0
Complex cultivation patterns	20	4	3	3	2	4	1	3	9	4	0	3	0	0	0	0	0	0	2	0
Agriculture& natural vegetation	19	3	3	3	2	3	2	3	21	3	3	2	0	0	3	3	3	3	1	0
Agro-forestry areas	27	4	4	4	3	4	4	4	14	3	3	2	0	0	0	3	3	0	0	0
Broad-leaved forest	31	3	4	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0
Coniferous forest	30	3	4	4	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0
Mixed forest	32	3	5	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0
Natural grassland	30	3	5	4	4	4	5	5	5	0	3	0	0	0	2	0	0	0	0	0
Moors and heathland	30	3	4	4	5	4	5	5	10	0	2	0	0	0	1	0	2	5	0	0
Sclerophyllous vegetation	21	3	4	2	3	3	4	2	8	0	2	0	0	0	1	0	2	0	3	0
Transitional woodland shrub	21	3	4	2	3	3	4	2	5	0	2	0	0	0	1	0	2	0	0	0
Beaches, dunes and sand plains	10	3	3	1	1	1	0	1	2	0	0	0	0	0	0	0	0	2	0	0
Bare rock	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sparsely vegetated areas	9	2	3	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Burnt areas	6	2	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Glaciers and perpetual snow	3	2	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	5
Inland marshes	25	3	2	4	4	4	3	5	7	0	2	5	0	0	0	0	0	0	0	0
Peatbogs	29	3	4	4	4	4	5	5	5	0	0	0	0	0	0	0	0	5	0	0
Salt marshes	23	2	3	4	3	3	3	5	2	0	2	0	0	0	0	0	0	0	0	0
Salines	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Intertidal flats	13	2	3	0	2	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0
Water courses	18	4	4	0	3	3	3	1	12	0	0	0	3	0	4	0	0	0	0	5
Water bodies	23	4	4	0	4	4	3	4	12	0	0	0	3	0	4	0	0	0	0	5
Coastal lagoons	25	4	4	0	5	5	3	4	16	0	0	0	4	5	4	0	0	3	0	0
Estuaries	21	3	3	0	5	5	3	2	17	0	0	0	5	5	4	0	0	3	0	0
Sea and ocean	15	2	2	0	3	3	4	1	11	0	0	1	5	5	0	0	0	0	0	0

	Regulating services Σ	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	Cultural services Σ	Recreation& Aesthetic Values	Intrinsic Value of Biodiversity
Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0
Discontinuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial or commercial units	0	0	0	0	0	0	0	0	0	0	0	0	0
Road and rail networks	0	0	0	0	0	0	0	0	0	0	0	0	0
Port areas	3	0	0	3	0	0	0	0	0	0	1	1	0
Airports	0	0	0	0	0	0	0	0	0	0	0	0	0
Mineral extraction sites	0	0	0	0	0	0	0	0	0	0	0	0	0
Dump sites	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction sites	0	0	0	0	0	0	0	0	0	0	0	0	0
Green urban areas	11	2	1	0	2	1	2	1	1	1	3	3	0
Sport and leasure facilities	9	1	1	0	2	1	1	1	1	1	5	5	0
Non-irrigated arable land	5	2	1	1	1	0	0	0	0	0	1	1	0
Permanently irrigated land	5	3	1	1	0	0	0	0	0	0	1	1	0
Ricefields	4	2	0	0	2	0	0	0	0	0	1	1	0
Vineyards	3	1	1	0	1	0	0	0	0	0	5	5	0
Fruit trees and berries	19	2	2	2	2	2	2	1	1	5	5	5	0
Olive groves	7	1	1	0	1	1	1	1	1	0	5	5	0
Pastures	8	1	1	1	1	0	4	0	0	0	3	3	0
Annual and permanent crops	7	2	1	1	1	1	1	0	0	0	1	1	0
Complex cultivation patterns	5	2	1	1	1	0	0	0	0	0	2	2	0
Agriculture& natural vegetation	13	3	2	1	2	1	3	0	1	0	5	2	3
Agro-forestry areas	13	2	1	1	1	1	2	1	1	3	3	3	0
Broad-leaved forest	39	5	4	3	2	5	5	5	5	5	10	5	5
Coniferous forest	39	5	4	3	2	5	5	5	5	5	10	5	5
Mixed forest	39	5	4	3	2	5	5	5	5	5	10	5	5
Natural grassland	22	2	3	1	1	0	5	5	5	0	6	3	3
Moors and heathland	20	4	3	2	2	0	0	3	4	2	10	5	5
Sclerophyllous vegetation	7	2	1	1	1	0	0	0	0	2	6	2	4
Transitional woodland shrub	3	1	0	0	0	0	0	0	0	2	4	2	2
Beaches, dunes and sand plains	6	0	0	5	1	0	0	0	0	0	7	5	2
Bare rock	3	0	0	1	1	0	0	0	1	0	4	4	0
Sparsely vegetated areas	3	1	0	1	1	0	0	0	0	0	0	0	0
Burnt areas	1	1	0	0	0	0	0	0	0	0	0	0	0
Glaciers and perpetual snow	10	3	3	0	4	0	0	0	0	0	5	5	0
Inland marshes	14	2	2	4	2	0	0	4	0	0	0	0	0
Peatbogs	24	4	5	3	3	0	0	3	4	2	8	4	4
Salt marshes	8	1	0	5	0	0	0	2	0	0	3	3	0
Salines	2	2	0	0	0	0	0	0	0	0	2	2	0
Intertidal flats	7	1	0	5	0	0	0	1	0	0	4	4	0
Water courses	10	1	0	2	1	0	0	3	3	0	10	5	5
Water bodies	7	2	1	1	2	0	0	1	0	0	9	5	4
Coastal lagoons	5	1	0	4	0	0	0	0	0	0	9	5	4
Estuaries	9	0	0	3	0	0	0	3	3	0	7	4	3
Sea and ocean	13	3	5	0	0	0	0	5	0	0	6	4	2

Reference: Burkhard, Kroll and Windhorst 2009

Table A3: Correlation between flood risk and aggregated class of land use

	Very high	High	Medium	Low	Insignificant
Aggregated Wetlands	0.0480	0.6350	0.7368	0.8282	0.7825
	(0.6353)	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Aggregated Water Bodies	0.1427	0.5381	0.5446	0.5897	0.8531
	(0.1566)	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Aggregated Forests	0.0294	-0.2037	-0.2893	-0.2843	-0.2973
	(0.7717)	(0.0420)*	(0.0035)**	(0.0041)**	(0.0027)**
Aggregated Artificial Areas	0.1258	0.2721	0.3329	0.3123	0.3708
	(0.2124)	(0.0062)**	(0.0007)***	(0.0016)**	(0.0001)***

Table A4: Correlation between flood risk and socioeconomic indicators

	Very high	High	Medium	Low	Insignificant
Population density	0.0253	0.1590	0.2120	0.2182	0.2483
	(0.8031)	(0.1142)	(0.0342)*	(0.0292)*	(0.0128)*
Total dependency ratio	-0.1387	-0.2705	-0.2856	-0.2428	-0.2445
	(0.1688)	(0.0065)**	(0.0040)**	(0.0149)*	(0.0142)*
Old-age dependency ratio	-0.1343	-0.2653	-0.2854	-0.2438	-0.2481
	(0.1828)	(0.0076)**	(0.0040)**	(0.0145)*	(0.0128)*
Share of minorities	-0.1509	-0.0708	0.0028	0.0403	0.0104
	(0.1339)	(0.4841)	(0.9779)	(0.6909)	(0.9179)
Education	0.1312	0.2648	0.2491	0.2202	0.2168
	(0.1931)	(0.0078)**	(0.0125)*	(0.0277)*	(0.0302)*
Income	0.2838	0.3189	0.2758	0.2030	0.1660
	(0.0042)**	(0.0012)**	(0.0055)**	(0.0428)*	(0.0988)
Inequality	-0.0186	0.2215	0.2586	0.2585	0.3206
	(0.8545)	(0.0268)*	(0.0094)**	(0.0011)**	(0.2704)
Unemployment	0.0033	-0.0414	-0.0554	-0.0648	-0.0410
	(0.9738)	(0.6826)	(0.5838)	(0.5219)	(0.6851)
Housing with repair needed	-0.2321	-0.1845	-0.1245	-0.0865	-0.0817
	(0.0201)*	(0.0661)	(0.2170)	(0.3919)	(0.4190)
Buildings built before 1981	0.0635	0.0297	-0.0413	-0.0690	-0.0948
	(0.5300)	(0.7689)	(0.6832)	(0.4950)	(0.3479)

Figure A11: Distribution of wetlands

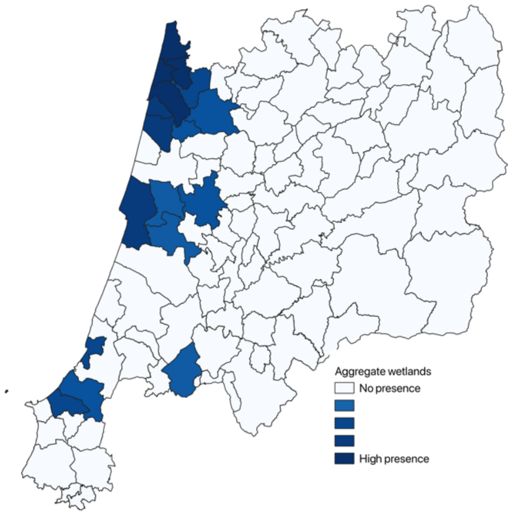


Figure A12: Distribution of water bodies

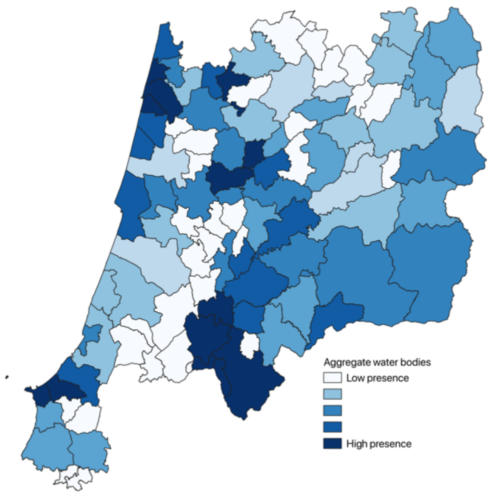


Figure A13: Distribution of the high risk of flood

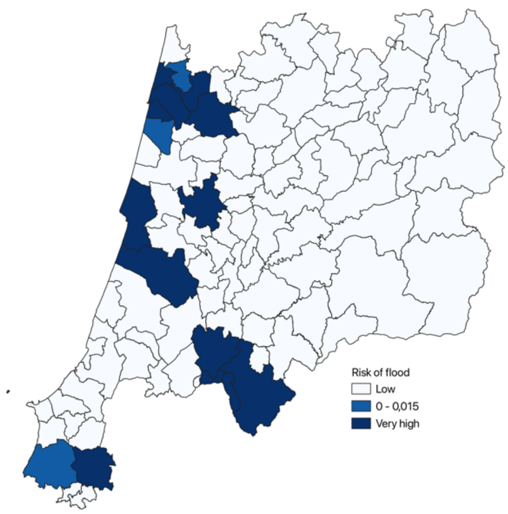


Figure A14: Distribution of the very low risk of flood

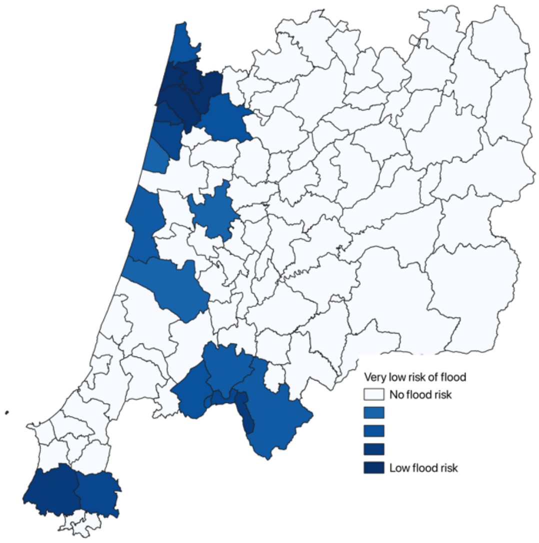


Table A5: Correlation between fire risk and aggregated class of land use

	Very high	High	Medium	Low	Very low
Aggregated Wetlands	-0.2308	-0.2766	-0.2810	0.0901	0.2568
	(0.0209)*	(0.0053)**	(0.0046)**	(0.3729)	(0.0099)**
Aggregated Water Bodies	-0.1808	-0.2029	-0.2938	0.0332	0.2278
	(0.0718)	(0.0429)*	(0.0030)**	(0.7429)	(0.0227)*
Aggregated Forests	0.7011	0.7202	-0.0777	-0.7033	-0.7286
	(0.0000)***	(0.0000)***	(0.4421)	(0.0000)***	(0.0000)***
Aggregated Artificial Areas	-0.5308	-0.5154	-0.2792	0.3627	0.6022
	(0.0000)***	(0.0000)***	(0.0049)**	(0.0002)***	(0.0000)***

Table A6: Correlation between fire risk and socioeconomic indicators

	Very high	High	Medium	Low	Very low
Population density	-0.4095	-0.4332	-0.2312	0.2136	0.4990
	(0.0000)***	(0.0000)***	(0.0206)*	(0.0329)*	(0.0000)***
Total dependency ratio	0.5139	0.3872	0.0854	-0.3979	-0.5001
	(0.0000)***	(0.0001)***	(0.3984)	(0.0000)***	(0.0000)***
Old-age dependency ratio	0.5485	0.4153	0.0779	-0.4375	-0.5278
	(0.0000)***	(0.0000)***	(0.4413)	(0.0000)***	(0.0000)***
Share of minorities	-0.2509	-0.2272	-0.0976	0.2506	0.2892
	(0.0118)*	(0.0230)*	(0.3342)	(0.0119)*	(0.0035)**
Education	-0.5154	-0.3548	-0.0470	0.3760	0.4376
	(0.0000)***	(0.0003)***	(0.6425)	(0.0001)***	(0.0000)***
Income	-0.5455	-0.3481	-0.0200	0.3647	0.4776
	(0.0000)***	(0.0004)***	(0.8435)	(0.0002)***	(0.0000)***
Inequality	-0.5007	-0.4863	0.0110	0.4856	0.4440
	(0.0000)***	(0.0000)***	(0.9135)	(0.0000)***	(0.0000)***
Unemployment	0.1471	-0.0252	0.0046	-0.0016	-0.1706
	(0.1441)	(0.8035)	(0.9634)	(0.9874)	(0.0897)
Housing with repair needed	0.0037	0.0835	-0.1205	-0.0149	0.0168
	(0.9708)	(0.4088)	(0.2325)	(0.8834)	(0.8679)
Buildings built before 1981	0.3026	0.2678	-0.1341	-0.2457	-0.1564
	(0.0022)**	(0.0071)**	(0.1833)	(0.0138)**	(0.1201)

Figure A15: *Distribution of forests and semi natural areas*

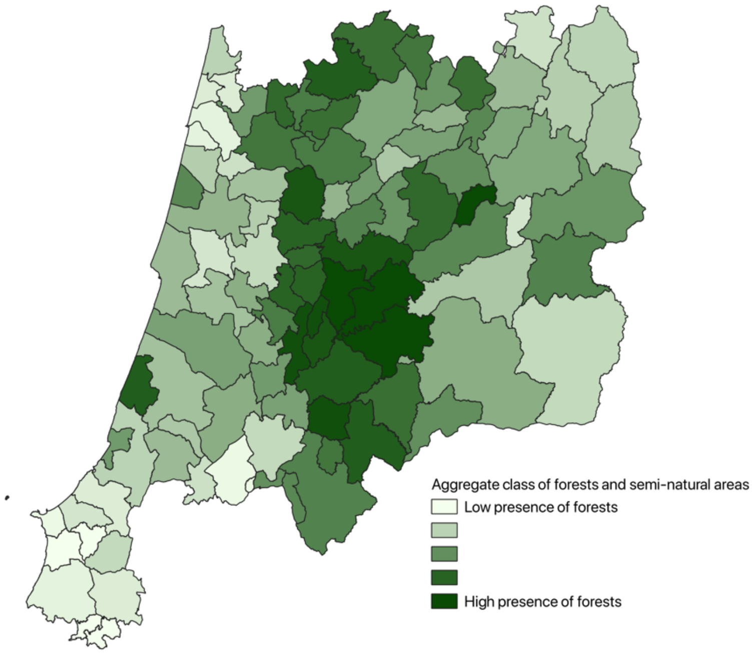


Figure A16: Distribution of the risk of fires

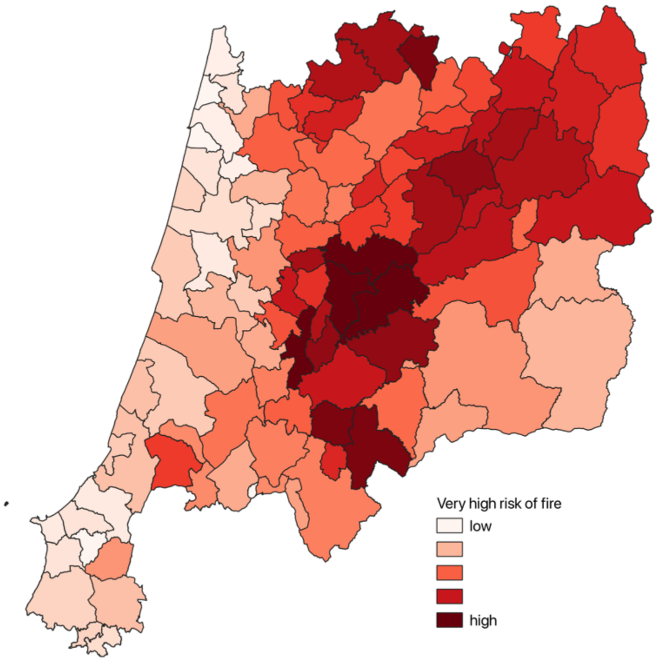


Figure A12: *Distribution of the risk of fires*

Table A6: Correlation between wetlands and socioeconomic indicators in the Aveiro sub-region

	Wetlands
Population density	0.5572
	(0.0750)
Total dependency ratio	-0.5711
	(0.0665)
Old-age dependency ratio	-0.5549
	(0.0765)
Share of minorities	0.5642
	(0.0706)
Education	0.8010
	(0.0030)**
Income	0.7515
	(0.0077)**
Inequality	0.7402
	(0.0092)**
Unemployment	0.4723
	(0.1424)
Housing with repair needed	-0.4253
	(0.1922)
Buildings built before 1981	-0.1261
	(0.7118)

Table A7: Correlation between flood risk and wetlands in the Aveiro sub-region

	Very high	High	Medium	Low	Very low
Aggregated Wetlands	0.5150	0.7711	0.6708	0.7521	0.6679
	(0.1050)	(0.0055)**	(0.0239)*	(0.0076)**	(0.0247)*