RISK ANALYSIS 5

Laura Asensio Martínez, Francisco García Sánchez, Nareme Herrera López, Cecilia Ribalaygua

5.1 CLIMATE EXPOSURE ANALYSIS

According to the definition in the 6th IPCC Assessment Report (MITECO, 2022[1]), **exposure** is defined as the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructures or economic, social or cultural assets in places and environments that could be adversely affected. For the present framework, this is directly related to the occurrence of climate-related hazard events, both for the current horizon and for the projected short-, medium- and long-term horizons. The steps to address the exposure analysis are as follows:

- **Identification of the set of elements** that may be affected by each of the priority climate hazards in the municipality of Santander. In this sense, and in general, five large sets of elements or exposure components have been identified:

  1. Resident population
  2. Residential buildings and housing
  3. Infrastructure, utilities and recreational facilities (roads, power lines, railway infrastructure, port area, buildings for public services, such as sports complexes, industrial or recreational facilities, etc.)
  4. Economic assets (shops, offices, industrial or agricultural buildings and hotels)
  5. Areas of interest and natural resources (beaches, coastal habitats, ecosystems, etc.).

- **Obtaining the set of exposed elements** by means of **cartographic intersection** in a Geographic Information System (GIS) environment for each of the hazard scenarios analysed in the previous section. As a result of this intersection, the level

[1] Climate Change: Impacts, Adaptation and Vulnerability (Summary Guide to the IPCC Sixth Assessment Report, Group II) Available at: https://www.miteco.gob.es/content/dam/miteco/es/cambio-climatico/publicaciones/publicaciones/guia_local_para_adaptacion_cambio_climatico_en_municipios_espanoles_tcm30-178446.pdf

of climatic exposure is obtained at the municipal level for each of the elements considered.

- **Calculation of indicators of the level of climate exposure** per census section per set of elements and climate scenario. This phase is dedicated to the generation of standardised climate exposure indicators at census section scale, understood as a representative measure of the level of climate exposure by group or set of elements.
- Calculation of the **Final Combined Exposure Index** for each of the climate scenarios considered. This includes an initial summation of the values obtained per component and a new normalisation of the data series, taking as maximum value the highest value of the census section for the most pessimistic scenario.

Below, we present Santander's exposure results for each of the hazards analysed.

EXTREME RAINFALL EVENTS

The exposure results for this hazard have been obtained through the analysis of **water-logging points** in extreme rainfall conditions with a special effect on floodable roads by census section.

For the study of the trend of extreme rainfall events in Santander, the periodicity of episodes of accumulated rainfall of 40 mm per day or more has been analysed for the historical series of 1985-2014. Thereafter, these results have been projected under local scenarios of climate change in the short, medium and long term.

According to the average of the climate models for the historical series, there are about 3 extreme rainfall events per year in the municipality of Santander. In the short term, an increase in the frequency of such events is expected, reaching values of 3.5 events/year on average for all the scenarios analysed. In the medium term, extreme rainfall events could occur between 3.5 and 4.5 times a year on average and depending on the scenario, and around 5 events/year in the long term in the most pessimistic scenario, SSP3-7.0.

TABLE 5.1. *Results of the Frequency of Extreme Rainfall Events in Santander*

HISTORICAL AVERAGE: 2.93878	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Short Term(2016-2040)	3.59749	3.56932	3.54964	3.51727
Medium Term (2041-2070)	3.63165	3.88392	4.18938	4.46125
Long Term (2071-2100)	3.73712	4.42478	4.83402	5.15589

Source: CINCc (UC) - FIC, 2024 based on local climate scenarios from the outputs of the sixth IPCC report

The analysis combines different processes and data sources, such as the analysis of **topographic subsidence conditions (Blue Spots)**, the analysis of waterlogging areas documented by PEMUSAN, and the evaluation of trends of extreme rainfall events under climate change conditions.

Based on its validation, it has been established that:

- The set of road sections coinciding with local depressions in the terrain or modelled blue points are considered to be floodable sections with high uncertainty.
- On the other hand, the roads coinciding with the flood risk areas established by the PEMUSAN are considered floodable sections with low uncertainty and high probability, with variation at P10 years.

Endorheic zones or sinkholes have been detected, using the 'Blue Spots' level 1 modelling methodology, which allows an initial detection of local depressions in the territory. For this purpose, a Digital Elevation Model (DEM) with a sufficient level of detail has been used to obtain an adequate representation of the transformations introduced by the layout of the road. For this purpose, the 2 m resolution Digital Terrain Model of the National Geographical Institute has been used, obtained from the LiDAR data (2nd Coverage).

From this DEM, the process needs to calculate those areas that, due to their relief morphology, could become waterlogged in situations of intense rainfall.

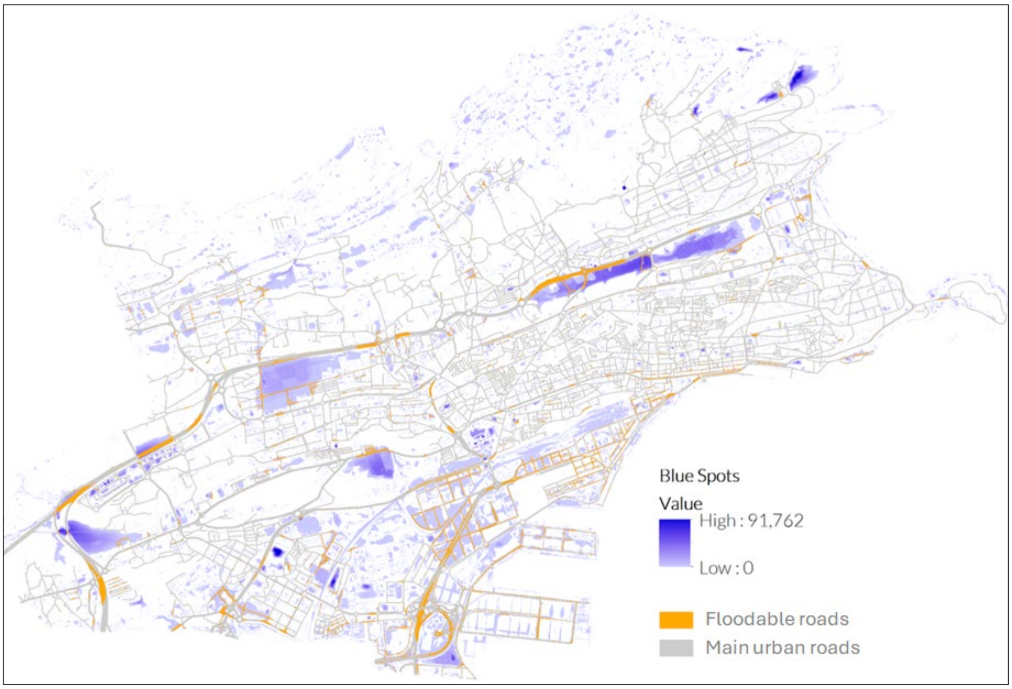


Figure 5.1. *Roads susceptible to waterlogging from Blue Spots modelling*
Source: CINCc (UC) - FIC, 2024.

Subsequently, by means of flood risk mapping provided by the Santander City Council, based on the Municipal Emergency Plan drawn up in 2016 and the geolocation of the records of interventions carried out from 2018 to 2022 by the Fire Brigade of the municipality, the points of conflict that may be exacerbated by periods of extreme rainfall in the future have been validated.

The process of delimiting flood-prone roads likely to flood due to extreme rainfall events in the municipality of Santander integrates the results obtained and analysed in the previous steps with the following criteria:

- The set of road sections coinciding with local depressions in the terrain or modelled blue points are considered to be flood-prone sections with **high uncertainty**. The possible occurrence of flooding along them will depend on the magnitude of an extreme rainfall event and the state of the drainage system and municipal sewers.
- All roads coinciding with the flood risk areas established by the PEMUSAN are considered flood-prone sections with low uncertainty and high probability, taking into account return periods of 10 years. These areas also assume a low capacity, insufficiency or deterioration of the municipal drainage system.
- The set of roads included in the intervention records, which coincide in geolocation and description, are considered to be flood-prone sections with low uncertainty and variable probability, as the magnitude of the events that generate these interventions are not documented.

The set of roads included in the intervention registers, which coincide in geolocation and description, are considered to be floodable stretches with low uncertainty and variable probability. The results show the surface area exposed in both conditions and the percentage of the total km^2 of roads in the affected municipality.

TABLE 5.2. *Characteristics according to level of uncertainty*

CATEGORY	DESCRIPTION	ESTIMATED Km^2 OF FLOODABLE ROADS	% OF TOTAL Km^2 OF MUNICIPAL ROADS IN THE MUNICIPALITY
Floodable roads with High Uncertainty	Roads located in local ground depressions. No flooding events have been documented.	0.645985	13.24%
Floodable roads with Low Uncertainty	Roads with documented flooding events at local level, PEMUSAN and Firefighters Intervention Record	0.17079	3.5%

Source: CINCc (UC) - FIC.

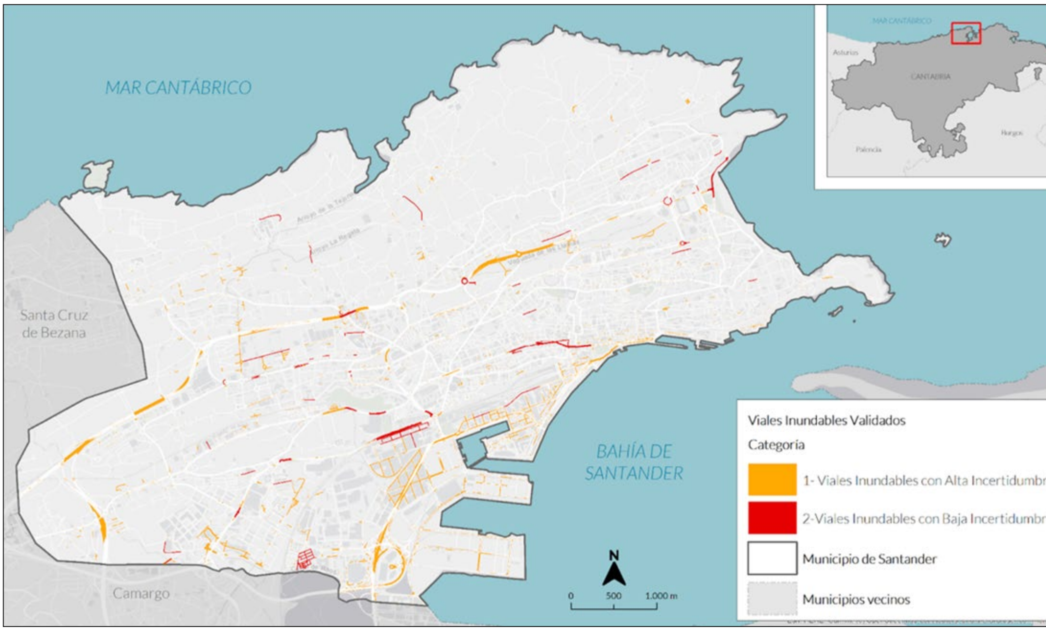


Figure 5.2. *Location of roads susceptible to waterlogging*
Source: CINCc (UC) - FIC, 2024.

This analysis and modelling does not consider the municipal drainage system on a detailed scale, such as **runoff** and **accumulation** of flow generated by extreme rainfall events, considering current and future conditions for different return periods, as this technical information is not managed by the entity managing the drainage network. However, in technical meetings held with local technical managers, the current capacity of the system to resolve specific flooding events and adequately drain the public space has been reported. In any case, the information accumulated is sufficient for the municipality to have a map of exposure that allows it to focus on and prioritise strategies for action

FLUVIAL FLOODING

For the fluvial flooding areas analysed, two main sets of **exposure elements** or components have been identified:

1. **Road infrastructure**, especially roads and railway infrastructure. The base cartography comes from the National Topographic Base at detailed scale (IGN, 2022).
2. **Economic assets**, specifically herbaceous crop areas, and natural resources, specifically natural land areas covered by woodland, scrubland, grassland or natural pasture. The base mapping is from the high-resolution SIOSE Land Cover and Uses (PNOA, 2017).

Exposed Road Infrastructure

A total of 6 sections of **secondary paths**, with a length of 381.3 metres, are located in areas threatened by river flooding within the municipality of Santander. The cutting off of these roads due to fluvial flooding events could temporarily limit access to certain nearby private properties.

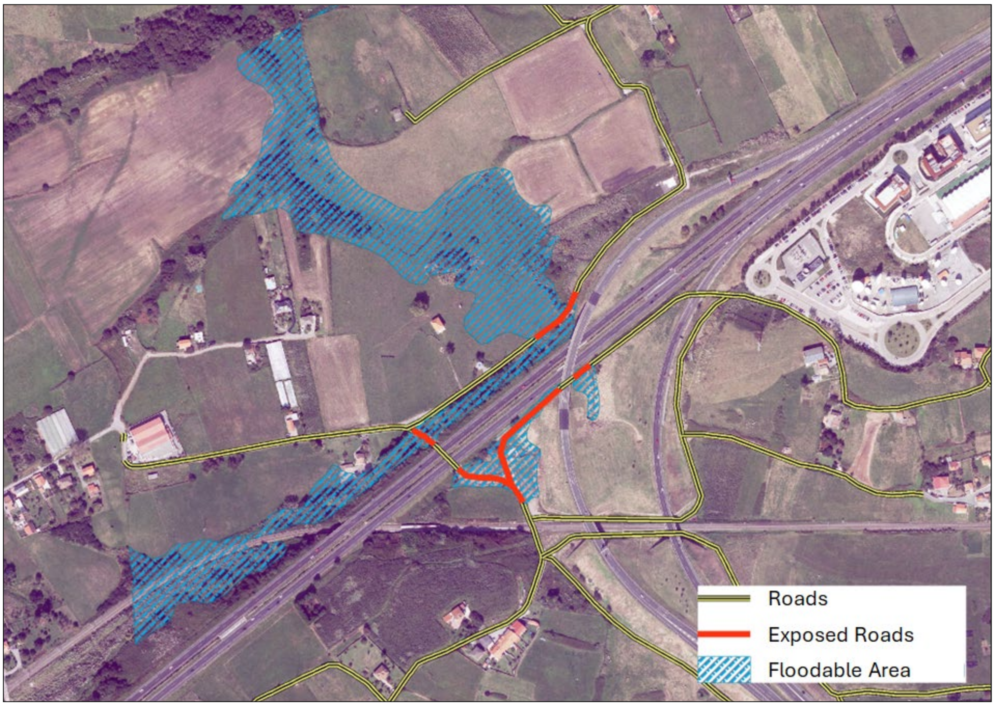


Figure 5.3. *Detail of the section of the conventional railway line that is located in areas of river flooding*

Source: CINCc (UC) - FIC, 2024.

In addition, a small section of the **conventional railway** line with a length of 152.5 metres is also exposed to the hazard of fluvial flooding, which specifically corresponds to the first section of the entrance to the municipality at its western end. In this case, although the length of the section is shorter, the occasional flooding could generate a temporary interruption in the regular transit of the railway line.

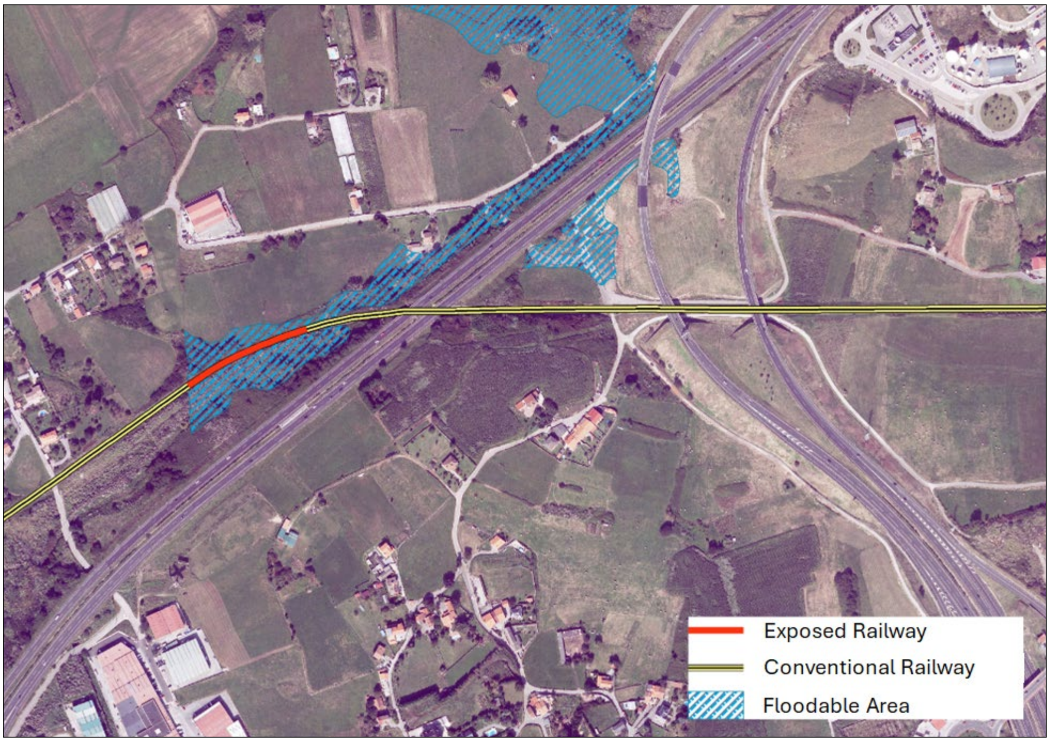


Figure 5.4. *Detail of the section of the conventional railway line that is located in areas of river flooding.*

Source: CINCc (UC) - FIC, 2024.

Exposed Crops and Exposed Natural Terrestrial Areas

TABLE 5.3. *Distribution of vegetation cover in the flood zone*

COVERAGE	AREA (Ha)
Woodland	0.08361
Herbaceus crops	0.074942
Scrub	0.204449
Pasture	1.918821
Pasture - scrub	1.622782
Grassland	2.170966
Land with little or no vegetation	1.342482
Artificial green area and urban treees	0.048441

Source: CINCc (UC) - FIC, 2024.

The fluvial flooding area contains an area of 749.4 m^2 for arable crops and a remaining area of 7.34 ha with various natural vegetation covers, including natural grasslands, pastures and scrubland.

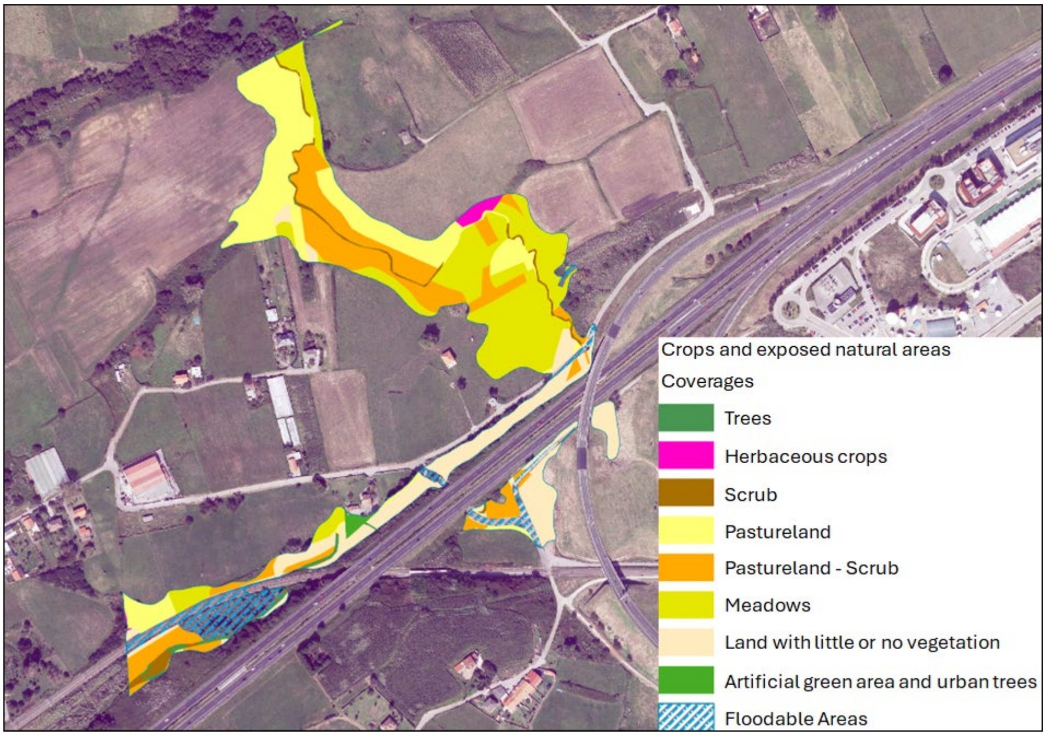


Figure 5.5. *Crops and natural areas exposed to river flooding events*

Source: CINCc (UC) - FIC, 2024.

URBAN HEAT ISLANDS

The resident population exposed to diurnal urban heat islands (UHI) has been obtained from the intersection between the area proposed as UHI and the official mapping of inhabitants per plot of the Santander City Council, using the approximation estimation method through population densities per plot, for those areas exposed.

A total of 58,964 people reside in plots located within the areas proposed as ICU for the municipality of Santander as a whole. At census section level, the percentage of exposed resident population shows a high variability. The highest percentage values are concentrated in certain central sections coinciding with the consolidated urban centre of the municipality, together with the south-western sections, including the industrial areas and the port area. On the other hand, the east coast and a large part of the north coast have zero values.

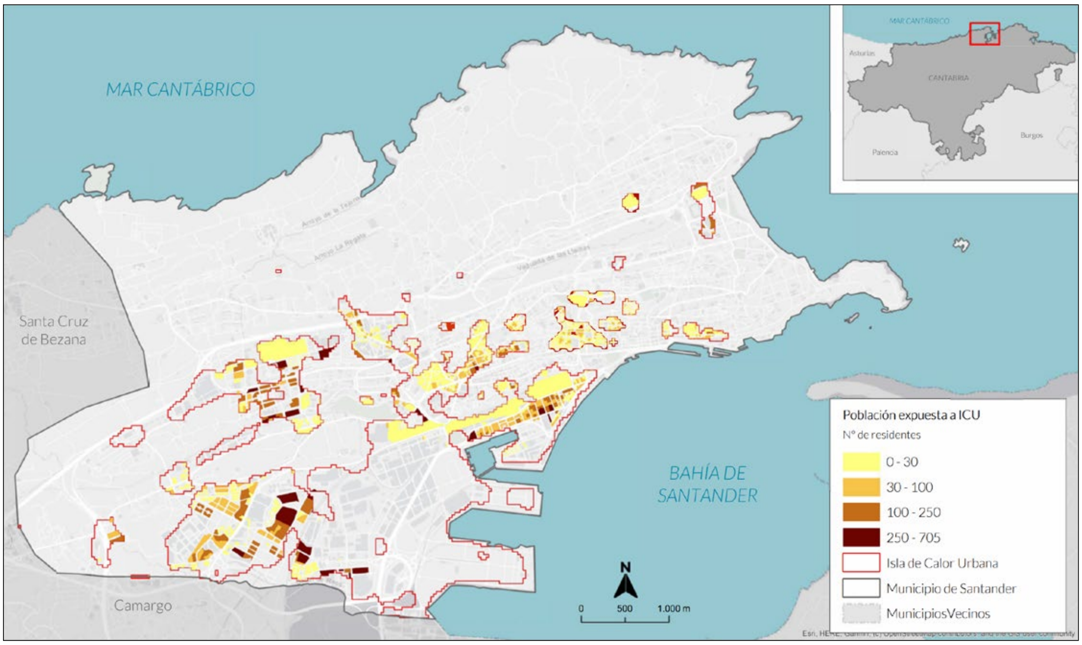


Figure 5.6. *Resident Population Exposed per plot to Potential Diurnal Heat Islands*

Source: CINCc (UC) - FIC, 2024.

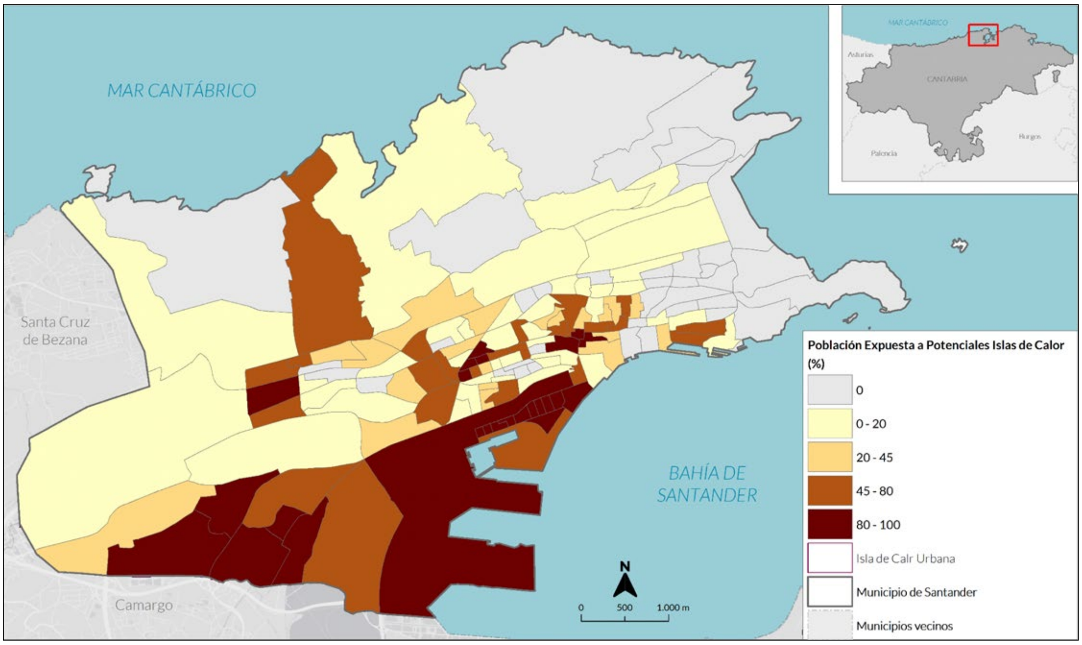


Figure 5.7. *Percentage of Resident Population Exposed to Potential Diurnal Heat Islands*

Source: CINCc (UC) - FIC, 2024.

EXTREME SOUTHERLY WIND

In the case of extreme wind events, the PEMUSAN zoned the municipality into two large areas, those experiencing north winds and Galician winds, and those exposed to south winds, with these slopes experiencing the greatest number of interventions.

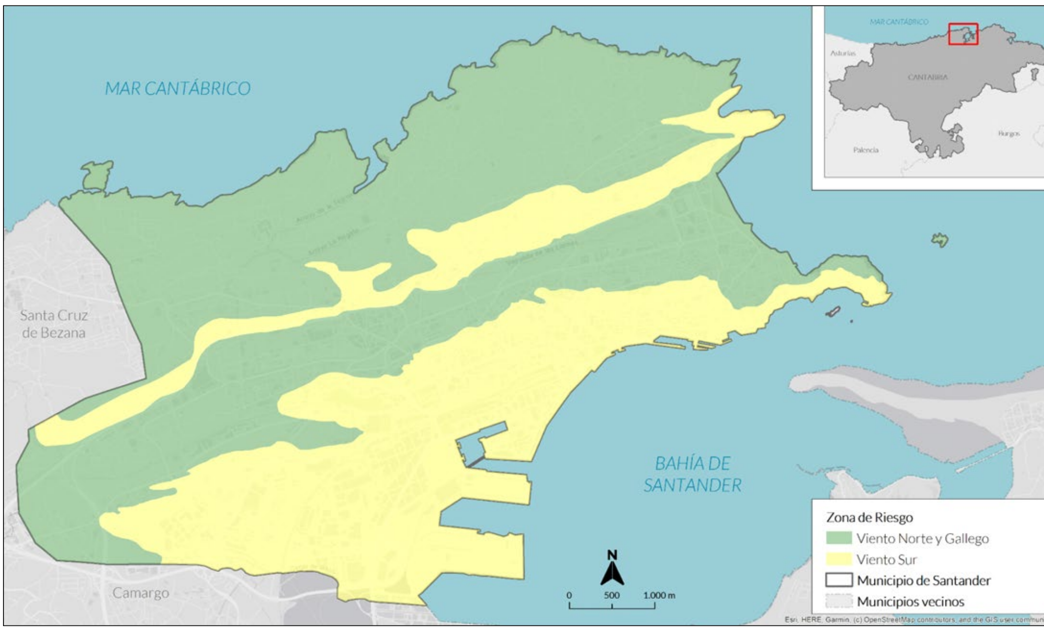


Figure 5.8. *Zones at risk from strong winds in the municipality of Santander*
Source: CINCc (UC) - FIC, 2024 based on information from the Santander Municipal Emergency Plan, Santander City Council, 2016.

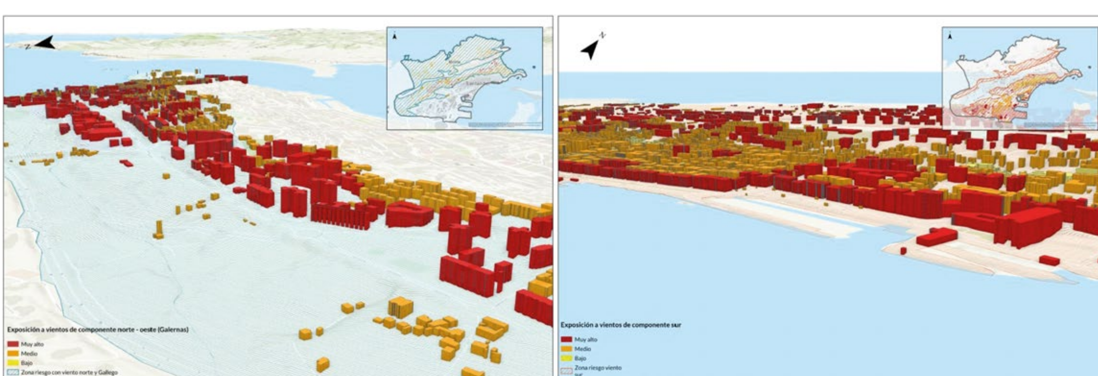


Figure 5.9. *Exposed Elements and Degree of Exposure to Extreme Wind*
Source: CINCc (UC), 2024.

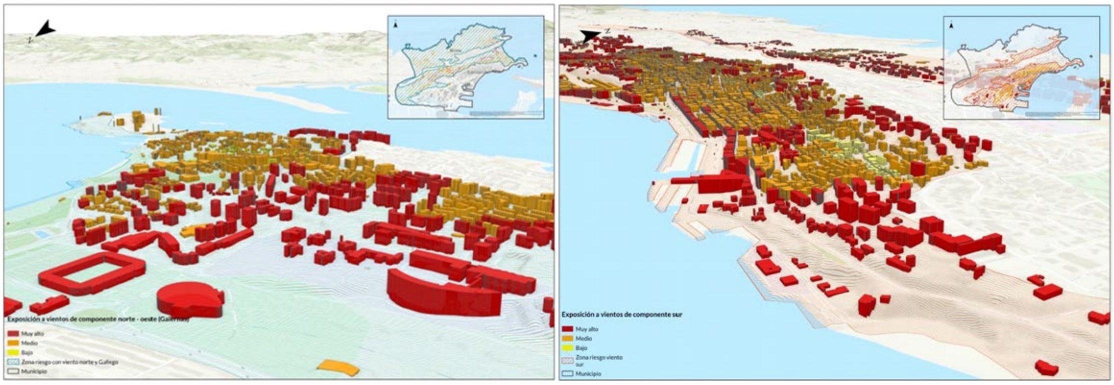


Figure 5.10. *Exposure to north-northwest and south-southwest winds in the areas defined by PEMUSAN (2016)*

Source: CINCc (UC), 2024.

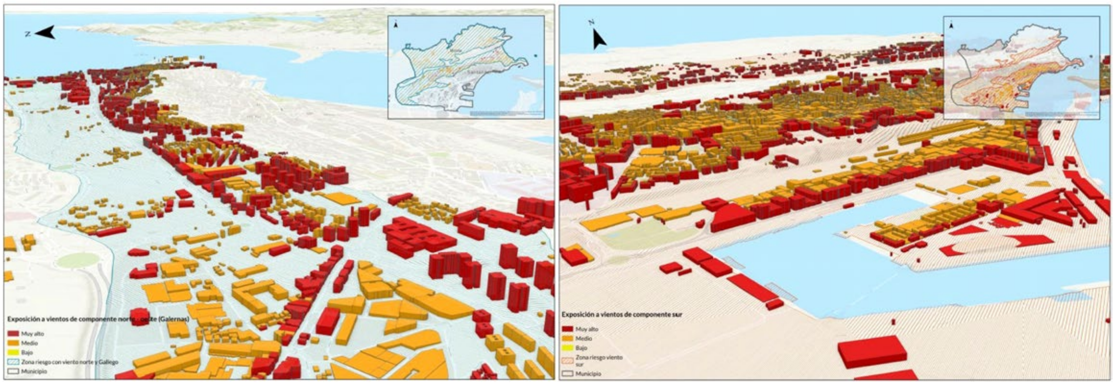


Figure 5.11. *Distribution of extreme wind exposure in different areas of the city*

Source: CINCc (UC), 2024.

The previous images (figures 5.8-5.11) show some areas of exposure to extreme wind, both in the case of north-westerly and southerly wind phenomena. However, for the purposes of calculation, the southern wind has been considered as a priority.

The level of exposure derived from southerly winds has been analysed on the basis of the percentage of the surface area of the census section whose slopes have this orientation.

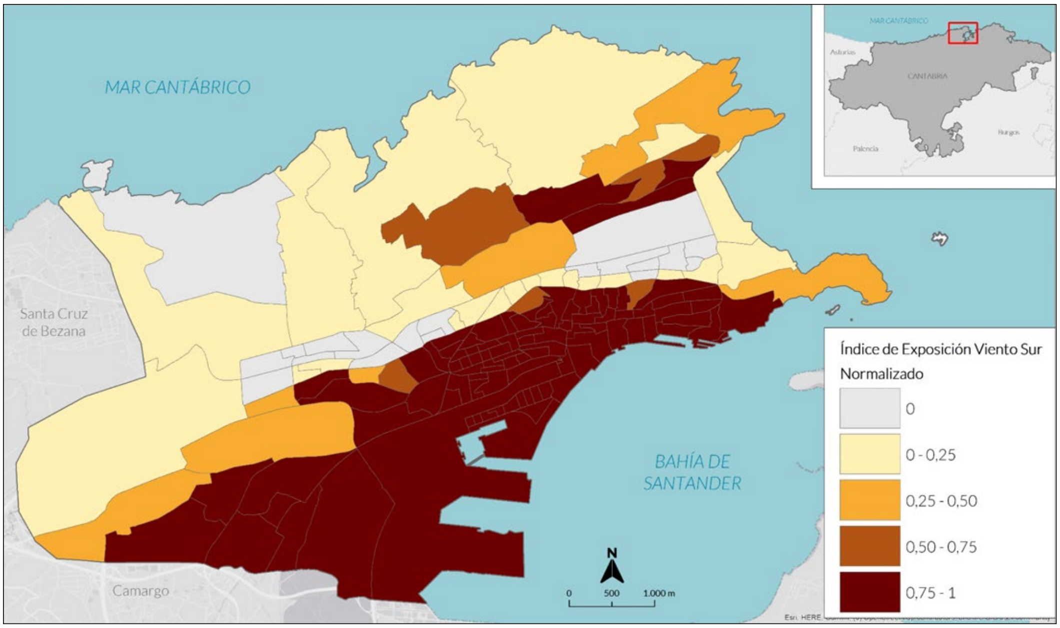


Figure 5.12. *Normalised Index of Exposure to Southerly Wind Gust*

Note: Obtained as a percentage of the area of the census section that is south-facing.

Source: CINCc (UC) - FIC, 2024.

COASTAL FLOODING OR SEA SURGES

Resident Population Exposed

The resident population exposed to coastal flooding events is obtained from the intersection between the flood stain of each scenario and the available official mapping of inhabitants per plot. The use of this approximation method has certain limitations, as it does not take into account, for example, those residing on the upper floors of these plots; and must, therefore, be interpreted under conditions of overestimation and high uncertainty. Another issue to take into account is the presence of a floating population that may be potentially exposed to coastal flooding events, i.e., tourists and visitors or related population. Due to their high spatio-temporal dynamism, their estimation is highly complex.

For the scenario projected to 2050 and RCP 8.5, the estimated population in flood areas is approximately 341 people, which represents an overall increase of 1496% compared to the historical one. Again, there is an increase in the values for the neighbourhoods exposed in the historical period, as well as affecting new neighbourhoods, specifically in the north and south of the municipality, coinciding with urban land of a residential nature.

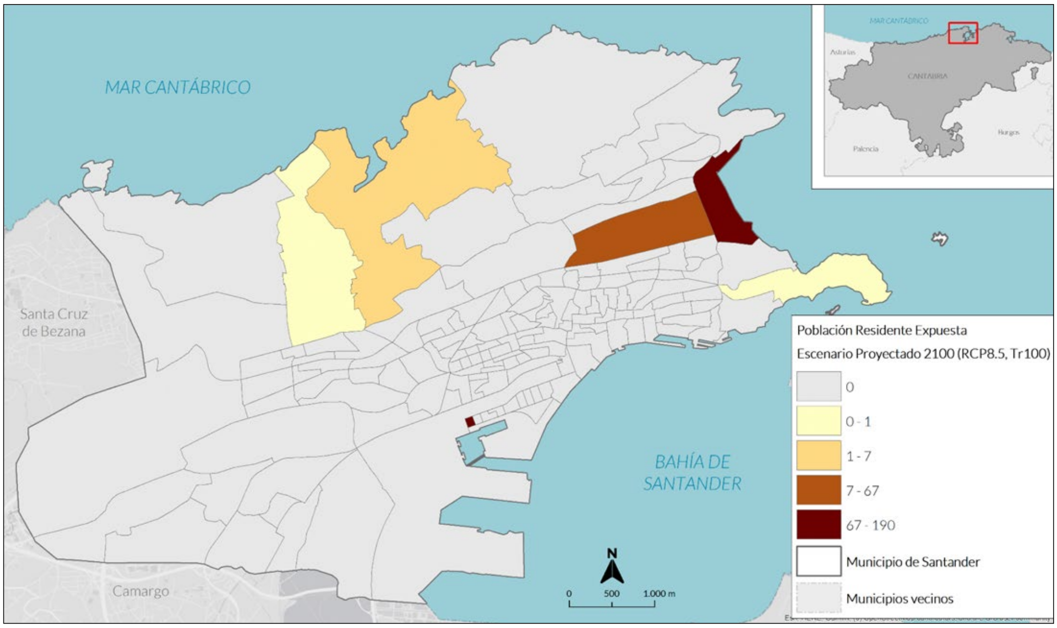


Figure 5.13. *Resident population exposed to coastal flood hazards*

Note: For the projected scenario RCP8.5 to 2100 with a return period of 100 years by census sections.

Source: CINCc (UC) - FIC, 2024.

TABLE 5.4. *Resident population exposed by coastal flooding and scenarios, historical and projected.*

MEDIUM SCENARIO (TR100 YEARS)	EXPOSED RESIDENT POPULATION TOTAL	INCREASE OVER HISTORICAL (%)
Historical	27 residents	
Projected RCP4.5 2050	96 residents	255.5%
Projected RCP8.5 2050	120 residents	344.4%
Projected RCP4.5 2100	197 residents	629.6%
Projected RCP8.5 2100	431 residents	1496.3%

Source: CINCc (UC) - FIC, 2024.

Residential Construction and Exposed Housing

The residential buildings exposed to coastal flood hazard in each of the scenarios considered have been obtained from the mapping of buildings of the General Directorate of Cadastre (Catastro, 2023). Exposed residential buildings may be totally or partially contained within the flood areas. In addition, the number of ground floor housing corresponding to exposed residential buildings has been estimated for each scenario, through specific queries to the open data of the electronic headquarters of the cadastre. There are 5 dwellings on the ground floor that are exposed to coastal flooding for the municipality as a whole, both for the historical scenario and for the scenarios projected at mid-century. This figure increases to 7 and 9 dwellings exposed for the scenarios at the end of the century, RCP 4.5 and 8.5, respectively. The results obtained for each of the coastal flood hazard scenarios are presented in table 5.5 and figures 5.14 and 5.15 below.

TABLE 5.5. *Results for Residential Construction and Exposed Housing*

MEDIUM SCENARIO (TR100 YEARS)	EXPOSED RESIDENTIAL BUILDINGS			ESTIMATED EXPOSED GROUND FLOOR DWELLINGS
	N.°	AREA (m^2)*	INCREASE OVER HISTORICAL (%)	
Historical	8	10,112		5
Projected RCP4.5 2050	8	10,112	0	5
Projected RCP8.5 2050	12	11,759	16.3	5
Projected RCP4.5 2100	19	14,485	43.2	7
Projected RCP8.5 2100	27	18,101	79.0	9

** Built-up floor area*
Source: CINCc (UC) - FIC, 2024.

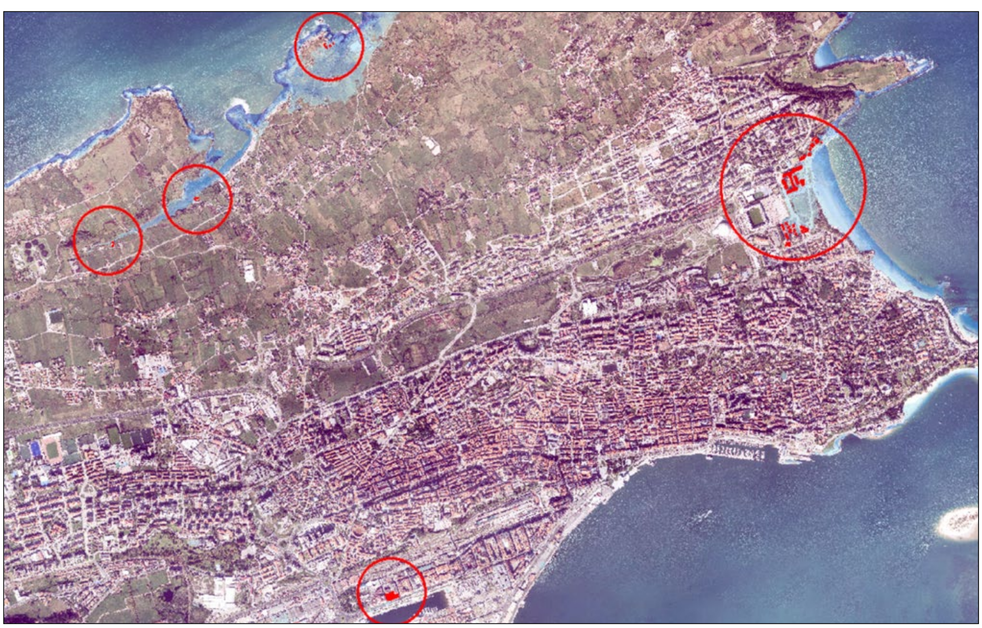


Figure 5.14. *Detail of the location of residential buildings exposed to coastal flooding in the N, E and S.*
Note: For the scenario projected to 2050 (RCP8.5, Tr100 years).
Source: CINCc (UC) - FIC, 2024.

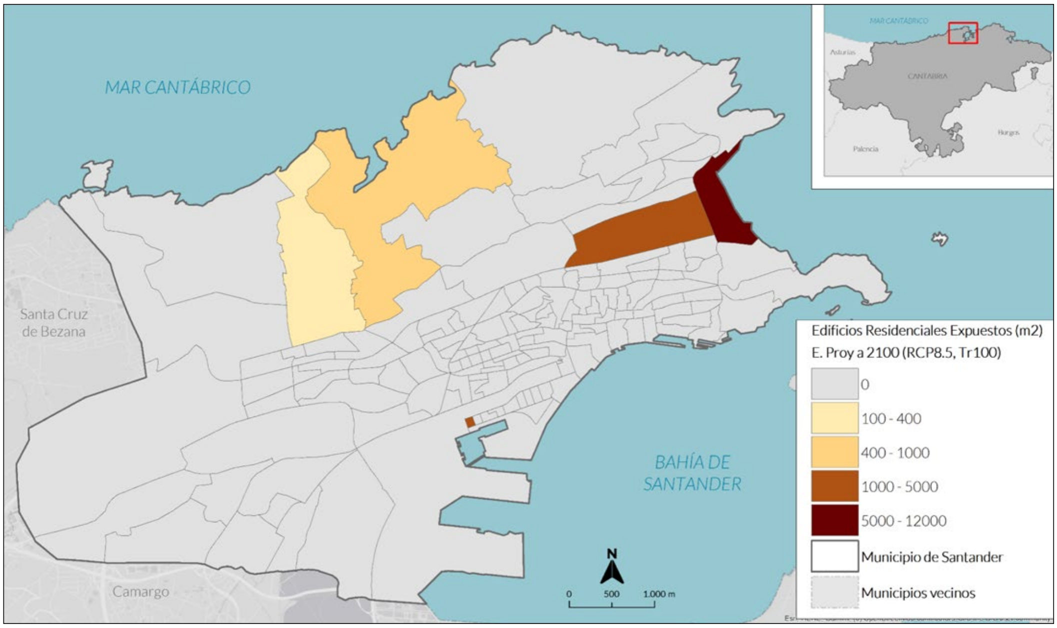


Figure 5.15. *Area (m²) of residential buildings exposed to coastal flooding*

Note: For the projected scenario to 2100 (RCP8.5, Tr100) in the municipality of Santander

Source: CINCc (UC) - FIC, 2024.

It can be observed that in the port sector, the flood stain could affect some residential areas. However, it is plausible that given the protection conditions of the Varadero sector, and with constructive actions of a defensive and punctual nature, these properties would not be affected.

EXPOSED INFRASTRUCTURE AND FACILITIES

This block assesses the municipal infrastructure located in the coastal flooding areas for each of the scenarios, including road and port infrastructure, buildings used for public services, industrial and recreational facilities, and the municipality's historical complexes. The databases used come from the National Topographic Base (IGN, 2022) at a detailed scale (1:2000) and from the building databases of the General Directorate of Cadastre (INSPIRE Servicio Catastral, 2023).

The assessment of the exposed infrastructure as a whole presents several different units of measurement, depending on the specific type of element analysed. In order to analyse the level of exposure for the set of elements contained in this group at the census section scale, the results obtained for each scenario and element have been previously normalised on a scale of 0 to 1. This allows, firstly, to compare the level of exposure between each of the scenarios and between each of the census sections, while identifying those sections with a higher concentration of infrastructure and facilities exposed to coastal flooding in a comprehensive manner. The results of the level of exposure in infrastructure and facilities, obtained for the year 2100 and the scenario RCP8.5, are presented in table 56 and figure 5.16 below.

TABLE 5.6. *Set of infrastructures and facilities exposed to coastal flooding*

MEDIUM SCENARIO (TR100 YEARS)	EXPOSED VIALS			PUBLIC BUILDINGS, INDUSTRIAL AND RECREATIONAL FACILITIES		HISTORIC SITES (m^2)
	ROADS (Km)	PATHS (Km)	STATION PORT OF FC (m^2)	N.°	AREA (m^2)*	
Historical	1	2	298	7	40,770	4,538
Projected RCP4.5 2050	1.3	2.3	298	8	42,789	6,765
Projected RCP8.5 2050	1.9	2.3	298	8	42,789	8,016
Projected RCP4.5 2100	3.2	3.1	1,357	10	44,851	12,977
Projected RCP8.5 2100	4.1	3.5	3,100	12	58,377	18,045

** Built on Ground Floor*
Source: CINCc (UC) - FIC, 2024.

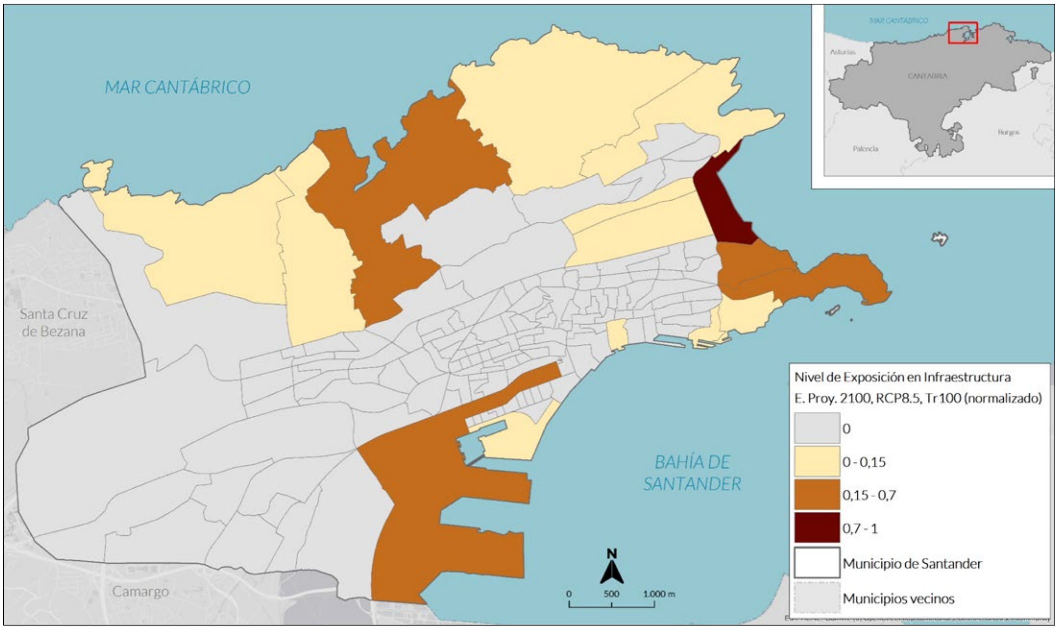


Figure 5.16. *Level of Exposure in Infrastructure and Facilities due to Coastal Flood Hazards*
Note: For the scenario projected to 2100 (RCP8.5, Tr100) by census sections in the municipality of Santander.
Source: CINCc (UC) - FIC, 2024.

ECONOMIC ASSETS EXPOSED

The analysis of economic assets exposed to coastal flooding events is carried out through the identification of commercial premises, offices, buildings used for agricultural activities, restaurants and hotels located totally or partially in the areas of incidence of each of the scenarios considered. The databases used come from the National Topographic Base (IGN, 2022) at a detailed scale (1:2000) and from the building databases of the General Directorate of Cadastre (INSPIRE Servicio Catastral, 2023).

TABLE 5.7. *Set of economic assets exposed to coastal flooding for each of the scenarios*

MEDIUM SCENARIO (TR100 YEARS)	COMMERCIAL STORES, HOTELS AND OFFICES			CONSTRUCTIONS INTENDED FOR AGRICULTURAL ACTIVITIES		
	N.°	AREA (m^2)	INCREASE OVER HISTORICAL (%)	N.°	AREA (m^2)	INCREASE OVER HISTORICAL (%)
Historical	5	10,253	–	27	2,376	–
Projected RCP4.5 2050	5	10,253	0	28	2,390	0.6
Projected RCP8.5 2050	7	11,576	13	28	2,390	0.6
Projected RCP4.5 2100	9	12,824	25	31	2,594	9.2
Projected RCP8.5 2100	12	14,334	40	38	2,903	22.2

Source: CINCc (UC) - FIC, 2024.

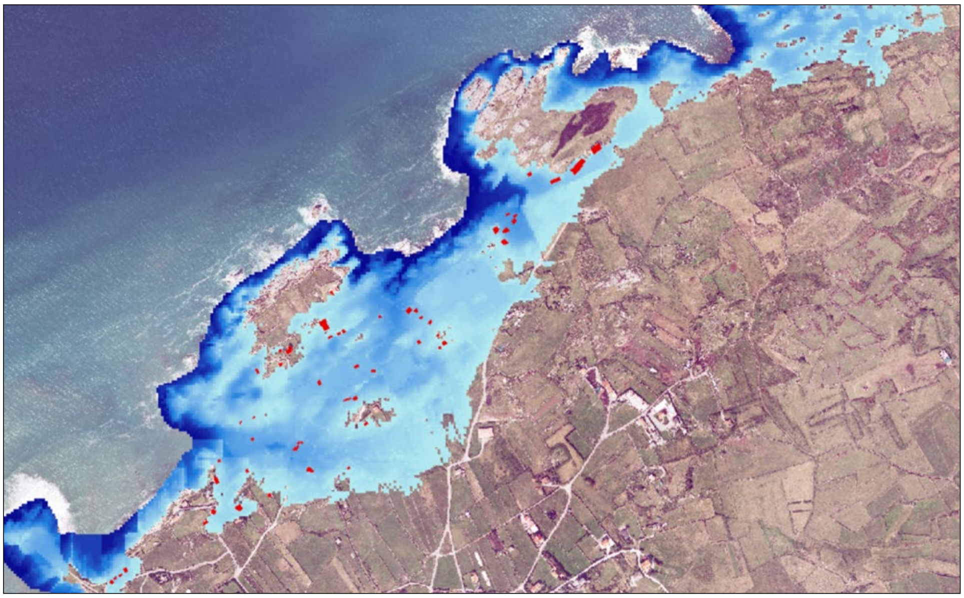


Figure 5.17. *Detail of concentration of buildings exposed to coastal flooding*

Note: For agricultural activities and for the scenario projected to 2100 (RCP8.5, Tr100) in the northern sector

Source: CINCc (UC) - FIC, 2024.

Figure 5.18. *Detail of the concentration of economic assets in the East Coastal Sector*

Note: For the scenario projected to 2100

Source: CINCc (UC) - FIC, 2024.

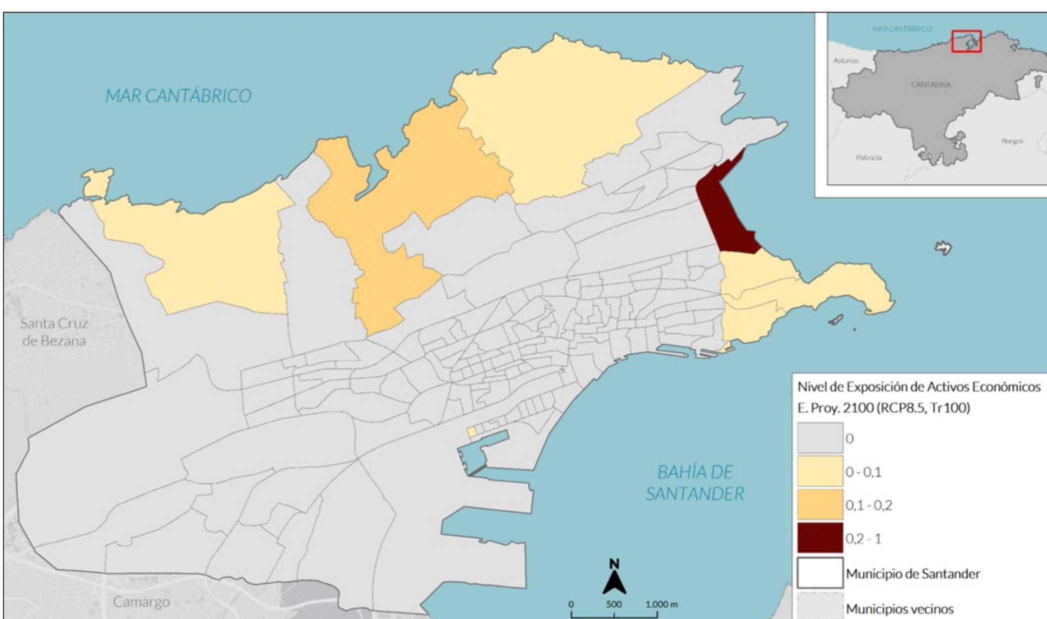


Figure 5.19. *Level of Exposure of Economic Assets to coastal flooding*

Note: For the scenario projected to 2100 RCP8.5, (Tr100) by census section in Santander

Source: CINCc (UC) - FIC, 2024.

The results obtained for each of the scenarios are calculated at census section level, including the exposed surface area. The normalised exposure results in economic assets to flood hazards for the end-of-century scenario RCP8.5 are presented in figure 5.19 from the previous page.

AREAS OF INTEREST AND NATURAL RESOURCES ON DISPLAY

The analysis of areas of interest and natural resources exposed to coastal flooding events is carried out through the identification of beaches and coastal habitats located in the areas of incidence of coastal flooding for each of the scenarios considered. The mapping of beaches in the municipality comes from the Adapta-Costa Cantabria Report (2019-2021), and the mapping of coastal habitats considered comes from the National Inventory of Terrestrial Habitats (MITECO, 2005).

TABLE 5.8. *Set of natural resources exposed to coastal flooding*

MEDIUM SCENARIO (TR100 YEARS)	EXPOSED BEACHES			EXPOSED COASTAL HABITATS		
	AREA (Ha)	(% SUP)	INCREASE OVER HISTORICAL (%)	AREA (Ha)	(% SUP)	INCREASE OVER HISTORICAL (%)
Historical	32.89	87.15	–	41.87	24.2	–
Projected RCP4.5 2050	33.72	89.34	2.5	42.3	24.5	1.23
Projected RCP8.5 2050	33.78	89.50	2.7	42.3	24.5	1.23
Projected RCP4.5 2100	34.84	92.32	5.9	46.6	26.9	11.3
Projected RCP8.5 2100	35.20	93.30	7.1	48.4	28.0	15.6

Source: CINCc (UC) - FIC, 2024.

The municipality has 15 beaches covering an area of almost 38 hectares, of which 7 correspond to sandy beaches within the urban area. In general, the percentage of beaches exposed to coastal flooding events is very high in all the scenarios considered, from values of more than 87% for the historical scenario, to more than 93% of the exposed beach area for the most pessimistic scenario, RCP8.5 projected to 2100 (figure 5.20).

The exposure results obtained for each of the scenarios are also calculated in this case at the census section level. For each of the scenarios and for each section, the percentage of exposed beach area in relation to the total beach area of the census section has been obtained. figure 5.21 shows the results obtained for the historical scenario and for the scenario projected to 2100, RCP8.5, Tr100 years.

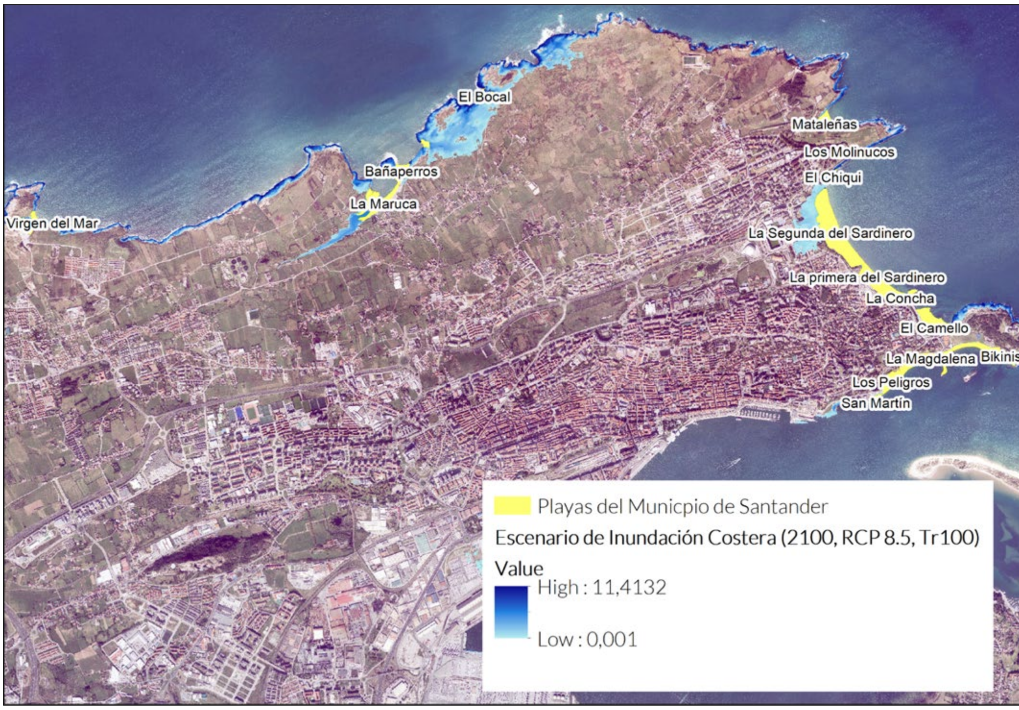


Figure 5.20. *Coastal Flood Exposure Map*

Source: CINCc (UC) - FIC, 2024.

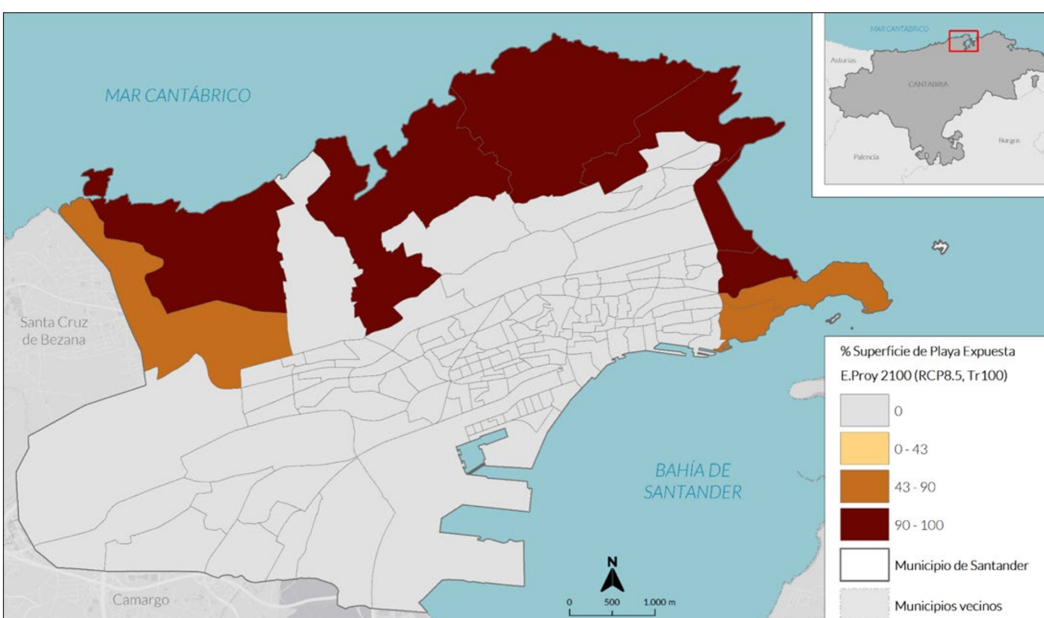


Figure 5.21. *Percentage of beach area exposed to coastal flooding*

Note: Per census section for the scenario projected to 2100 (RCP8.5, Tr100)

Source: CINCc (UC) - FIC, 2024.

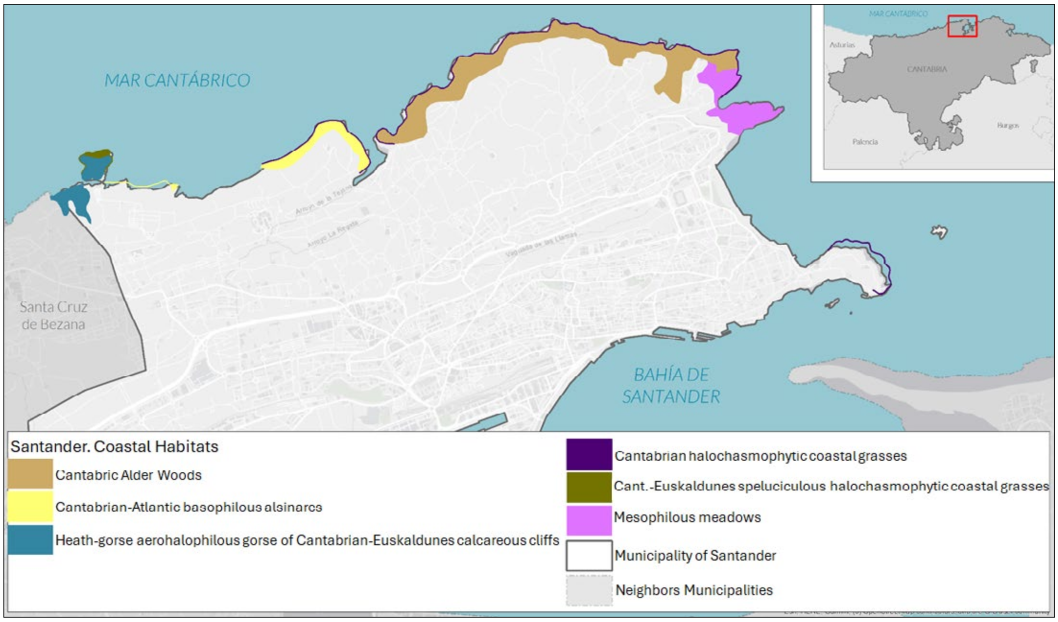


Figure 5.22. *Coastal habitats of Santander.*

Source: CINCc (UC) - FIC, 2024.

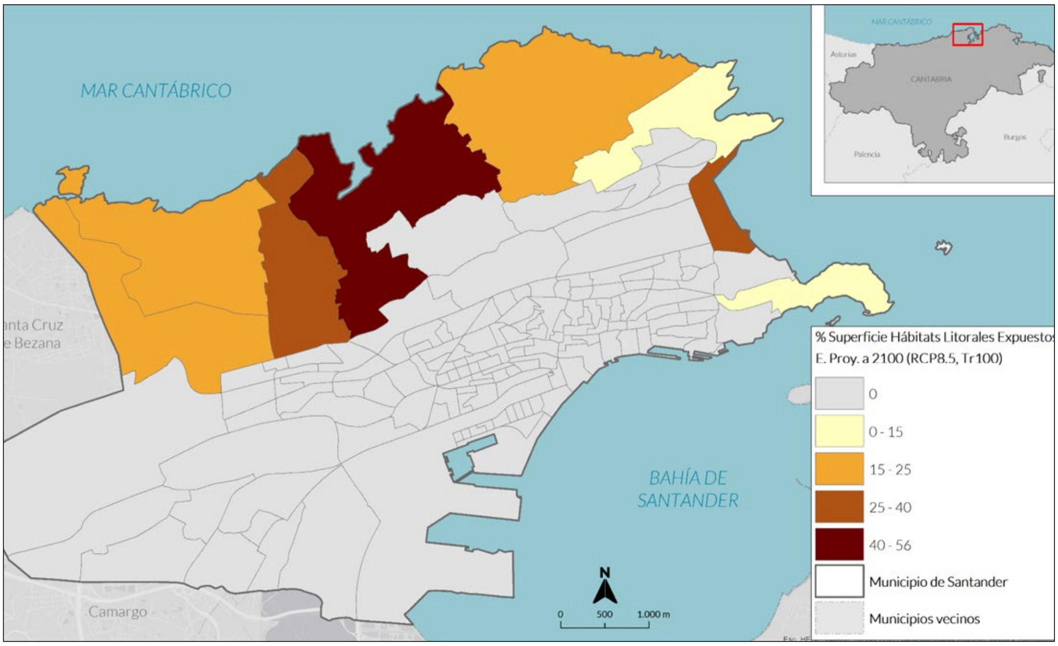


Figure 5.23. *Percentage of area of coastal habitats exposed to coastal inundation*

Note: Per census sections for the projected scenario to 2100 (RCP8.5, Tr100)

Source: CINCc (UC) - FIC, 2024.

On the other hand, the municipality of Santander has an area of approximately 173 hectares of terrestrial coastal habitats, mainly represented by coastal vegetation present on the cliffs, and various alliances of species, such as quercineae, Cantabrian alder groves, mesophyll meadows, Erica heaths, gorse heaths, among others, which are mainly distributed to the north, north-east of the municipality (figure 5.22).

The area of **terrestrial coastal habitats** exposed to coastal flooding events ranges in absolute values from 41 to 48 ha, for the historical and projected scenario to 2100 (RCP8.5, Tr100), respectively, which represents 24% to 28% of the total area of coastal habitat in the municipality in percentage terms, with a projected increase of approximately 15% for the most pessimistic scenario compared to the historical scenario (figure 5.23).

Combined Exposure Index for Coastal Flood Hazards

In the previous sections, exposure indicators have been obtained for each of the components analysed for coastal flood hazard events, as a sum of the exposure values normalised by type of element included in each component. However, the **Combined Exposure Index** allows for:

1. An identification of those census sections with the **highest concentration** of elements exposed to coastal flooding using a multi-dimensional or multi-sectoral approach.
2. A **holistic view of the information**, i.e., a comprehensive and combined assessment that, nevertheless, can be broken down into different components in a coherent and consistent manner, as they are derived from precise elementary quantifications of the territory.
3. A relative comparison o the level of exposure between **multiple climate scenarios**, assessment the level of change, analysis of the trends in the territory and derivation of possible higher priority intervention points from the exposure component.

The final results of the Combined Exposure Index for the historical scenario, the projected 2050 and RCP8.5 and the projected 2100 and RCP8.5, are presented below.

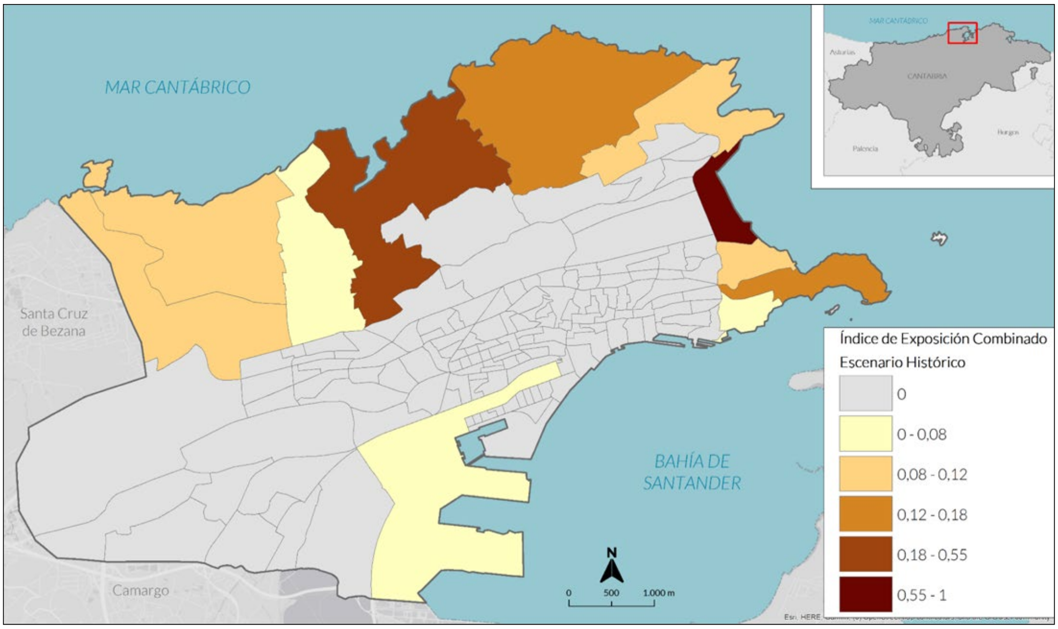


Figure 5.24. *Combined Exposure Index (dimensionless) to Historical Coastal Flood Hazards*

Source: CINCc (UC) - FIC, 2024.

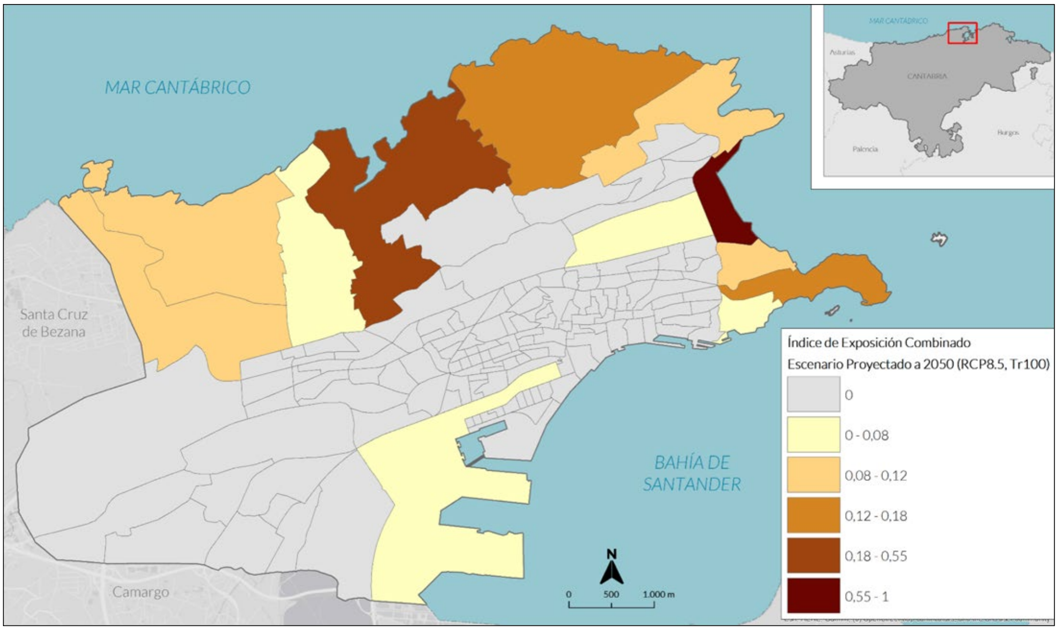


Figure 5.25. *Combined Exposure Index (dimensionless) to Coastal Flood Hazard 2050*

Source: CINCc (UC) - FIC, 2024.

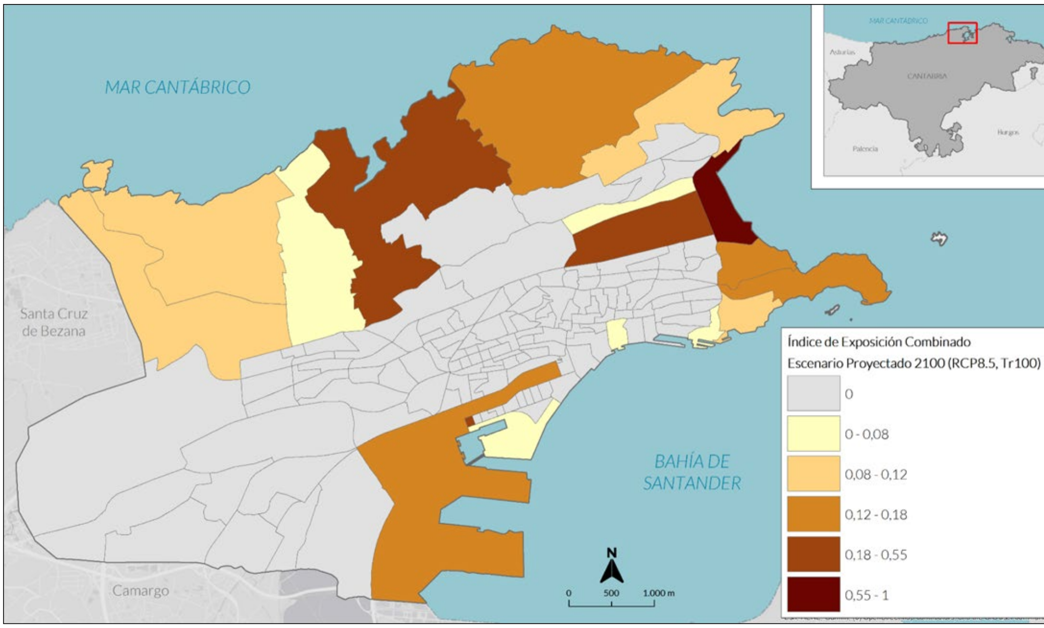


Figure 5.26. *Combined Exposure Index (dimensionless) to Coastal Flood Hazard 2100*
Source: CINCc (UC) - FIC, 2024.

5.2 VULNERABILITY ANALYSIS

Vulnerability is defined as the 'propensity or predisposition to be adversely affected'. Vulnerability encompasses a number of concepts and elements, such as **sensitivity** or susceptibility to harm and **adaptive capacity**, which involves being prepared to cope and adapt to the problem (IPCC, 2022a). In general, the vulnerability of ecosystems and people to climate change differs substantially between regions. Even within regions, it is influenced by aspects such as intersecting socio-economic development patterns, unsustainable land and ocean use, inequity, marginalisation, historical and current patterns of inequality, among many other demographic issues.

During 2010-2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions compared to regions with very low vulnerability (IPCC, 2022b). Vulnerability at different spatial levels is typically exacerbated by inequality and marginalisation linked to gender, ethnicity, low income or combinations of these, especially for many indigenous peoples and local communities. Also in the future, human vulnerability will continue to be concentrated where the capacities of local, municipal and national governments, communities and the private sector are least able to provide basic infrastructure and services. Key infrastructure systems such as sanitation, water, health, transport, communications and energy will become increasingly vulnerable, if design standards do not take into account changing climatic conditions.

VULNERABILITY ANALYSIS METHODOLOGY AND PHASES

The methodology for approaching the vulnerability study is centred on a mixed process that combines the assessment of specific factors of sensitivity and adaptive capacity at the local level with a social, economic, material and environmental approach, together with expert judgement, through the following phases of development:

- Phase 1: **Identification of climate vulnerability factors** for each of the prioritised hazards. This phase includes the initial development of a list of climate vulnerability factors derived from local literature and document review processes. This initial list of potential factors is subjected to public assessment through citizen workshops with key institutional participation.
- Phase 2: **Collection of information and assessment** of vulnerability indices. For the relevant vulnerability factors, the available official sources of information that enable their evaluation are analysed. Once these sources of primary information have been collected, contrasted and validated, the vulnerability assessment is addressed through indicators, understood as a measure that characterises the vulnerability of a system, specifically for the socio-economic, environmental and material components. For each of the key vulnerability factors, at least one representative vulnerability indicator is developed.
- Phase 3: **Normalisation of the values** of the evaluated indices with respect to the highest value that the series can reach. This normalisation makes it possible to relativise the magnitude of the index and enables its comparison and subsequent integration. For this purpose, the linear normalisation method is applied to obtain values from 0 to 1.
- Phase 4: **Integration and development of a final climate vulnerability index** for each of the key hazards, obtained by combining each of the normalised vulnerability indices and weighted according to their relevance. This relevance is analysed by combining the relevance value given by the set of respondents in the risk perception workshop, together with the relevance value given under expert judgement. This weighting makes it possible to establish an order of hierarchy and relevance between the standardised indices for each of the hazards.
- Phase 5: **Analysis of projected vulnerability** to 2050 and 2100. This last phase includes the definition of hypotheses and scenarios of change for each of the sensitivity factors analysed for 2050 and 2100. As a result of these hypotheses, percentage change forecasts will be established, which will be applied at census section level with respect to the value obtained for the current horizon.

STANDARDISATION AND COMBINATION OF INDICATORS

Once phases 1 and 2 of defining indicators and obtaining specific data for them have been completed, the standardisation of the set of sensitivity indicators assessed will enable their subsequent integration. The final vulnerability index for each of the hazards is usually based on a combination of quantitative data or indicators, so it is necessary to incorporate a method of control and standardisation of variables that makes them comparable with each other while allowing their standardised integration into a final indicator. The 'objectivity' of quantitative data is maintained after the standardisation process, providing essential information relating to the context or factor analysed in each case.

The normalisation process is carried out using the simple linear method to obtain values from 0 to 1, therefore, as a result of the normalisation process, rates are obtained with values that are presented in a constant range between 0 and 1, taking into account the minimum and maximum values reached by the series, by means of the following equation:

$$Z_i = (x_i - \text{minimum } (x)) / (\text{maximum } (x) - \text{minimum } (x))$$

where:

- **Z_i**: The i- umpteenth normalized value in data set.
- **x_i**: The i- umpteenth value in data set.
- **minimum (x)**: The minimum value in the data set.
- **maximum (x)**: The maximum value in the data set.

For certain sensitivity factors, an additional process of **combining indicators** is carried out, with the aim of comprehensively assessing complex circumstances that do not depend on a single indicator or several independent indicators. In other words, a given reality under a specific context, such as precarious housing, depends, in turn, on several specific multidimensional variables or circumstances that have a synergistic effect. For these cases, the sum of the values of their respective indicators per census section is first calculated and then the result is normalised using the same linear procedure. The following tables show the **Sensitivity Indicators** (socio-economic, material and environmental), which include the set of factors and indicators evaluated, together with the normalisation and combination method used in each case.

TABLE 5.9. *Socio-economic sensitivity*

TYPE	N.°	SENSITIVITY FACTOR	INDICATOR OF SENSITIVITY	METHOD STANDARDISATION
SOCIO-ECONOMIC SENSITIVITY	SE 1	Level of social poverty by income	SE1-1: Percentage of population with income per consumption unit below 60% of the median at the national level	LINEAR 0 TO 1
	SE 2	Level of social poverty due to housing precariousness	SE2-1: No. of Dwellings <45m² low-income sections / No. of Dwellings census section	LINEAR 0 TO1 (COMBINED)
			SE2-2: No. of 1-bedroom dwellings / No. of dwellings census section	
			SE2-3: No. of Dwellings without collective or private heating / No. of Dwellings census section	
	SE 3	Unemployment level	SE3-1: % Unemployed population / Labour force by census section	LINEAR 0 TO 1
	SE 4	Level of social inequality	SE4-1: Gini index	LINEAR 0 TO 1
	SE 5	Insufficient education level	SE5-1 % Population illiterate, uneducated or with first degree / Population >15 years old by census section	LINEAR 0 TO 1
	SE 6	Insufficient level of health coverage	SE6-1: Percentage of population residing outside the optimal service areas of public health facilities.	LINEAR 0 TO1 (COMBINED)
			SE6-2: Percentage of census section area outside the optimal service areas of public health facilities	
	SE 7	Population density level	SE7-1: N° inhabitants / km²	LINEAR 0 TO 1
	SE 8	Presence of vulnerable groups	SE8-1: % Population aged >65 years / Total population of the census section	LINEAR 0 TO 1
			SE8-2: % Population aged <5 years / Total population of the census section	LINEAR 0 TO 1
	SE 9	Level of sectoral climate dependence (employed in climate-dependent sectors	SE9-1:Percentage of employed in dependent sectors / Total Employed Population by census section	LINEAR 0 TO 1
	SE 10	Gender differences	SE10-1:Percentage of women by census section	LINEAR 0 TO 1

Source: CINCc (UC) - FIC, 2024.

TABLE 5.10. *Material sensitivity*

TYPE	N.°	SENSITIVITY FACTOR	INDICATOR OF SENSITIVITY	METHOD STANDARDISATION
MATERIAL SENSITIVITY	M1	Age of dwellings	M1-1:Percentage of Dwellings in pre-1940 buildings / total dwellings by census section	LINEAR 0 TO 1
	M2	Construction quality deficiency in housing	M2-1: % of dwellings with poor construction quality / Total No. of dwellings per census section	LINEAR 0 TO 1
	M3	Poor state of maintenance of dwellings	M3-1% dwellings in dilapidated, bad or substandard condition / Total number of dwellings in the census section	LINEAR 0 TO 1
	M4	Building density level	M4-1: No. of dwellings / ha	LINEAR 0 TO 1

Source: CINCc (UC) - FIC, 2024.

TABLE 5.11. *Environmental Sensitivity, Quality of Life and Social Well-being*

TYPE	N.°	SENSITIVITY FACTOR	INDICATOR OF SENSITIVITY	METHOD STANDARDISATION
ENVIRONMENTAL SENSITIVITY, QUALITY OF LIFE AND SOCIAL WELL-BEING	A1	Level of social poverty due to housing precariousness	A1-1 Built-up volume / census section surface area	LINEAR 0 TO1 (COMBINED)
			A1-2 % Impervious urban area / census section area	
	A2	Noise level and air pollution	A2-1 Estimated % pop affected by noise > 65 dB per census section (FB indicator CBA- 004)	LINEAR 0 TO1 (COMBINED)
			A2-2 Air Pollution Level Atmospheric Pollution from Vehicular Traffic	
	A3	Tourist pressure level	A3-1: Tourist Function Rate (bed places/100 inhab)	LINEAR 0 TO1 (COMBINED)
			A3-2: Socio-environmental Pressure Index taking into account tourist areas (Mobiles)	
			A3-3: Unregulated Accommodation Tourist Function Rate (Airbnb)	
	A4	Level of anthropic pressure	A4-1: Deficit of m^2 of green areas per inhabitant compared to the optimum of $20m^2$ / inhabitant per census section	LINEAR 0 TO 1

[…/…]

Continuation **TABLE 5.11**

TYPE	N.°	SENSITIVITY FACTOR	INDICATOR OF SENSITIVITY	METHOD STANDARDISATION
ENVIRONMENTAL SENSITIVITY, QUALITY OF LIFE AND SOCIAL WELL-BEING	A5	Presence of environmentally degraded areas	A5-1: % Surface area of degraded areas by census section	LINEAR 0 TO 1
	A6	Inadequate coverage of the municipal waste management system	A6-1: Estimated population of the census section outside the optimal coverage level of waste management	LINEAR 0 TO 1
	A7	Presence of buildings without energy certification	A7-1: % of Buildings with no energy certification or with certification below class E	LINEAR 0 TO 1
	A8	Population far from green areas	A8-1: % Population >400m of public green area of 0.5Ha minimum sup. (CBS-002 of the BF)	LINEAR 0 TO 1
	A9	Population without private green spaces	A9-1: % Estimated population by census section without private green spaces	LINEAR 0 TO 1

Source: CINCc (UC) - FIC, 2024.

Integration of Climate Sensitivity Indicators

Once the process of standardisation of the set of indicators has been completed, the final integration of the indicators for each of the climate hazards is carried out. The **integration process** involves the development of the following successive tasks:

1. Identification and selection of climate sensitivity indicators that impact each of the climate hazards
2. Assessment of the level of relevance ('weight') of each of the indicators by climate hazard
3. Calculation of the final Climate Sensitivity Index for each of the hazards assessed in the municipality, through the sum of values achieved for the set of indicators per census section, weighted by their relative weight or level of importance. This integration, therefore, offers the possibility of combining several inputs to create an integrated analysis of sensitivity, incorporating weights or relative importance with a double analytical focus, importance given for each indicator and for each hazard assessed.

$$\text{Weighted average} = \sum_{i=1}^{N} x_i P(x_i) = x_1 P(x_1) + x_2 P(x_2) + x_3 P(x_3) + \ldots + x_N P(x_N)$$

Both the selection process and the importance of sensitivity indicators are based on two sources of information:

(i) Results obtained in the participatory workshop with key actors, specifically those related to the vulnerability and sensitivity block (social and institutional perception);

(ii) Results obtained from the expert analysis based on the survey of 5 researchers from the team of the University of Cantabria and the Climate Research Foundation. The specific weight per indicator is obtained by adding the final score obtained per indicator (i+ii), divided by the final score captured for the set of indicators for each threat, as a factor of one.

In this method, the result of each indicator has been projected into the future for the 2050 and 2100 scenarios by incorporating official projections. For each of the climate sensitivity indicators analysed in the municipality of Santander, hypotheses of change for 2050 and 2100 have been established on the basis of a wide range of official documentary references with implications for territorial and political trends at the municipal level.

Results of the Projected Climate Sensitivity Index to 2050 and 2100

Projected Climate Sensitivity to Pluvial Flooding

For the flood hazard from extreme rainfall events, the mean value of the Santander sensitivity index is 0.56, approximately 12% higher than the base value of the index. For this scenario projected to the middle of the century, the highest minimum values, around 0.22, are expected. Also higher maximum values, reaching a value of 1 in neighbourhoods in the south of the capital, higher than the maximum of 0.9 are reached in the current horizon. The sharpest increases are reached mainly in peripheral neighbourhoods to the north, south and east of the municipality (figure 5.27).

For the projected scenario (2100), a decreasing trend is observed in the sensitivity index, with an average value of 0.52, 4.18% higher than the base scenario. The largest decreases occur in sections located along the south coast and in the centre of the capital (figure 5.28).

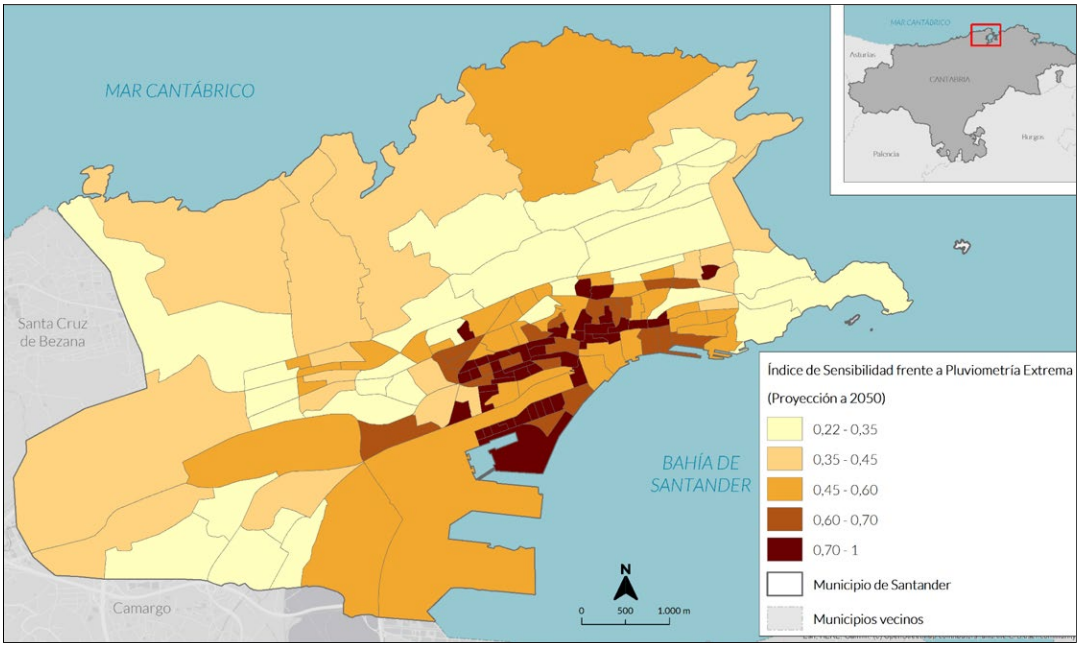


Figure 5.27. *Normalised Index of Climate Sensitivity to Rainfall Flood Events 2050*

Source: CINCc (UC) - FIC, 2024.

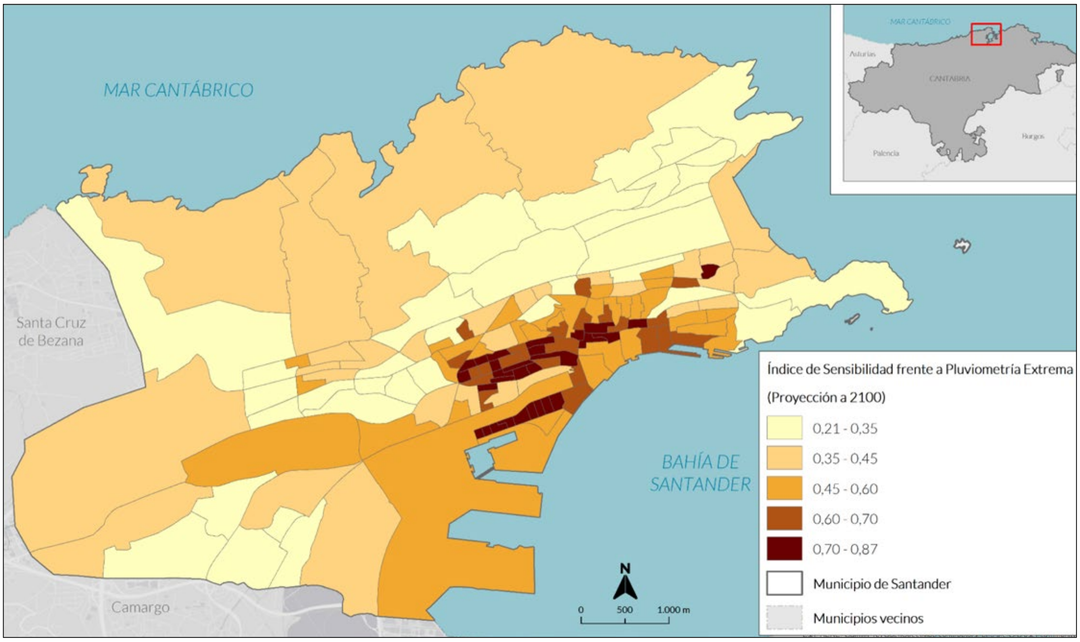


Figure 5.28. *Normalised Index of Climate Sensitivity to Rainfall Flood Events 2100*

Source: CINCc (UC) - FIC, 2024.

Projected Climate Sensitivity to Extreme Temperature Events

Finally, for the extreme temperature event hazard, the mean value is 0.59, 9.7% lower than the base value of the index. For this projected mid-century scenario, a generalised decrease in the sensitivity index values is expected.

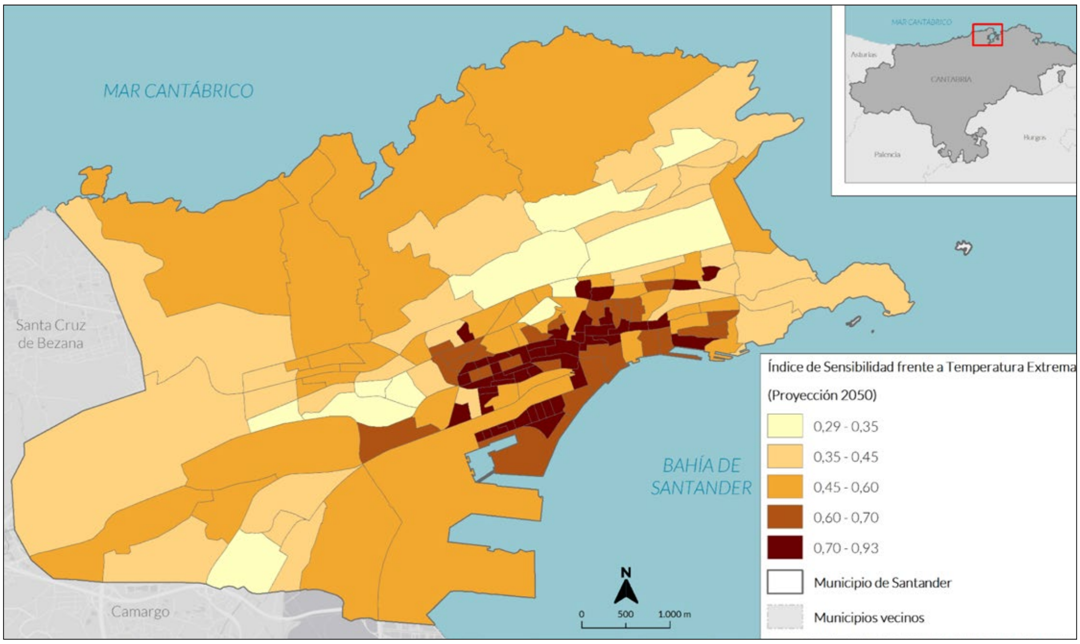


Figure 5.29. *Normalised Index of Climate Sensitivity to Extreme Temperature Events 2050*

Source: CINCc (UC) - FIC, 2024.

In the scenario projected at the end of the century, the average value of the lowest sensitivity index of the municipality, of around 0.49 is reached, almost 20% lower than the base value of the index. For this scenario, the lowest sensitivity values are foreseen for both the lower and upper end of the index, reaching maximums of up to 0.78 in certain sections of the consolidated urban centre. This decreasing trend is also generalised, mainly associated with the northern and western suburbs.

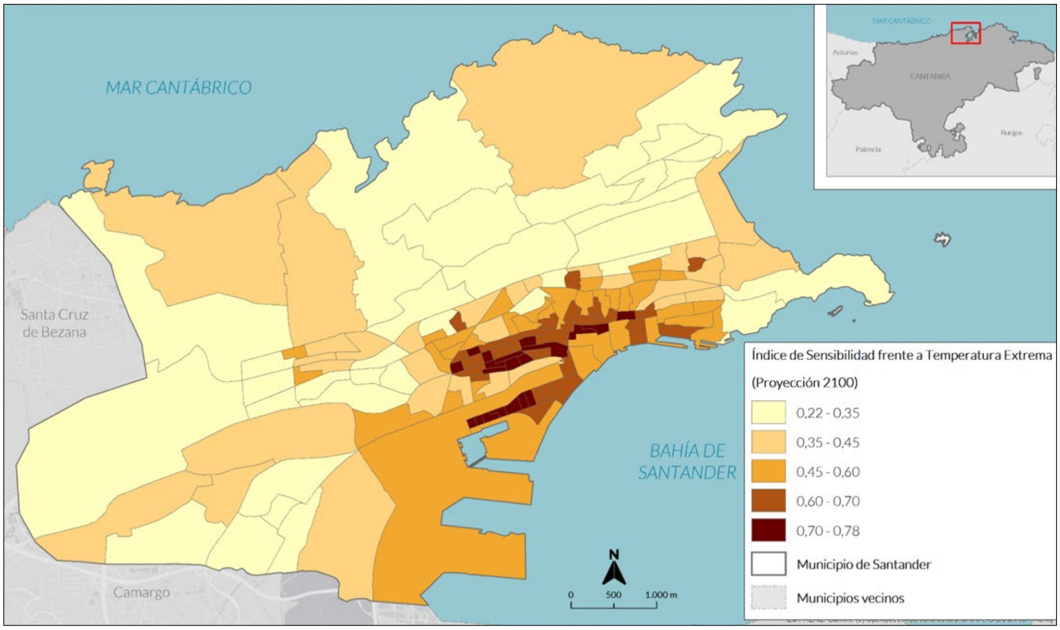


Figure 5.30. *Normalised Index of Climate Sensitivity to Extreme Temperature Events 2100*
Source: CINCc (UC) - FIC, 2024.

Projected Climate Sensitivity to Meteorological Drought Events

For the meteorological drought hazard, the average value of the municipal sensitivity index is 0.55, approximately 9% lower than the base value of the index. For this projected mid-century scenario, a generalised decrease in sensitivity index values is expected, which is mainly observed in the northern, western and southern suburbs, together with some highly sensitive neighbourhoods in the centre of the capital (figure 5.31).

For the scenario projected at the end of the century, the lowest average value of the municipality's sensitivity index, of around 0.48, is reached. For this scenario, the lowest values are expected for both the lower and the upper end of the index. This decreasing trend is also generalised, mainly associated with the northern and western suburbs (figure 5.32).

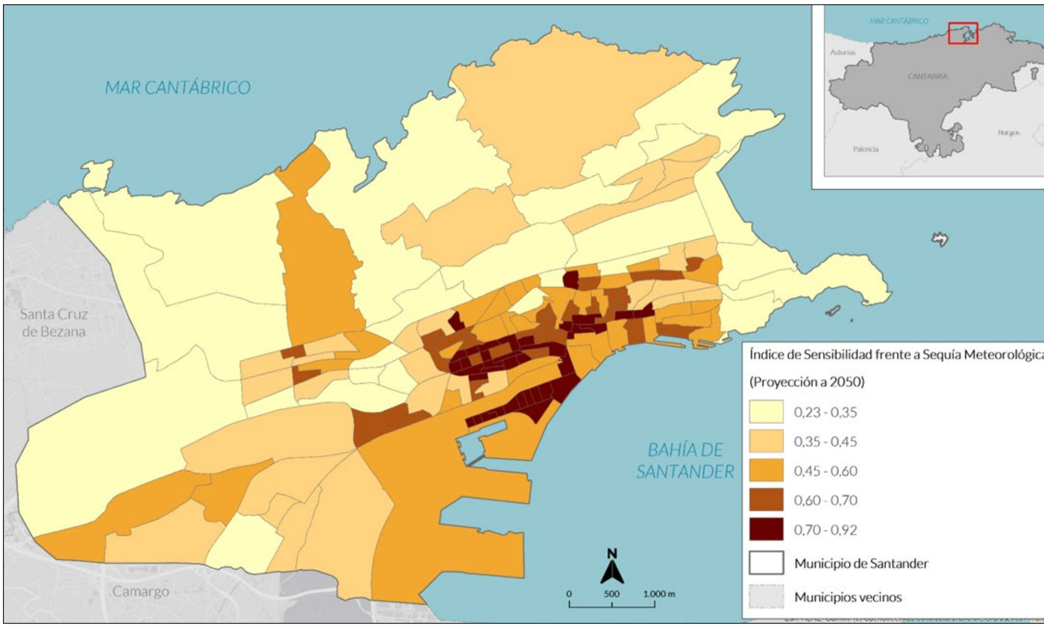


Figure 5.31. *Normalised Index of Climate Sensitivity to Meteorological Drought Events 2050*

Source: CINCc (UC) - FIC, 2024.

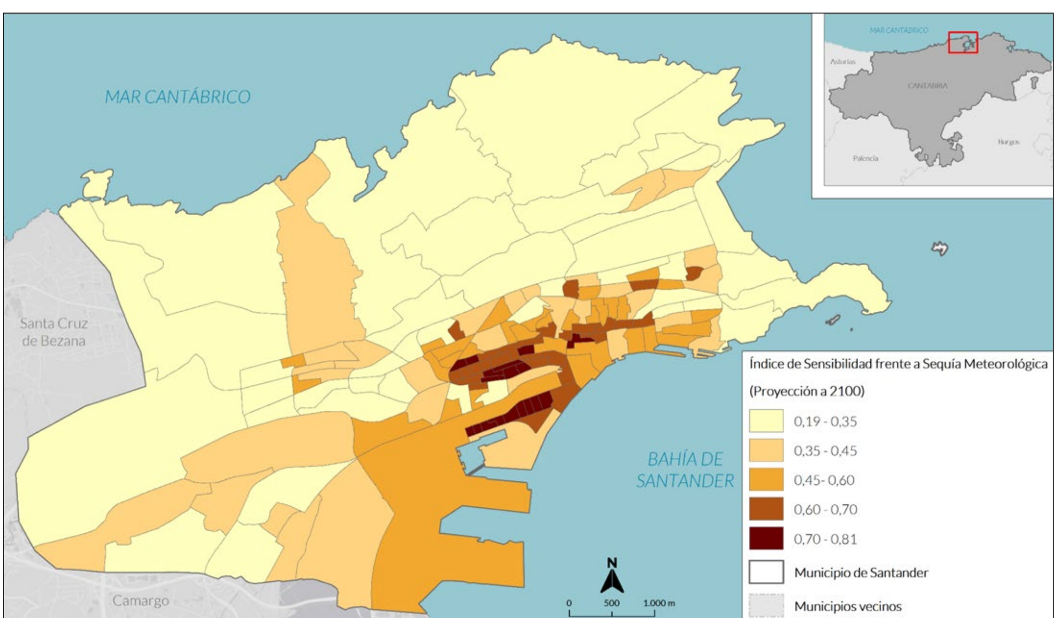


Figure 5.32. *Normalised Index of Climate Sensitivity to Meteorological Drought Events 2100*

Source: CINCc (UC) - FIC, 2024.

Projected Climate Sensitivity to Extreme Wind Events

For this hazard, the average value of the sensitivity index is 0.56, 9.3% lower than the base value of the index. For this scenario projected to the middle of the century, a generalised decrease in the values of the sensitivity index is foreseen, reaching minimum values above 0.31 for some neighbourhoods located along the diagonal that runs through the municipality (figure 5.33).

For the scenario projected at the end of the century (figure 5.34), there is a general downward trend and a marked decrease in the sensitivity index compared to the previous scenario, with an average value of 0.45 for the municipality, 27% lower than the base scenario.

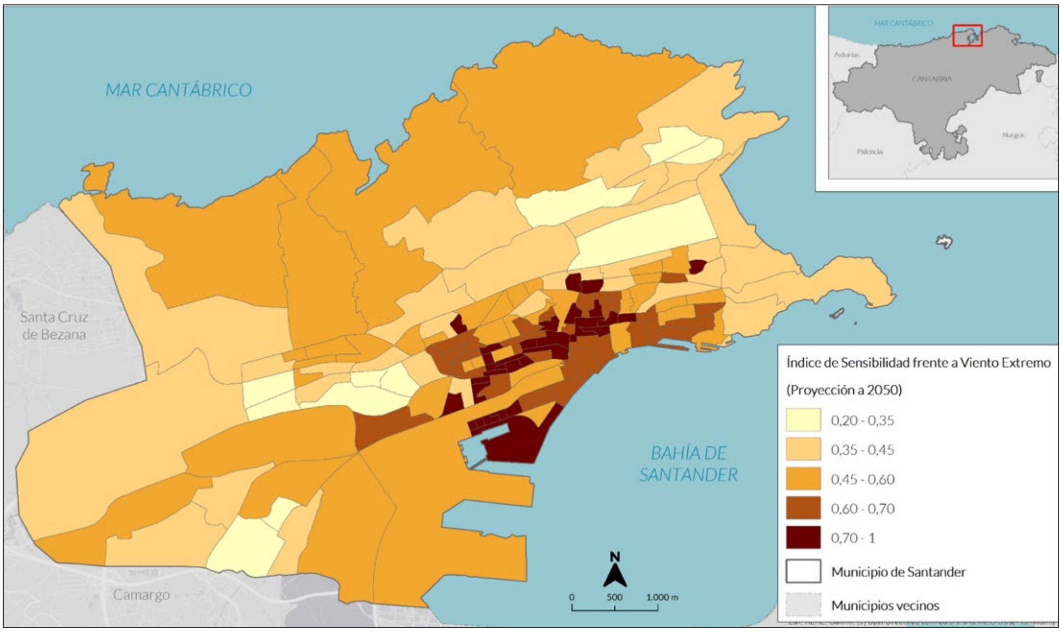


Figure 5.33. *Normalised Index of Climate Sensitivity to Extreme Wind Events 2050*

Source: CINCc (UC) - FIC, 2024.

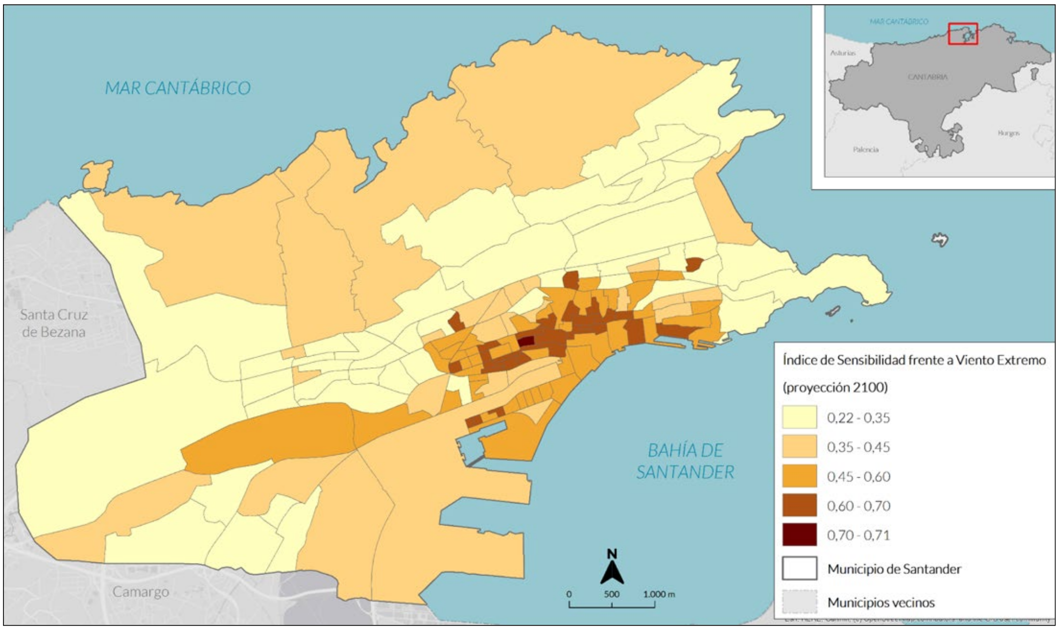


Figure 5.34. *Normalised Index of Climate Sensitivity to Extreme Wind Events 2100*

Source: CINCc (UC) - FIC, 2024.

Projected Climate Sensitivity to Coastal Floods

The mean value of the normalised climate sensitivity index for coastal flooding is 0.54 for 2050, which is a final increase of about 3.3% compared to the mean value obtained for the current horizon. Overall, the climate sensitivity to coastal flooding tends to decrease in the medium term in the northern peripheral sectors, while it displays an increasing trend in the urban centre sections (figure 5.35).

By the end of the century, the sensitivity to coastal flooding is around average values of 0.49, which represents a reduction of 5.9% with respect to the base value of the index. In this scenario there is a general downward trend in the municipality as a whole, with minimum values below 0.19 in sections to the north of the capital, and sharp decreases in sensitivity for sections of the south coast and the centre of the capital.

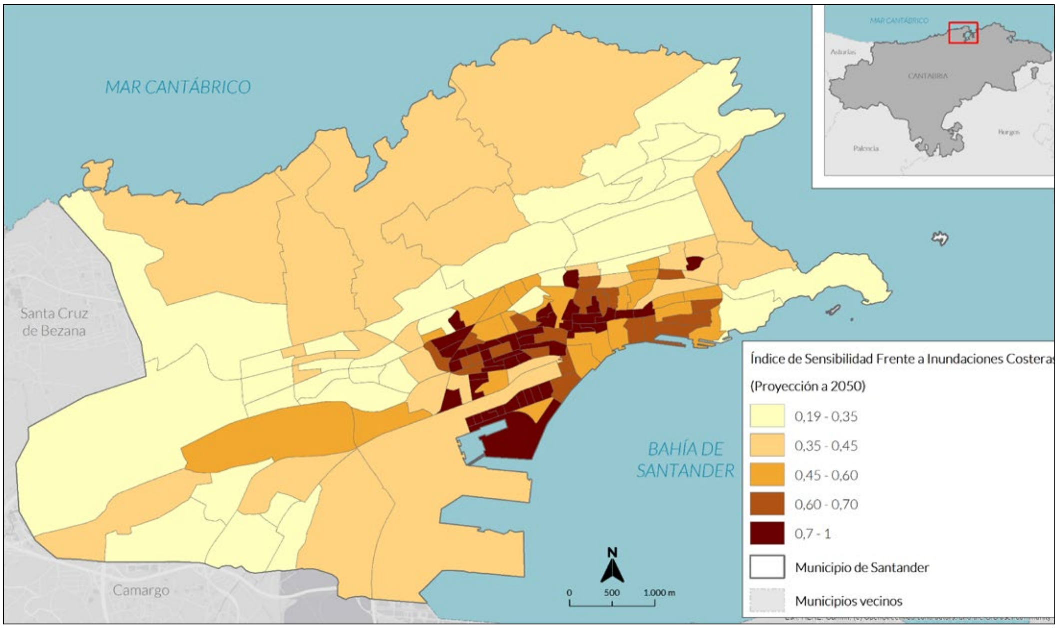


Figure 5.35. *Normalised Coastal Flood Climate Sensitivity Index 2050*
Source: CINCc (UC) - FIC, 2024.

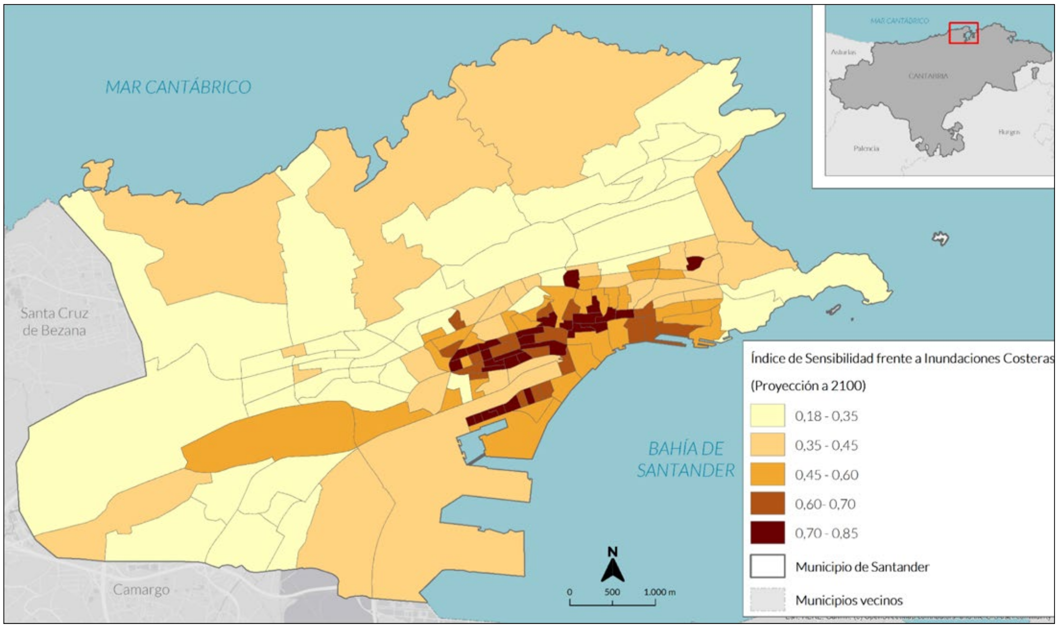


Figure 5.36. *Normalised Index of Climate Sensitivity to Coastal Floods 2100*
Source: CINCc (UC) - FIC, 2024.

5.3 CLIMATE RISK ANALYSIS

Risk represents the potential for losses that may occur to an exposed subject or system as a result of the convolution of **hazard**, **exposure** and **vulnerability**. Risk can be expressed mathematically as the probability of exceeding a certain level of economic, social or environmental consequences at a certain location and over a certain period of time.

$$\text{RISK INDEX} = \text{HAZARD} + \text{EXPOSURE} + \underbrace{[\text{Sensitivity} - \text{Adaptative Capacity}]}_{\text{VULNERABILITY}}$$

In this framework, risk is conceptualised holistically or integrally, according to the integration of social, economic, material and environmental approaches. Therefore, for the urban scale considered, risk is not only related to the potential occurrence of an event, but also to the vulnerability of the municipality as an internal risk factor, i.e., its capacity to withstand the hazard and its implications.

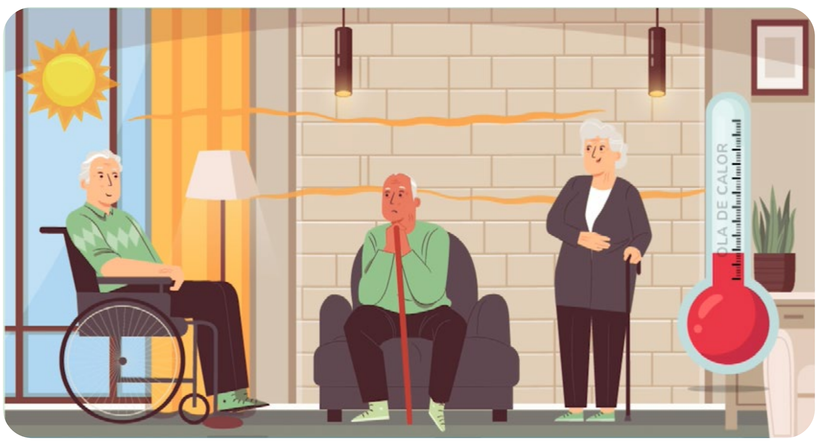
This vulnerability is analysed through a broad set of sensitivity factors at the census section scale, considering that the adaptive capacity will be implemented through the adaptation measures included in this document, including key aspects such as the updating of the various risk management and urban planning documents, as well as management, awareness and training mechanisms.

Figure 5.37. *Risk Components*
Source: IPCC, 2022b.

The IPCC 6th Assessment Report incorporates the inherently complex nature of climate risk, vulnerability, exposure and impacts, including feedbacks, cascades, non-linear behaviour and the potential for surprise.

By assessing the degree of exposure and vulnerability (socio-economic, material and environmental) to the hazards analysed, four types of risk have been identified. The first group includes risks related to **extreme rainfall**, which mainly affects roads in the urban area, with phenomena of flooding or surface runoff, and may also involve periods of flooding in watercourses and troughs.

Another large risk group includes phenomena derived from **extreme temperatures**, with a special incidence on surface temperatures. These situations contribute to urban heat islands, heat waves and the occurrence of hot nights with particular health impacts. In addition, periods of meteorological drought can be exacerbated by this phenomenon. A third group is related to **extreme wind**. This document, in particular, has focused on the impacts of southerly winds. Finally, the fourth group includes **coastal flooding** due to the set of impacts from sea level rise, combined with storm surges or the influence of stormy periods, or the south wind.



5.3.1. Risks from Extreme Rainfall

Risk from Pluvial Flood Events on Roads

The risk index for pluvial flooding events on roads for each time horizon and census section is obtained by combining and normalising three variables: (I) the Hazard Index, obtained from the average of the frequency of extreme rainfall events in the different climate scenarios; (II) the result of floodable roads as a representative measure of the level of Exposure, calculated as a percentage of km^2 of roads with a probability of flooding with respect to the total km^2 of roads in the municipality; and (III) the Climate Sensitivity Index for current and projected extreme rainfall events in 2050 and 2100.

The normalised risk index for flooding on roads due to extreme precipitation events maintains low to moderate values for both the historical and projected short-term periods in almost the entire municipality, except for certain neighbourhoods in the centre of the capital and the southern coast, where relatively higher values are reached, below 0.88. The average risk index in the municipality is 0.45 and 0.49 for the historical and projected short-term periods, respectively. For the medium and long term, a generalised increasing trend is observed, mainly towards medium or medium-high values in the normalised risk index, maintaining in both cases very moderate values in the northern and eastern sectors of the municipality. The average for the medium and long term is 0.55 and 0.57, respectively, reaching maximum values, mainly associated with residential neighbourhoods in the south, coinciding with the consolidated sector of the capital.

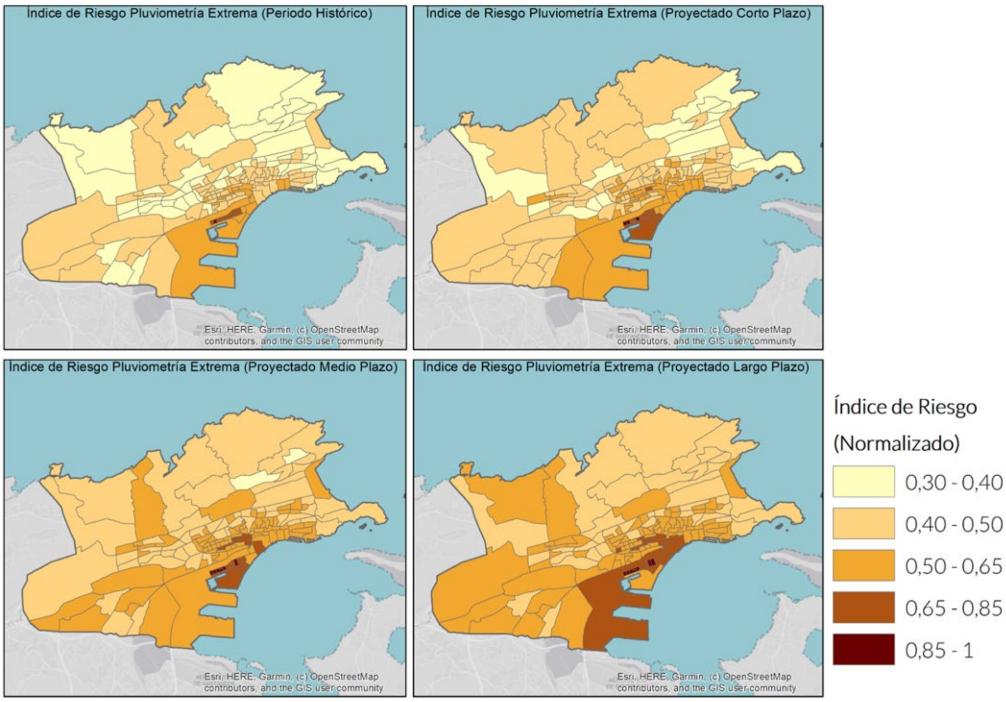


Figure 5.38. *Normalised Risk Index for Pluvial Flood Events on Roadways*

Note: For historical period (top left), projected short (top right), medium (bottom left) and long term (bottom right) by census sections.

Source: CINCc (UC) - FIC, 2024.

The **normalised risk index** for rainfall flooding events with significant impact on roads in the city centre shows a severe impact in different sections of the Castilla-Hermida neighbourhood, and with smaller but equally important values in other areas of the centre, in the area around the Estaciones, as well as in neighbourhoods such as Calle Alta and San Fernando. It should be borne in mind that the variability of rainfall can compromise the existing drainage system, so specific studies related to extreme rainfall in short periods should be considered for the sectors indicated. The detailed analysis of the real conditions of the drainage network in the face of these projections makes it possible to define the need to extend the network with a separate system or increase the sections of the existing collectors.

In any case, the proposal of the Adaptation Plan follows the criteria of sustainability and environmental protection, prioritising the creation of a separative network with rainfall harvesting measures and the combined implementation of nature-based solutions, sustainable drainage systems and increasing the permeability of urbanised soils to favour sustainable management of extreme rainfall. Given the high cost of these measures, it is considered necessary to prioritise urban sectors in which to develop adaptation solutions. Therefore, the urban sector of Castilla-Hermida and the central areas of the city of Santander should be placed on the priority list of investments aimed at reducing the impact of extraordinarily intense rainfall in short periods of time.

TABLE 5.12. *Neighbourhoods and census sections at high risk of Extreme Rainfall impacts*

NEIGHBOURHOOD	CENSUS SECTION	EXTREME RAINFALL			
		CURRENT	SHORT TERM	MEDIUM TERM	LONG TERM
Calle Alta - Cabildo	3907501009				
Castilla - Hermida - Pesquero	3907505005				
	3907505006				
	3907505007				
	3907505008				
	3907505009				
	3907505011				
	3907505012				
	3907505014				
	3907505015				
	3907505013				
Centro	3907501001				
	3907501002				
	3907501008				
Estaciones - Catedral	3907505001				
	3907505002				
	3907505004				
	3907505010				
	3907505003				
San Fernando	3907502004				
	3907502012				
	3907506001				
	3907506003				

Source: CINCc (UC) - FIC, 2024.

Risk from Fluvial Flood Events

The risk index for fluvial flood events is obtained by combining the normalised values of hazard, which is indicative of the percentage of the area under threat, exposure, expressed as the percentage of exposed roads, and the sensitivity values for flood events in the current period (figure 5.39).

Fluvial flooding has a relatively low incidence within the municipality of Santander. Flood zones only appear to the west of the municipality, coinciding with areas bordering the Arroyo Otero stream, which is approximately 1.3 km long and belongs to the Pas-Miera system of the Western Cantabrian Hydrographic Demarcation. This fluvial flood zone would affect a single census section of the municipality. The percentage of surface area threatened for this section would be 0.027%. Furthermore, within this sector, the exposed roads barely reach 0.5% of the total roads, so that, in general, the risk from fluvial flooding is low in Santander, with the possibility of triggering occasional impacts by cutting off access to private properties, or by temporary interruptions of the railway line.

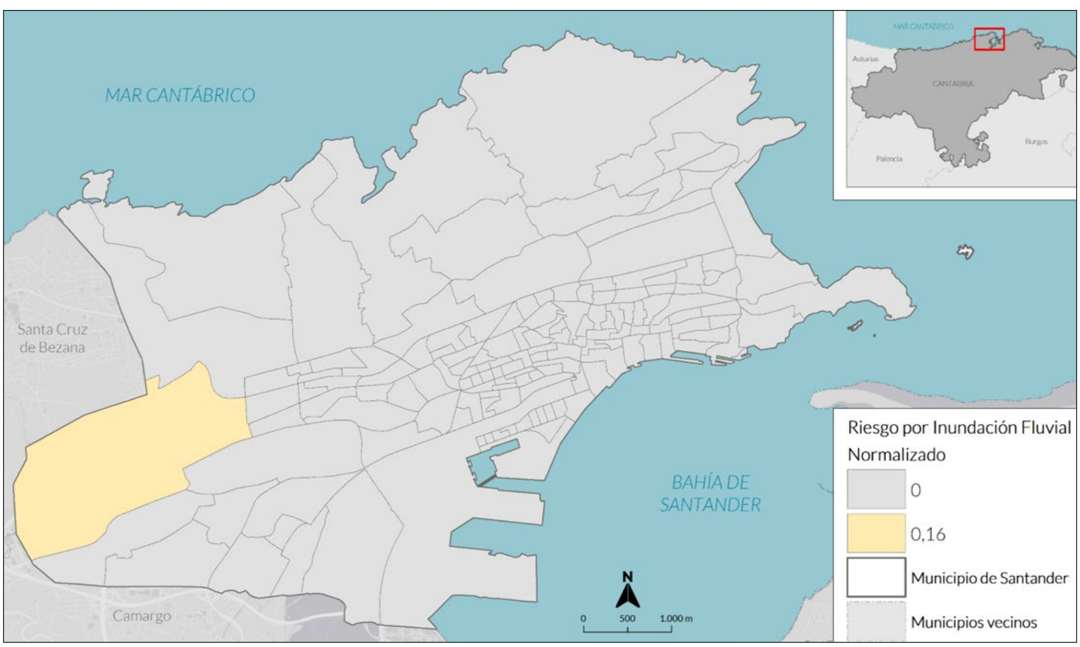


Figure 5.39. *Normalised Risk Index for Fluvial Flood events*
Source: CINCc (UC) - FIC, 2024.

As indicated above, the only census section affected, and with a low level of risk of river flooding, is in the Camarreal - Ojáiz / El Alisal neighbourhood. Although the impact of this threat on the territory is very low, the natural value of this sector should be enhanced and the area should be environmentally restored in coordination with the municipality of Santa Cruz de Bezana, with the aim of reducing possible impacts on the railway infrastructure and the natural environment.

TABLE 5.13. *List of neighbourhoods with the highest risk indexes for river flooding*

NEIGHBOURHOOD	CENSUS SECTION	RIVER FLOOD
Camarreal - Ojaiz / El Alisal	3907508004	

Source: CINCc (UC) - FIC, 2024.

5.3.2. Risks from Extreme Temperatures

Risk from Diurnal Heat Island Episodes

The normalised risk index for diurnal urban heat island phenomena in the municipality of Santander shows low or null values for the northern and eastern sections of the municipality. The southern areas of the municipality, coinciding with the port sector and residential sections of the centre, constitute the areas with the highest level of risk for the diurnal urban heat island phenomena. Several risk factors converge in these areas, as they concentrate high percentages of surface area exposed to such hazards, with high percentages of population and, in general, several conditions of human and environmental sensitivity.

These risk levels are mainly applicable to human health, and can cause general malaise, respiratory problems, sunstroke, dehydration or increased fatigue. Therefore, it can have an impact on the number of deaths or hospitalisations due to heat stroke from extreme temperature events, mainly for older population groups. These phenomena also aggravate the consequences of climate change in cities, for example by increasing the number or intensity of warm (torrid or equatorial) nights (figure 5.40).

The list of census sections and neighbourhoods with the highest risk indices corresponds to those defined in table 5.14. Given the volume of people living in the area around Castilla-Hermida, and some sectors of the city's central areas, priority should be given in these neighbourhoods to carrying out actions to adapt to this phenomenon. Likewise, as has been pointed out in terms of the degree of exposure, the industrial estates close to the port sector, Parayas and Candina in particular, present high levels of risk with a direct effect on the people who work in these areas.

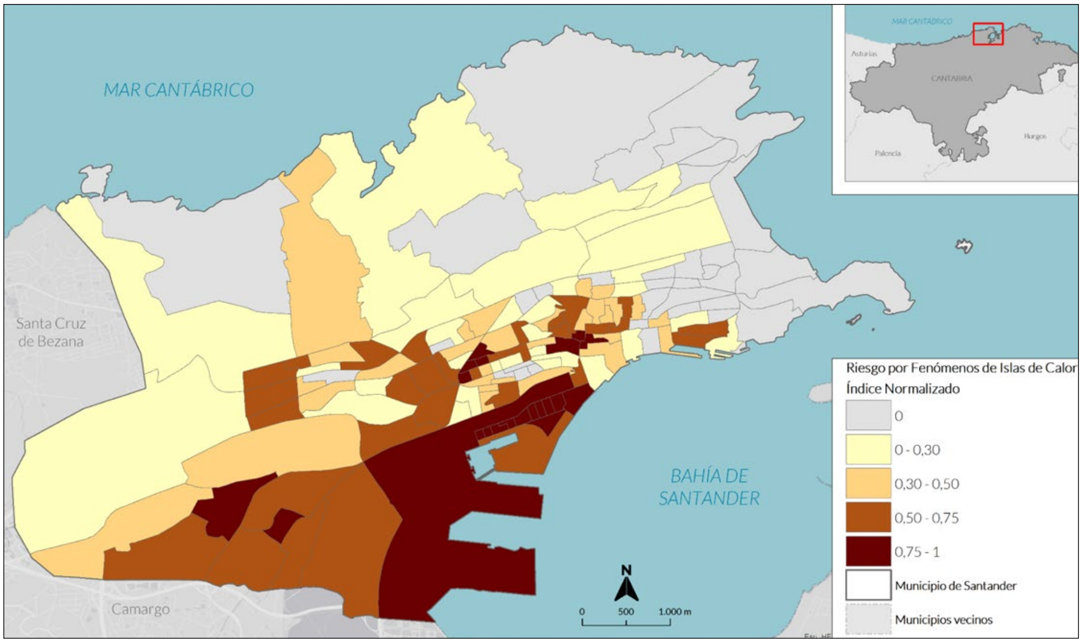


Figure 5.40. *Risk Index for Potential Diurnal Heat Islands*

Source: CINCc (UC) - FIC, 2024.

Some of these areas should be identified as Priority Adaptation Areas and the necessary corrective measures established, with a notable increase in vegetation, soil permeability and the use of high albedo materials.

TABLE 5.14. *List of neighbourhoods with the highest heat island risk indices*

NEIGHBOURHOOD	CENSUS SECTION	HEAT ISLAND
Castilla - Hermida - Pesquero	3907505005	
	3907505006	
	3907505007	
	3907505008	
	3907505011	
	3907505012	
	3907505014	
	3907505015	
Estaciones - Catedral / Castilla - Hermida - Pesquero	3907505003	
	3907505013	

[…/…]

Continuation **TABLE 5.14**

NEIGHBOURHOOD	CENSUS SECTION	HEAT ISLAND
Centro	3907501001	
	3907501004	
	3907501005	
Estaciones - Catedral	3907505004	
	3907505010	
La Tierruca	3907502007	
Peñacastillo – Hermanos - Calderón	3907508021	
	3907508029	
San Fernando	3907502010	
	3907502012	
	3907502026	

Source: CINCc (UC) - FIC, 2024.

Risk from the Occurrence of Warm Nights

The risk level for the occurrence of warm nights is applicable to **human health** and to the whole of the territory covered by the municipality of Santander. According to various sources, the ideal temperature for a good night's rest is between 16°C and 20°C, so that the occurrence of these events has a direct effect on the well-being of society, associated with difficulty in falling asleep and which, in turn, is related to other conditions such as accumulated fatigue or anxiety.

For the evaluation of the risk derived from the occurrence of warm nights, the results of the analysis of nights with minimum temperatures of 22ºC in Santander have been used, specifically, through the average number of nights with minimum temperatures of 22ºC, as a representative measure of the hazard, together with the results of climate sensitivity obtained for extreme temperature events for the current horizon and projected to 2050 and 2100, both previously normalised.

The normalised risk index for the occurrence of warm nights maintains low to moderate values for both the historical and projected short-term periods in almost the entire municipality, with the exception of certain neighbourhoods in the centre of the capital and the south coast, where relatively higher values are reached, always below 0.55. The average risk index for the municipality is 0.34 and 0.38 for the historical and projected short-term periods, respectively. These values are also strongly influenced by the **sensitivity component** with respect to the hazard component, which maintains a very insignificant incidence until the middle of the century.

For the medium term, there is a general increasing trend towards medium to high values in the normalised risk index. The average in this case stands at 0.46, reaching peaks of up to 0.65, mainly associated with neighbourhoods in the consolidated sector of the capital. For these projections, a relatively large decrease in the climate sensitivity component is expected, but this is not sufficient to offset the increase in the hazard index (figure 5.41).

This trend continues and increases towards the end of the century, where the highest risk levels are expected in general terms, with averages of around 0.7 and maximums of up to 0.87. This strong increase in the level of **risk for the end of the century** is mainly due to a strong increase in the average number of warm nights expected with respect to previous periods, which will also be accompanied by a higher incidence in residential neighbourhoods in the south, including an important part of the centre of the capital.

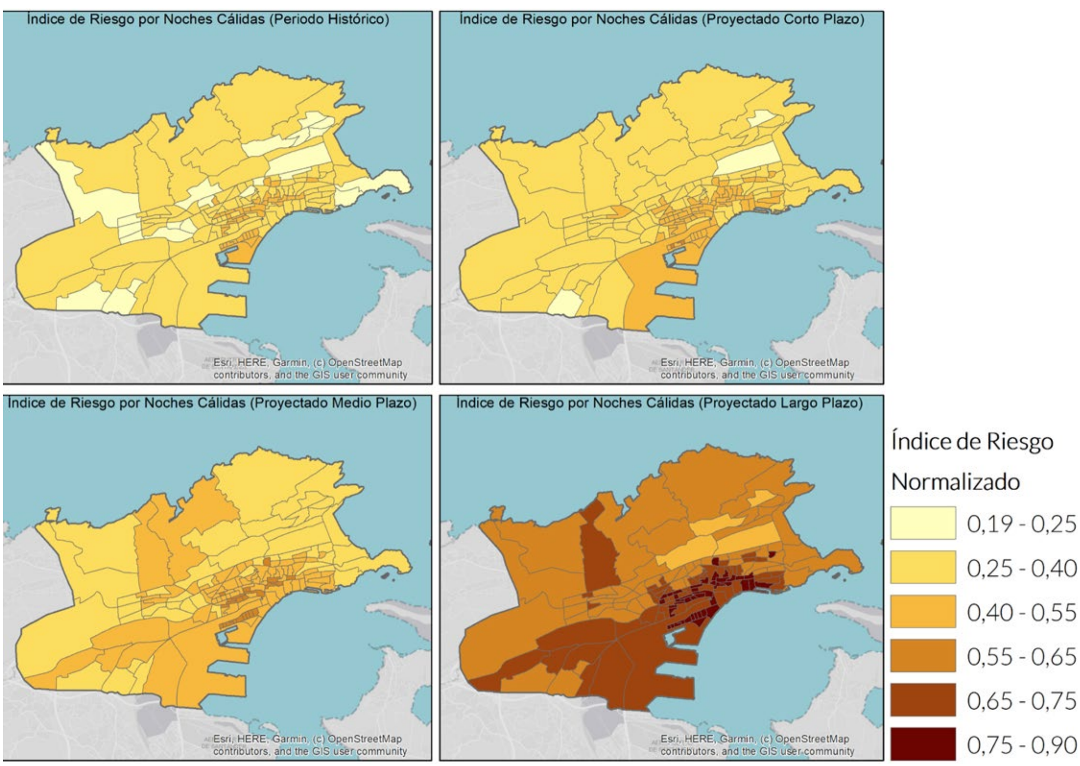


Figure 5.41. *Normalised Risk Index for the Occurrence of Warm Nights*

Note: For historical (top left), projected short (top right), medium (bottom left) and long term (bottom right) periods by census sections.

Source: CINCc (UC) - FIC, 2024.

The impact of warm nights will be very palpable in the long term in the neighbourhoods and census sections identified in the following table 5.15. The areas around Calle Alta, Estaciones, some sectors of the centre and Castilla-Hermida have high values along with other sectors of lower urban density.

TABLE 5.15. *Neighbourhoods and census sections affected by high risk indexes due to Warm Nights*

NEIGHBOURHOOD	CENSUS SECTION	WARM NIGHTS
		LONG TERM
Calle Alta - Cabildo	3907501009	
	3907501010	
	3907506002	
	3907506013	
Calle Alta - Valdecilla	3907506006	
	3907506007	
	3907506014	
Castilla - Hermida - Pesquero	3907505005	
	3907505006	
	3907505007	
	3907505011	
	3907505012	
	3907505014	
	3907505015	
	3907505013	
Centro	3907501003	
	3907501004	
	3907501005	
	3907501007	
	3907501008	
	3907503004	
	3907503006	
Estaciones - Catedral	3907505002	
	3907505004	
	3907505010	
	3907505003	
Los Castros - Fndo de Los Ríos	3907507008	
Los Castros - Pinares - V. C°	3907507018	
Prado - San Roque	3907503005	
Puerto Chico	3907503009	
	3907503010	
	3907504002	
San Fernando	3907502005	
	3907502010	
	3907502012	
	3907502025	
	3907502026	
	3907506001	
	3907506003	
Tetuán Vía Cornella	3907504004	
	3907501006	
	3907503002	

Source: CINCc (UC) - FIC, 2024.

In any case, this phenomenon has severe implications for people's health, particularly affecting vulnerable elderly people. The adaptation of dwellings, with improved insulation, favouring cross or forced ventilation, as well as control and management through early warnings and monitoring of the most vulnerable population are measures that should be prioritised in the urban sectors identified here.

Risk from Heat Wave Episodes

For the assessment of the risk from heat wave episodes, the results of the **normalised heat wave hazard index** obtained for the historical period and projected in the short, medium and long terms, which combine the intensity and frequency of these episodes, together with the results of climate sensitivity captured for **extreme temperature** events for the current horizon and that projected to 2050 and 2100, are used (figure 5.42).

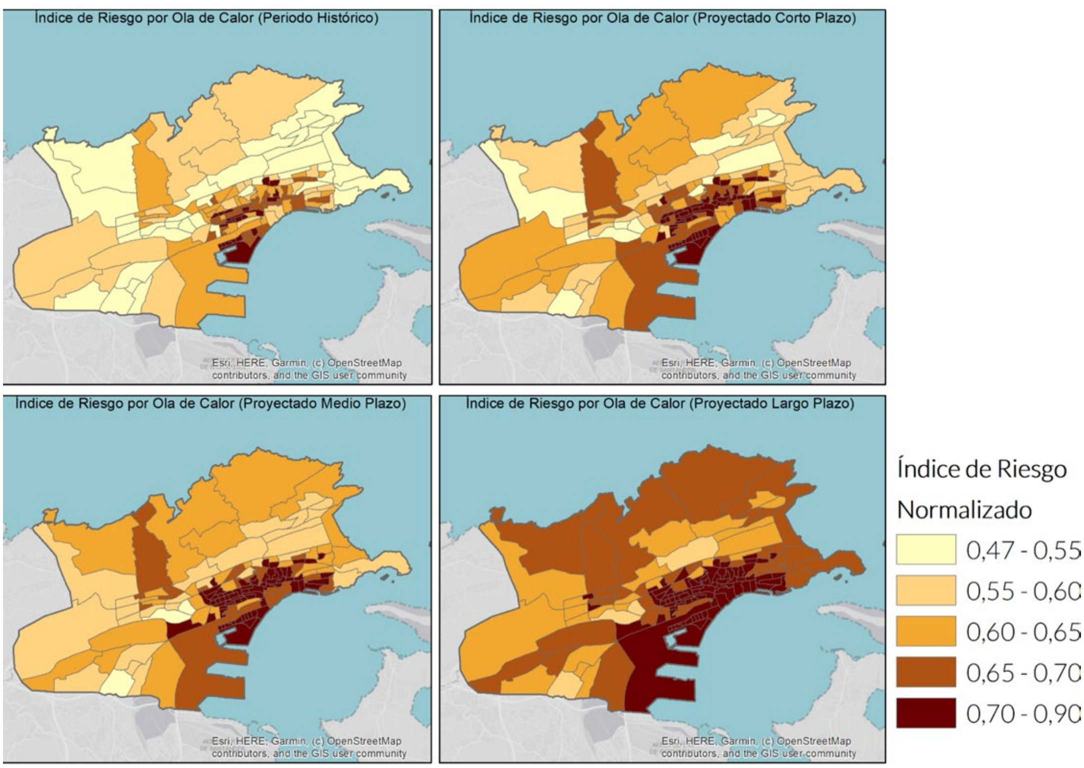


Figure 5.42. *Normalised Risk Index for the occurrence of heat waves*

Note: For historical (top left), projected short (top right), medium (bottom left) and long term (bottom right) periods by census sections.

Source: CINCc (UC) - FIC, 2024.

The normalised risk index for the occurrence of heat waves maintains values of relative importance for all the periods analysed, with minimum values above 0.47. Furthermore, it is expected that these adverse episodes will have a greater incidence in the central districts of the capital, maintaining relatively lower values for the rest of the peripheral sectors of the municipality.

The normalised risk index presents average values of 0.6 in the historical period and 0.66 for the projected period in the short and medium terms, with maximums below 0.78, 0.83 and 0.85 respectively. For the long term, there is a generalised upward trend in the risk index, reaching an average value of 0.73 and peaks of 0.87, mainly associated with neighbourhoods in the consolidated sector of the capital and the port sector. For the projected periods, a relatively large decrease in the climate sensitivity component is expected, but this is not sufficient to offset the increase in the hazard index. Therefore, this strong increase in the risk level by the end of the century is mainly due to a strong increase in the expected hazard index compared to previous periods.

The neighbourhoods and census sections that reach very high risk values at the end of the century are shown below. The identification of vulnerable people in these sectors makes it possible to establish guidelines and programmes for risk management in the face of events of these characteristics. Areas of the city centre and the neighbourhood of Cabildo, Calle Alta, in Castilla-Hermida, Fernández de los Ríos and San Fernando, are particularly sensitive to this phenomenon and already have census sections that exceed very high risk thresholds (table 5.16).

In these sectors, priority should be given to a series of actions focused on controlling the most vulnerable populations exposed to this type of phenomena, with early warning protocols and emergency health management.

TABLE 5.16. *Neighbourhoods and census sections with high long-term heat wave risk indices*

NEIGHBOURHOOD	CENSUS SECTION	HEAT WAVES			
		HISTORICAL	SHORT TERM	MEDIUM TERM	LONG TERM
Calle Alta - Cabildo	3907501009				
	3907501010				
	3907506002				
	3907506013				
Calle Alta - Valdecilla	3907506006				
	3907506007				
	3907506009				
	3907506014				

[…/…]

Continuation **TABLE 5.16**

NEIGHBOURHOOD	CENSUS SECTION	HEAT WAVES			
		HISTORICAL	SHORT TERM	MEDIUM TERM	LONG TERM
Campogiro - Cajo	3907506010				
Castilla - Hermida - Pesquero	3907505005				
	3907505006				
	3907505007				
	3907505008				
	3907505009				
	3907505011				
	3907505012				
	3907505014				
	3907505015				
Castilla -Hermida	3907505013				
Cazoña	3907502024				
	3907508006				
Centro	3907501001				
	3907501002				
	3907501003				
	3907501004				
	3907501005				
	3907501007				
	3907501008				
	3907503004				
	3907503006				
Centro / Estaciones	3907505001				
Ciudad Jardín - Cuatro Caminos	3907502008				
	3907502009				
	3907502013				
Estaciones - Catedral	3907505002				
	3907505004				
	3907505010				
Estaciones - Castilla	3907505003				
G. Dávila - Los Castros	3907507005				
La Tierruca	3907502002				
	3907502007				
	3907502022				

[…/…]

Continuation **TABLE 5.16**

NEIGHBOURHOOD	CENSUS SECTION	HEAT WAVES			
		HISTORICAL	SHORT TERM	MEDIUM TERM	LONG TERM
Los Castros - Fernando de Los Ríos	3907507008				
	3907507009				
Los Castros - Los Pinares - V. Del Camino	3907507013				
	3907507014				
	3907507015				
	3907507018				
Prado - San Roque	3907503003				
	3907503005				
	3907503007				
	3907503008				
	3907503013				
	3907503014				
Puerto Chico	3907503009				
	3907503010				
	3907504001				
	3907504002				
	3907504003				
San Fernando	3907502004				
	3907502005				
	3907502006				
	3907502010				
	3907502011				
	3907502012				
	3907502015				
	3907502025				
	3907502026				
	3907506001				
	3907506003				
	3907506005				
San Francisco - Pronillo	3907507002				
	3907507003				

[…/…]

Continuation **TABLE 5.16**

NEIGHBOURHOOD	CENSUS SECTION	HEAT WAVES			
		HISTORICAL	SHORT TERM	MEDIUM TERM	LONG TERM
Tetuán	3907504004				
	3907504005				
	3907504006				
	3907504007				
	3907504008				
Vía Cornella	3907501006				
	3907502020				
	3907502021				
	3907503001				
	3907503002				

Source: CINCc (UC) - FIC, 2024.

Heat waves are evolving into events of greater magnitude, duration and affecting more people, requiring a comprehensive approach that incorporates a public health perspective, **preparedness** and **response**, and **early warning** (OPS, OMS, 2019). The number of deaths attributable to heat during the period 2000-2009 for Santander was 16 people (Carmona et al., 2016). However, we do not have up-to-date detailed figures on the impact of excessive heat. Absolute values are available for the whole community of Cantabria. The system for monitoring daily all-cause mortality (MoMo)[2] was developed in 2004, within the framework of the 'Plan of preventive actions against the effects of excessive temperatures', coordinated by the Ministry of Health, to reduce the impact on the health of the population as a consequence of excess temperature.

The MoMo Panel (Ministerio de Sanidad, 2023) updates daily estimates of excess mortality due to all causes and attributable to an excess or defect in temperature, by population (national, Autonomous Community and provincial), sex and age group. The evolution of deaths attributable to excess temperature has been very erratic in recent years, with 3 deaths in 2019, 7 in 2020, 2 in 2021 and 3 in 2022. However, Cantabria suffers a notable increase in the period studied (1 May to 31 October), with the figure rising to 76 deaths in 2023.

It should be noted that the episodes of heat waves in 2023 were extraordinary and unusual, with a very high incidence between the months of August and September. The orographic conditions of the community of Cantabria determine the propensity for increased heat impact

2 See: Ministerio de Sanidad (2023). https://momo.isciii.es/panel_momo/

in some valleys in mountainous areas, where high ozone concentrations occur. In sectors where the physical limits imposed by the topography are not so evident, generally along the coast, the situations are less agressive. However, in the light of the data, we cannot rule out the impact that heat waves have on coastal municipalities such as Santander.

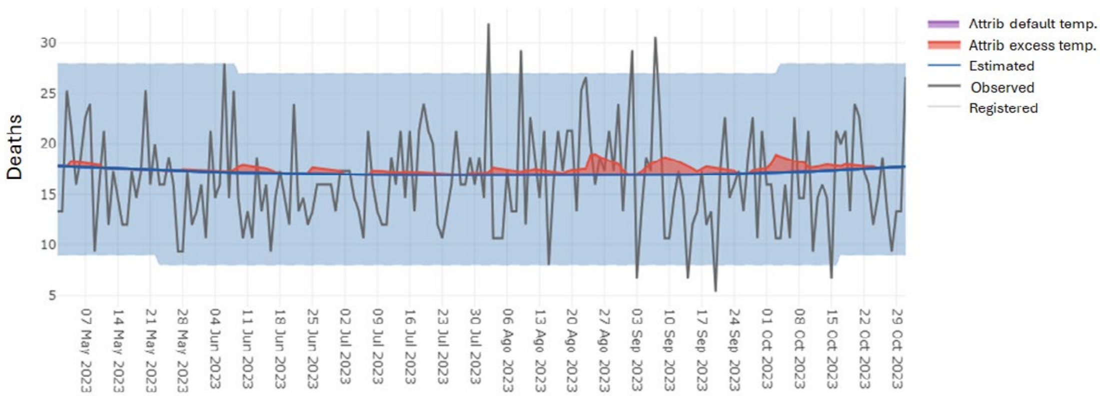


Figure 5.43. *Observed and estimated deaths, attributable to excess temperature*

Source: MOMO, 2024.

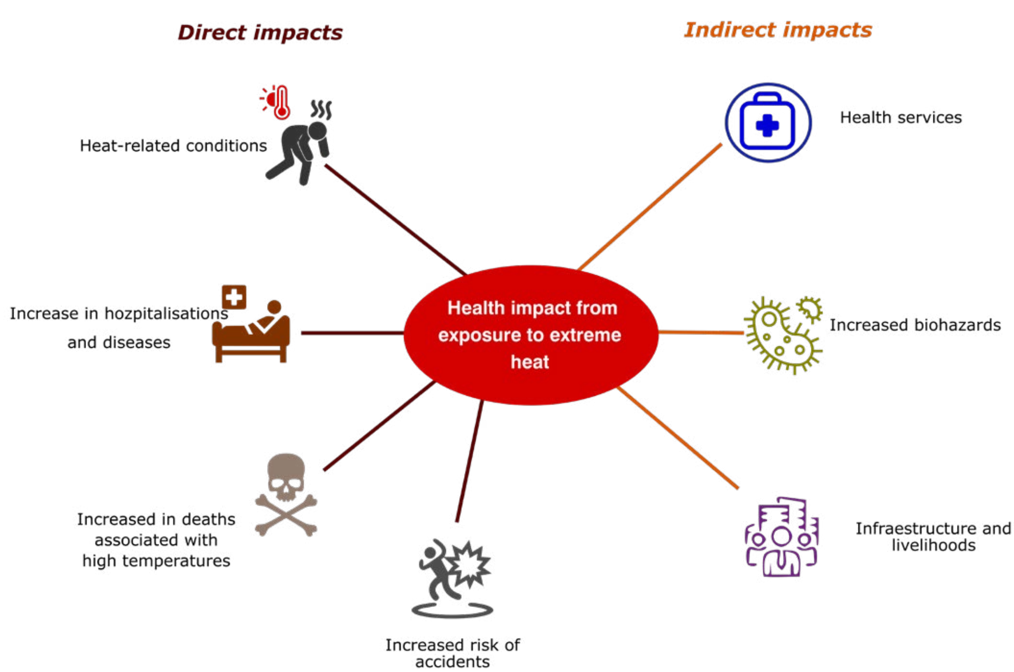


Figure 5.44. *Direct and indirect impacts of extreme heat exposure*

Source: CINCc (UC), 2024, based on data from OPS, OMS (2019).

The excess mortality recorded in 2023 shows a temporary situation that cannot be extrapolated to future episodes; however, we must be aware of the magnitude of the phenomenon and ensure an adequate response for the management of heat waves.

The direct and indirect impacts of exposure to extreme heat are reflected in figure 5.44 and involve a set of situations that can put health and assistance services in a critical situation, while entailing a considerable cost in resources and materials for the public health and civil protection system.

Risk from Meteorological Drought Episodes

The Meteorological Drought Risk Index in Santander is obtained by integrating the results of the **Drought Hazard Index** for each time horizon, captured as a normalised average value of the SPEI accumulated at 24 and 60 months, together with the results of the current and projected climate sensitivity index in the medium and long terms. The Drought Risk Index for the short, medium and long terms is analysed as a relative value that tries to establish a deviation with respect to the historical period, considering the historical drought as the reference or base value (figure 5.45).

The normalised risk index for drought episodes maintains low to moderate values in the short term, with average values around 0.38 and maximum values below 0.58, remaining at the risk threshold with respect to the historical period and with a higher incidence for the southern areas, mainly due to their greater sensitivity.

The risk for successive periods is increasing, mainly due to increases in the 24-month and 60-month cumulative SPEI, indicating a trend towards drier thresholds, respectively. The medium and long-term normalised risk index has mean values around 0.46 and 0.58, and maxima below 0.65 and 0.75, respectively. In both cases, it is expected that these adverse episodes will have a higher incidence in the central districts of the capital, maintaining relatively lower values for the rest of the peripheral sectors of the municipality.

For the projected periods, a relatively significant decrease in the climate sensitivity component is expected, which, however, is not sufficient to counteract the increase in the hazard index. Therefore, this increase in the risk level by the end of the century is mainly due to the successive increase in the expected hazard index compared to the reference period.

It should be noted that the phenomenon of drought will be exacerbated by the end of the century and there are numerous neighbourhoods and census sections that may be affected with high risk index (table 5.17). The neighbourhoods of El Cabildo, Calle Alta, Castilla-Hermida and Pesquero, as well as San Fernando, have been identified as very high risk sectors in the medium and long terms. It is, therefore, necessary to establish and prioritise a control-monitoring and response programme in these urban sectors given the numerous effects that they have on services and public risk management.

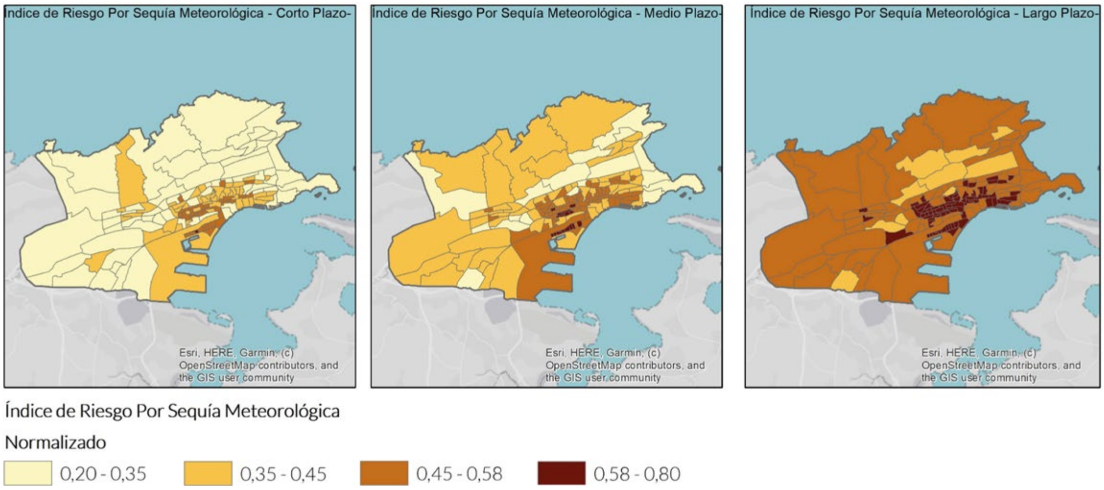


Figure 5.45. *Meteorological Drought Risk Index*

Source: CINCc (UC) - FIC, 2024.

TABLE 5.17. *Set of neighbourhoods and census sections with high drought risk indices*

NEIGHBOURHOOD	CENSUS SECTION	DROUGHT		
		SHORT TERM	MEDIUM TERM	LONG TERM
Calle Alta - Cabildo	3907501009			
	3907501010			
	3907506002			
	3907506013			
Calle Alta - Valdecilla	3907506006			
	3907506007			
	3907506014			
Campogiro - Cajo	3907506010			
Castilla - Hermida - Pesquero	3907505005			
	3907505006			
	3907505007			
	3907505011			
	3907505012			
	3907505014			
	3907505015			
	3907505013			
Cazoña	3907502024			
	3907508006			

[…/…]

Continuation **TABLE 5.17**

NEIGHBOURHOOD	CENSUS SECTION	DROUGHT		
		SHORT TERM	MEDIUM TERM	LONG TERM
Centro	3907501001			
	3907501003			
	3907501004			
	3907501005			
	3907501007			
	3907501008			
	3907503004			
	3907503006			
Ciudad Jardín - Cuatro Caminos	3907502008			
	3907502009			
	3907502013			
Estaciones - Catedral	3907505002			
	3907505004			
	3907505010			
	3907505003			
La Tierruca	3907502002			
	3907502007			
Los Castros - Fernando de Los Ríos	3907507008			
	3907507009			
Los Castros - Los Pinares - V. Del Camino	3907507013			
	3907507014			
	3907507015			
	3907507018			
Prado - San Roque	3907503005			
	3907503008			
	3907503013			
Puerto Chico	3907503009			
	3907503010			
	3907504002			
	3907504003			
San Fernando	3907502004			
	3907502005			
	3907502006			
	3907502010			

[…/…]

Continuation **TABLE 5.17**

NEIGHBOURHOOD	CENSUS SECTION	DROUGHT		
		SHORT TERM	MEDIUM TERM	LONG TERM
San Fernando	3907502011			
	3907502012			
	3907502015			
	3907502025			
	3907502026			
	3907506001			
	3907506003			
	3907506005			
San Francisco - Pronillo	3907507002			
	3907507003			
Tetuán	3907504004			
	3907504006			
	3907504007			
Vía Cornella	3907501006			
	3907502020			
	3907502021			
	3907503002			

Source: CINCc (UC) - FIC, 2024.

5.3.3. Extreme Wind Risk

Risk from Episodes of South Wind Gusts

For evaluating the risk from the occurrence of southerly wind gusts, the results of the **normalised hazard index** are used, obtained through the mean value per census section of the maximum southerly wind gust for the historical period, and projected in the short, medium and long terms, together with the results of climate sensitivity captured for extreme wind events for the current horizon and projected to 2050 and 2100. This is done together with the results of exposure, obtained through the percentage of south-facing surface area per census section.

The normalised risk index for the occurrence of southerly wind gusts maintains values of relative importance for all the periods analysed, with minimums of 0 for the sections free of south-facing slopes, and minimums above 0.39 for the remaining sections (figure 5.46). Furthermore, it is expected that these adverse episodes will have a greater incidence in the southern sector of the municipality, including the port area and central districts of the capital, maintaining relatively lower values for the rest of the peripheral sectors of the municipality.

The normalised risk index presents average values of 0.69 in the historical period and 0.68 and 0.66 for the projected period in the short and medium term, with maximums reaching levels of 0.97, 0.96 and 0.92, respectively. For the long terms, there is a general downward trend in the risk index, reaching an average value of 0.62 and peaks of 0.87, mainly associated with neighbourhoods in the consolidated sector of the capital. This decrease in the projected periods is mainly due to a decrease in the future climate sensitivity index, together with a decrease, in this case, not very noticeable in the hazard index.

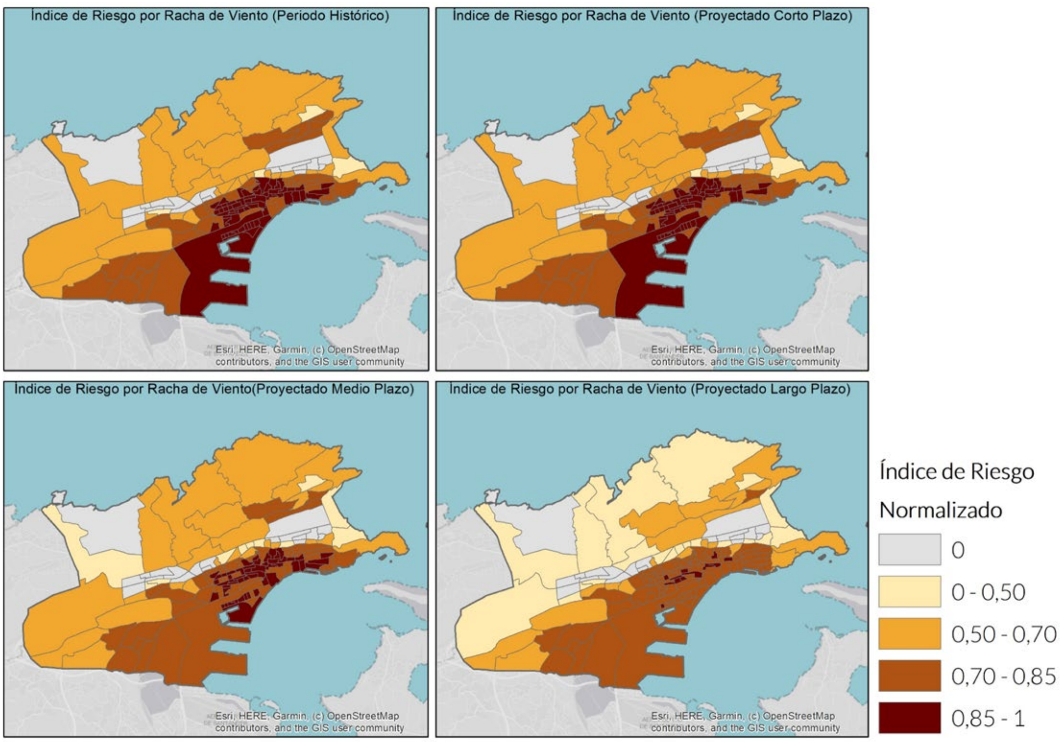


Figure 5.46. *Normalised Wind Risk Index for Southerly Wind Gusts*

Source: CINCc (UC) - FIC, 2024.

The following is a list of neighbourhoods with their census sections that maintain very high risk indices for south wind gusts, despite the general reduction of wind in the long term (table 5.18). With a very uneven distribution, the impact of this phenomenon on buildings can be considerable, which is why their maintenance with the revision of façade elements and possible loose parts in roofs and ceilings must be programmed and managed by the private sector.

Dwellings located on high points and facing south, south-east along with heights of more than five storeys are particularly vulnerable to this phenomenon.

On the other hand, the health effects of this climatic component must be considered by the health services and the vulnerable population in these sectors must be monitored.

TABLE 5.18. *Neighbourhoods and sections that maintain high long-term Extreme Wind Risk Indices*

NEIGHBOURHOOD	CENSUS SECTION	EXTREME WIND			
		CURRENT	SHORT TERM	MEDIUM TERM	LONG TERM
Calle Alta - Cabildo	3907501009				
	3907506002				
	3907506013				
Calle Alta - Valdecilla	3907506014				
Castilla - Hermida - Pesquero	3907505007				
Centro	3907501003				
	3907501004				
	3907501008				
Puerto Chico	3907503009				
San Fernando	3907502025				
	3907506001				

Source: CINCc (UC) - FIC, 2024.

5.3.4. Coastal Flood Risk

Risk from Coastal Flood Events on the Urban Environment

The **Normalised Risk index** for coastal flooding events shows very high values for the sector coinciding with the Sardinero coasts in all the scenarios analysed with respect to the rest of the coastal sectors of the municipality.

For the historical scenario (figure 5.47), the risk index maintains moderate values for the coastal sector in the north of the municipality, including the coastal area bordering the San

Pedro del Mar estuary, Bañaperros and El Bocal. The same shows relatively low values for the rest of the threatened coastal neighbourhoods to the north, east and south of the municipality.

In the middle of the century (figure 5.48), for the RCP8.5 emission scenario, a similar level of risk is foreseen with respect to the historical scenario. This could also affect the urban neighbourhood adjacent to the Sardinero sector, due to the greater extension of the coastal flooding area in that sector for that period.

At the end of the century (figure 5.49), for the RCP8.5 emission scenario, greater increases in the level of risk are expected, mainly for the eastern and southern sectors of the municipality, as well as new neighbourhoods that could be impacted by coastal flooding events. The risk index reaches its highest value in this scenario in the Sardinero sector, followed by the consolidated urban sector in the south of the municipality.

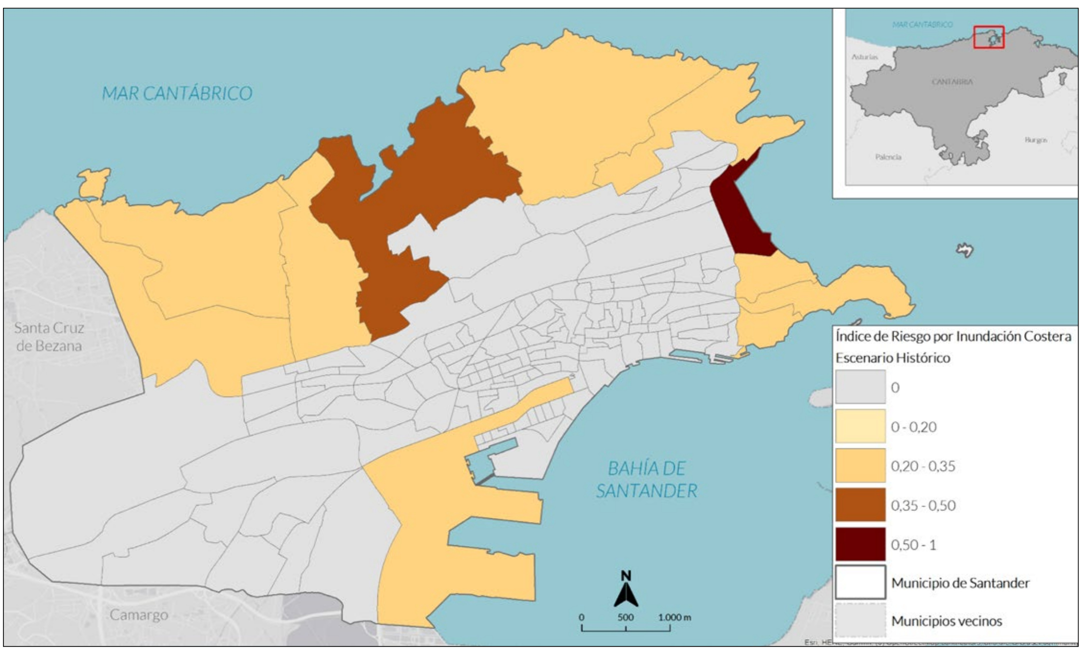


Figure 5.47. *Normalised Coastal Flood Hazard Index, Historical Scenario*

Source: CINCc (UC) - FIC, 2024.

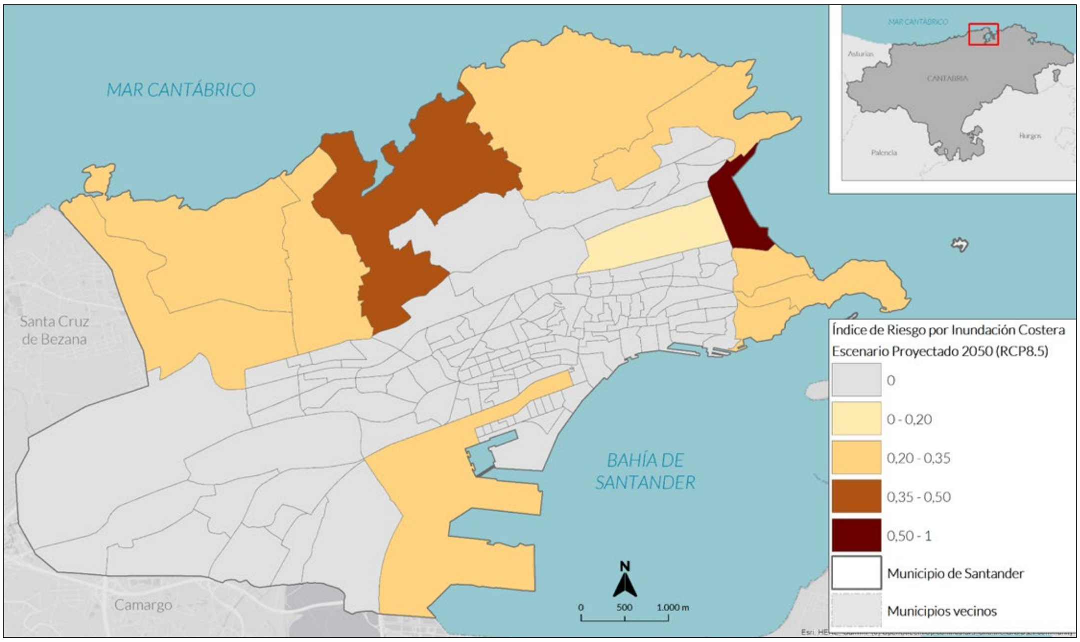


Figure 5.48. *Normalised Coastal Flood Risk Index, Projected Scenario to 2050 (RCP8.5)*
Source: CINCc (UC) - FIC, 2024.

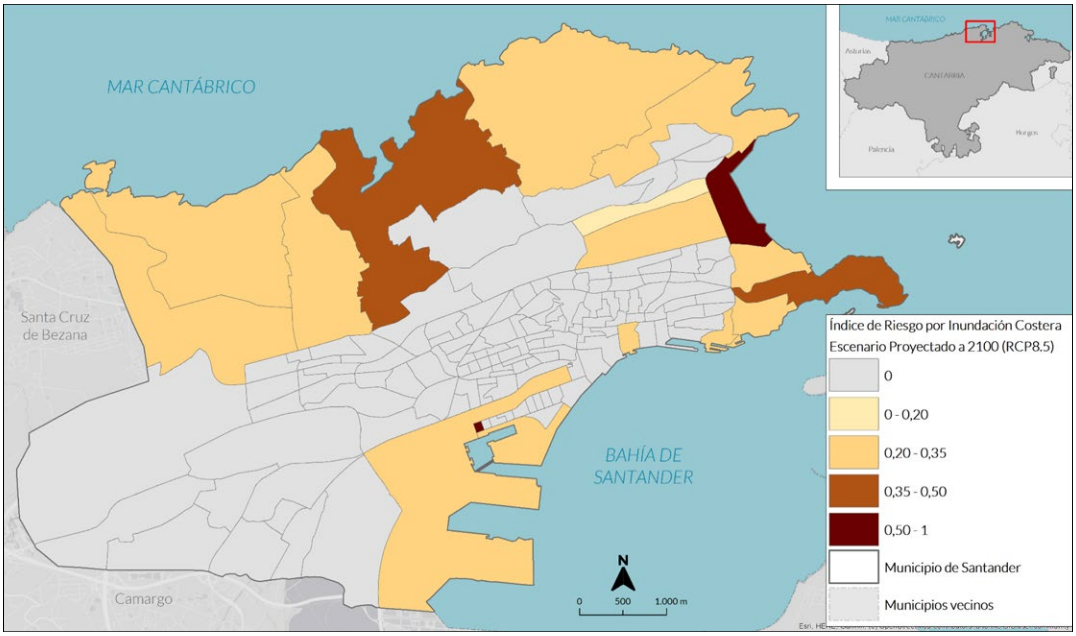


Figure 5.49. *Normalised Coastal Flood Hazard Index, Projected Scenario to 2100 (RCP8.5)*
Source: CINCc (UC) – FIC, 2024.

TABLE 5.19. *Neighbourhoods and census sections at medium, high and very high long-term risk of Coastal Floods*

NEIGHBOURHOOD	CENSUS SECTION	COASTAL FLOODING		
		CURRENT	MEDIUM TERM	LONG TERM
Puerto Chico	3907504001			
Tetuán	3907504008			
Sardinero	3907504009			
	3907504010			
	3907504011			
	3907504012			
	3907504013			
Castilla - Hermida - Pesquero	3907505008			
	3907505009			
	3907505015			
Monte	3907508009			
Cueto	3907508011			
	3907508012			
San Román de la Llanilla	3907508007			
	3907508024			

Source: CINCc (UC) - FIC, 2024.

Rising sea levels, with extreme phenomena such as storm surges, pose a clear risk to the coastline of the city of Santander. The most significant impacts occur on the beaches of the municipality, with retreat and loss of sand, putting pedestrian areas and infrastructures at risk. The neighbourhood of El Sardinero and the surrounding beaches, especially the Second Beach, is a highly vulnerable sector, which has maintained very high risk indices throughout the different periods analysed. This situation can cause the height to rise in certain coastal areas where, in periods of intense southerly winds, the water can affect various sectors of Castilla-Hermida and Puerto Chico. Likewise, the northern beaches along the neighbourhoods from Cueto to San Román de la Llanilla may be affected and increase the risk values.

5.4 DIAGNOSTIC AND STRATEGIC PROPOSALS FOR SCN

F. García, C. Ribalaygua, N. Herrera, L. Asensio, C. Gil, J. González, D. Rasilla, P. Fernández, S. Pérez, F. Conde

Based on a comprehensive diagnosis, several **strategic proposals** for Santander Capital Natural have been proposed. These are thematic projects that bring together the main ideas and solutions contributed throughout the process, both in the technical and citizen workshops as well as in the technical sessions held with experts.

5.4.1. Diagnostic

Following the development of hazard-specific risk indices, the cross-cutting conclusions identify four main risk groups facing Santander. The impact of **extreme precipitation**, **high temperatures**, potential health and building impacts caused by **extreme wind** and, finally, impacts on the coastline due to **coastal flooding**. These risk groups highlight the need to address a set of adaptation measures for an effective response to Santander's climate resilience.

Addressing the risks associated with **pluvial flooding** events, especially in critical urban areas such as Castilla-Hermida and Santander city centre, requires priority attention. These locations show a severe impact due to rainfall variability, which compromises the existing drainage system and requires the extension of the network with separative systems or the increase of collector sections.

Although the risk of **fluvial flooding** is practically non-existent, it is advisable to identify and protect these areas that are currently little affected in order to reduce future risks, and to work with the municipality of Santa Cruz de Bezana to restore these areas environmentally.

Also noteworthy is the risk associated with **high temperatures**, which requires the definition of Urban Adaptation Areas (García, 2019), emphasising the need to implement adaptive actions in industrial estates close to the port, as well as in areas with a high density of vulnerable population. Heat waves, prolonged drought and the threat of hot nights also require attention, especially in densely populated neighbourhoods such as Calle Alta, Las Estaciones and Castilla-Hermida, where it is recommended to improve housing conditions and establish early warning protocols to protect the vulnerable population.

Exposure to **extreme winds**, especially those of a southerly component, has a special effect on the vulnerable population as well as on high-rise buildings along the first line of impact of wind gusts.

To complete this diagnosis, it highlights the risk associated with rising **sea levels** in combination with storm events or storm surges, mainly affecting the beaches of the municipality, such as El Sardinero, and the need to establish various protection measures in other vulnerable coastal areas.

It, therefore, highlights the need to take measures to protect the population and infrastructure from the risks associated with climate change in the city of Santander, favouring early recovery from extreme events. The set of measures proposed below seek to respond to these risks by controlling and managing the impacts associated with them.

5.4.2. Strategic Proposals for Santander Capital Natural

In coherence with the previous diagnosis, four strategies have been proposed focused on the challenge of facing the main impacts deduced for the future scenario in the municipality of Santander, within the framework of the Santander Capital Natural project. These proposals identify the main adaptation objectives based on the needs detected in the study along with the collaboration of institutions and experts, as well as citizens.

1. Developing Green Infrastructure as a Cross-cutting Adaptation Resource

The benefits that nature brings in terms of health, well-being, environmental sustainability and resilience to climate change, lead to the need to incorporate this resource as a key tool in the improvement of cities. In the context of climate change, some of the services provided by green infrastructure contribute dramatically to the improvement of air quality, the mitigation of greenhouse gases, the regulation of urban climate and the adaptation of the urban fabric to direct threats, especially extreme rainfall and rising temperatures.

Therefore, the identification and development of a strong green infrastructure in the city of Santander is a key cross-cutting measure to achieve a truly resilient city. Green infrastructure must be planned, designed and maintained to maximise its benefits while minimising negative impacts. To ensure its effectiveness, it must consider:

- Connectivity of green spaces.
- Type of vegetation.
- Water management.
- Community participation.

Ecosystem connectivity of green infrastructure is necessary to promote biodiversity and provide strategic ecosystem services for urban adaptation in Santander. Ecological corridors and connectivity between green areas can contribute to increasing the resilience of urban ecosystems to climate change impacts, such as heat waves, floods and droughts, by helping to regulate the water cycle, improve air quality, control soil erosion or provide habitats for pollination and pest control.

Figure 5.50. *Ecosystem Connectivity of Santander's Green Infrastructure*
Source: CINCc (UC), 2024.

In the case of Santander, the **Vaguada de Las Llamas corridor** has become the centre of gravity of a complex multifunctional system that allows connectivity between the rural areas of the north and the landscaped poles, generally in private areas, of the east (El Sardinero) and southwest (Nueva Montaña). A green structure with a very marked **east-west** component, defined by the topographical conditions whose protection and promotion should be a strategic issue, needs to be introduced in the regulatory documents for the development of urban planning.

Therefore, the design of the municipal green infrastructure should optimise the potential for connectivity between public and private green spaces. An initial assessment of private plots of land destined for landscaped or naturalised green spaces, either due to a lack of buildings or specific uses, totals almost three million m^2 of surface area. This is equivalent to 44% of the existing green space of the urban land.

The development of the Green Infrastructure Plan, incorporated as a specific action within the Santander Capital Natural Strategy, offers the opportunity to integrate potential private space sites that can be integrated into the ecosystemic network. These green spaces facilitate the connection of the powerful urban green facilities that function as strategic linear corridors, the Magdalena Peninsula and the coastal cliffs (Peligros - Magdalena - El Camello), the north-eastern coastal green system (El Faro, Mataleñas Park - Mesones Park), the transversal corridors (Las Llamas - Parque de Sotileza or del Agua - Parque del Doctor Morales or de la Vaca - La Remonta) and their extensions towards Peñacastillo as far as the marshes of the Raos Canal. Not to forget the extensive rural space in the north where it is possible to recover, through its network of paths and trails, a linear network of once abundant coastal holm oak wood, which enhances the natural values of the area and protects it from the influence of the north and north-westerly winds.

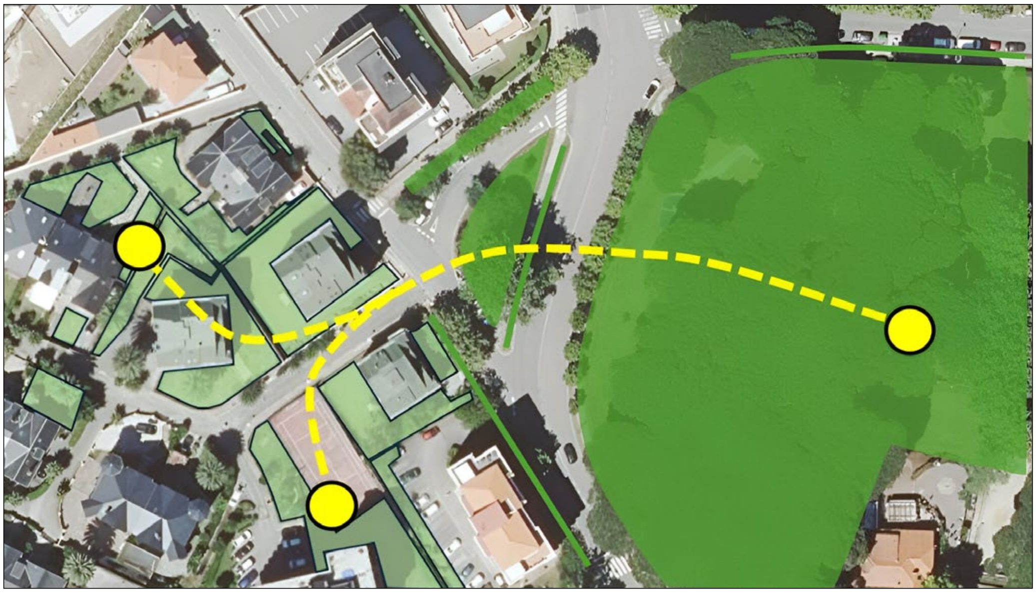


Figure 5.51. *Potential connectivity between private and public green spaces*
Source: CINCc (UC), 2024.

Santander's historical natural conditions[3] are far from the future **climate scenarios** developed by the FIC for this Plan (using the latest statistical downscaling techniques). The future climate scenarios depict a horizon in which a generalised rise in temperatures may compromise the resilience of the traditional tree and shrub species that have developed in the municipality.

In this future climate context, not all contemporary plant species will have a chance of survival. For this reason, the Plan provides a list of **adapted plant species**. The aim is to provide a list of species adapted for planting by the municipal technical services and within the actions included in the Santander Capital Natural project, based on the analysis of the potential behaviour of these species under the new conditions. Although it is worth noting the possibility of finding favourable microclimates in certain areas of the city, the stress that these species may suffer in the near future must be taken into account. In this analysis, the assessment carried out by Dr. Mariano Sánchez García (Real Jardín Botánico de Madrid) at the request of the drafting team stands out, where he identifies the behaviour of the current species in a scenario of increased temperatures and a change in the predicted rainfall regime (see table 5.20).

The table shows **42 tree and shrub species** with their expected behaviour in 2050 and 2100 using a four-colour traffic light. Green represents favourable behaviour in relation to climate change for each horizon. Yellow represents species that, by 2050, can be used with some caution depending on where they are planted. These species require surfaces that are slightly protected from the afternoon sun in the summer months, by establishing new zoning or by placing them in partial shade from other plants.

Practically all species, in the distant horizon (2100), will worsen their ability to withstand environmental conditions, and will be located in the orange and red bands. Species in these conditions require irrigation in the face of heat waves and periods of drought. A suitable strategy would be to plant in semi-shaded areas or in the shade of trees or large shrubs and in places where a certain amount of water is stored in the subsoil after rainfall.

3 In order to understand the origins of the ecosystemic connectivity of the municipality, and within the SCN project, in February 2023, Sebastián Pérez and Sara Núñez proceeded to collect a total of 15 sediment samples to be studied from a palynological point of view in the mediaeval necropolis of Los Azogues, Santander. The samples showed relatively homogeneous characteristics throughout the sequence studied. From this analysis, it can be deduced that the site would be composed of a deciduous forest in terms of the tree layer, where species such as oak, willow and hazel have a good presence in the landscape. These species are accompanied by other species typical of deciduous woodland, such as alder, birch and ash, thus demonstrating a relatively humid climate.

The thesis of a humid climate is also supported by the presence of hydro-hygrophilous vegetation, such as different types of ferns. However, the space surrounding the site would have been dominated more by open areas, in which herbaceous vegetation was the most important, with very few shrubs. Specifically, the landscape domain corresponded to grass pastures together with anthropic-nitrophilous communities, which could be evidence that this population would have been linked, among other things, to economic production activities, since these grass pastures would correspond to pastures for livestock use.

TABLE 5.20. *List of species proposed for planting in Santander*

N.°	SPECIES	2050	2100
1	*Quercus robur*	[yellow]	[orange]
2	*Quercus pyrenaica*	[orange]	[red]
3	*Quercus ilex* subsp. Ilex	[green]	[yellow]
4	*Castanea sativa*	[yellow]	[orange]
5	*Fagus sylvatica*	[yellow]	[red]
6	*Betula alba /celtiberica*	[orange]	[red]
7	*Fraxinus excelsior*	[yellow]	[orange]
8	*Alnus glutinosa*	[yellow]	[orange]
9	*Tilia platyphyllos*	[yellow]	[orange]
10	*Tilia cordata*	[orange]	[red]
11	*Salix alba*	[orange]	[red]
12	*Salix atrocinerea*	[yellow]	[orange]
13	*Ulmus glabra*	[green]	[yellow]
14	*Ulmus minor*	[green]	[yellow]
15	*Juglans regia*	[green]	[yellow]
16	*Acer campestre*	[yellow]	[orange]
17	*Acer pseudoplatanus*	[yellow]	[orange]
18	*Prunus avium*	[yellow]	[orange]
19	*Prunus mahaleb*	[yellow]	[orange]
20	*Ilex aquifoliun*	[yellow]	[orange]
21	*Laurus nobilis*	[green]	[yellow]
22	*Arbutus unedo*	[green]	[yellow]
23	*Phillyrea latifolia* [Taxon]	[green]	[yellow]
24	*Rhamnus alaternus*	[green]	[yellow]
25	*Pistacia lentiscus*	[green]	[green]
26	*Ligustrum vulgare*	[green]	[green]
27	*Frangula alnus*	[orange]	[red]
28	*Coryllus avellana*	[orange]	[red]
29	*Crataegus monogyna*	[yellow]	[orange]
30	*Malus sylvestris*	[yellow]	[orange]
31	*Pyrus cordata /pyraster*	[yellow]	[orange]
32	*Sorbus aria*	[orange]	[red]
33	*Sorbus aucuparia*	[orange]	[red]
34	*Prunus spinosa*	[orange]	[red]
35	*Berberis vulgaris*	[yellow]	[orange]
36	*Cornus sanguinea*	[yellow]	[orange]
37	*Euonymus europaeus*	[yellow]	[orange]
38	*Sambucus nigra*	[yellow]	[yellow]
39	*Viburnum lantana*	[yellow]	[orange]
40	*Viburnun tinus*	[green]	[yellow]
41	*Rosa canina*	[green]	[green]
42	*Rosa semperviren*	[green]	[green]

Source: CINCc (UC), 2024, based on a list provided by the Santander City Council.

With global change, **new gardening techniques** also need to be developed, as traditional methods do not always provide adequate adaptation, and care should be taken to create inorganic beds or mulches, so that rainwater is used as much as possible and evaporation from the sun is reduced. For example, using combinations of plantings and the placement of stones with specific terraces for each plant or group of plants, thus capturing rainwater with appropriate treatment of the subsoil. In this sense, rain garden solutions can be an effective measure by encouraging landscape design techniques that maximise water efficiency.

In view of the expected changes in the annual distribution of rainfall and the increase in the number of days with high temperatures and the duration of heat waves, it is essential to **manage water** appropriately. Urban green spaces, both public and private, require adapted management, based on by-laws that are consistent with climate change. In addition to the aforementioned techniques in the use of species adapted to the future climate of Santander and the design of green spaces to reduce water consumption, wherein rainwater storage must be conceived as a priority, it is also key to **control water losses and leaks** in the distribution system. Prioritising efforts on leakage detection and consumption savings will allow better adaptation to periods of drought.

We believe that **community participation** in the development and maintenance of municipal green infrastructure (both public and private spaces) is crucial to obtain maximum benefits. Training programmes and awareness-raising campaigns on drought and water management, as well as the promotion of proper water management and the adoption of sustainable gardening practices, will achieve the resilience objectives of a good citizen-driven ecosystem network.

2. Permeabilising the Soil to Cope with Rain Floods

The climate scenarios show that the total amount of precipitation in the long term will not change significantly. However, the increase in dry periods means that torrential rainfall events in short time periods will increase. Therefore, the municipal drainage network may be compromised and sewage may be discharged to the surface, posing a risk to public health and the environment. Flooding can cause property damage, traffic disruption and safety risks to people.

To cope with pluvial flooding and reduce the impacts of extreme rainfall events in Santander, it is necessary to implement a series of strategies to increase **permeability** and **drainage capacity**.

The improvement and redesign of the municipal **sewerage network** in the areas identified as being at risk involves the enlargement of the sections of the existing collectors, as well as the implementation of a separate rainwater network to manage the flow of rainwater more efficiently and avoid saturation of the sewerage system. Sectors such as the area around the

Town Hall in Calle Jesús de Monasterio, Calle Gerardo de Alvear and Av. de Candina in the industrial estate of the same name, or some sections of Calle Castilla, may require specific studies for the implementation of improvements to the network.

Likewise, **surveillance and control of the rainwater evacuation network** of the various tunnels in the city must be reinforced, as these sections are particularly vulnerable to vehicular collapse due to waterlogging and flooding.

Figure 5.52. *Ponding in the tunnel of Calle Burgos, Santander*
Source: CINCc (UC), june 2023.

Some recurrent areas with flooding events, such as the Santiago Mayor Urbanisation in Nueva Montaña or Joaquín Salas Street near the Mercasantander industrial estate, can be solved with technical solutions aimed at controlling the opening to the sea and the drainage system of the Raos Canal, implementing the evacuation system.

In addition, the **construction of storm tanks** is an effective strategy to reduce the impact of extreme rainfall events. Storm tanks are underground storage structures that temporarily retain excess rainwater and release it in a controlled manner into the drainage network, thus preventing overflows and flooding. The municipality already has this type of infrastructure, but the installation of new tanks at other points of interest cannot be ruled out.

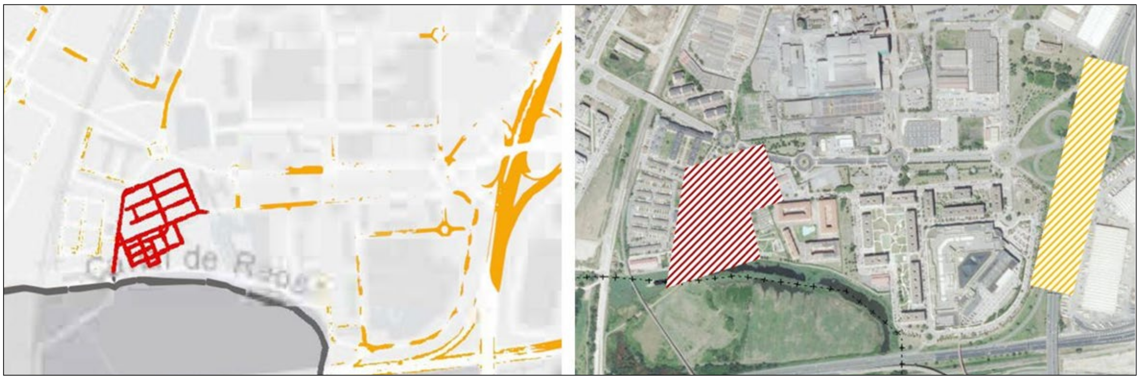


Figure 5.53. *Location of possible areas of ponding (Santiago Mayor - Av. de Parayas).*
Source: CINCc (UC), 2024.

In order to promote the **permeabilisation** of urban areas, one of the main measures is the adoption of Sustainable Urban Drainage Systems **(SUDS)**. These are drainage systems based on techniques capable of capturing and temporarily retaining rainfall, using elements such as permeable pavements or rain gardens, among others. The various SUDS solutions allow water to infiltrate slowly into the subsoil, reducing the volume of surface runoff that reaches the drainage network. It is essential that these measures are integrated into an overall water cycle management strategy, considering both green infrastructure and nature-based solutions. By combining the creation of green corridors and the protection and restoration of water ecosystems (which act as natural buffers against flooding), renaturation projects of impermeable spaces, such as the transformation of paved areas into parks and private areas, will contribute to increase the absorption capacity of the soil and reduce runoff, thus mitigating the risk of flooding.

3. Incorporate Urban Design Solutions to Combat Heat Islands

For the city of Santander to become more resilient to extreme heat and reduce the impacts of urban heat islands, strategies must address both mitigation and adaptation to climate change.

In terms of mitigation strategies, the promotion of sustainable modes of transport such as cycling and clean public transport will contribute to a significant reduction in greenhouse gas emissions, reducing urban warming generated by motorised vehicles. In terms of adaptation, **sustainable urban planning** is needed to encourage the increase of urban vegetation by planting trees and creating **shaded areas** to reduce ambient temperatures. In addition to absorbing carbon dioxide, urban trees have a thermoregulatory capacity and help to improve air quality with consequent positive effects on the health of the population.

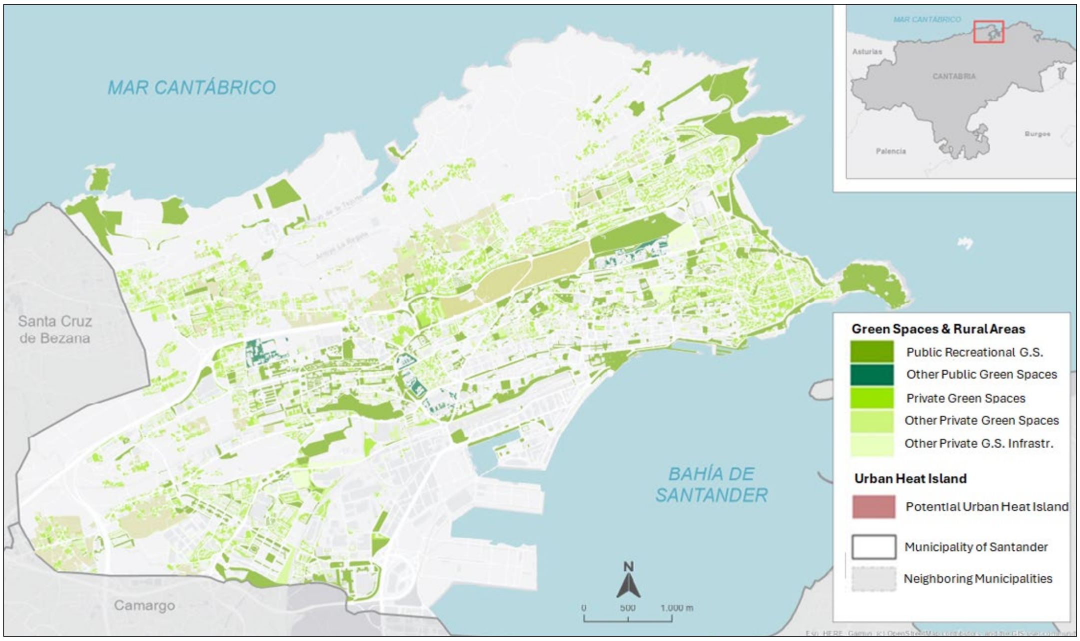


Figure 5.54. *Overlapping urban heat islands and green areas*

Source: CINCc (UC), 2024.

Santander's urban heat islands are determined, at certain times of the year, by the municipality's orographic conditions, the direction and intensity of the wind and the concentration of high temperatures driven by paved surfaces (sectors with low ground permeability, with large asphalted surfaces and paved with low albedo tiles, or sectors with a concentration of activities and buildings). To the south of the natural promontory of Peñacastillo, on both sides of Avenida Primero de Mayo in the residential neighbourhoods of Luis Pombo, Peñacastillo, around Mercasantander or Nueva Montaña, surface temperatures can be notable, as well as in the areas close to the port area, Candina, Parayas and Ciudad del Transportista. In other densely populated neighbourhoods such as El Alisal, La Albericia, around Cuatro Caminos, Calle Alta, Las Estaciones and Castilla-Hermida, or in areas of the city centre, next to the Town Hall or on the southern slopes of Paseo de Canalejas, improving the **thermal insulation of dwellings** with energy-efficient ventilation systems and air-conditioning equipment is recommended. The installation of cool roofs (cool and landscaped roofs), which reflect radiation, helps to reduce the temperature in buildings and reduces the effect of urban heat islands; and these solutions are of particular interest in industrial areas.

Finally, there is considerable room for improvement in public spaces. High-albedo pavements can be used, streets and recreational areas can be designed with materials and colours that reflect sunlight and reduce heat absorption. Also, water fountains that act as natural cooling systems can be incorporated, and shaded areas can be created using urban trees as the main adaptive resource.

4. Readjusting the Coastline to Adapt to Sea Level Rise and its Associated Effects

The **rise in sea level**, in combination with extreme storm events or storm surges, has a special effect on the Santander coastline. This phenomenon has already been recorded, especially on the beaches of the Sardinero, as well as other effects in different vulnerable coastal areas identified through the state project, PIMA Adapta.

Global warming causes thermal expansion of the oceans and melting of ice caps and glaciers, resulting in a progressive net rise in sea level. Changes in the tidal run have caused waves and currents to erode the coastline, while the construction of coastal infrastructure and other developments and anthropogenic activities have altered the natural balance of the coasts, increasing their vulnerability to erosion. To address **shoreline retreat**, adaptation measures are required, such as restoration of coastal habitats, **coastal spatial planning** and land use planning that takes into account the risks associated with climate change and sea level rise.

In the case of the coastal front of the beaches of El Sardinero, the retreat of the coastline could force a **rearrangement of the uses and the current physiognomy** of the environment, putting at risk infrastructures and buildings along the edge of the beaches, such as the promenade and car park on El Camello Beach, the Balneario de la Concha (La Concha Beach), the former Balneario de Pombo (First Beach of El Sardinero), and the buildings known as Cormorán and Parque de Trueba on the Second Beach of El Sardinero. This redevelopment could entail the demolition of the buildings and the extension of the intertidal space, increasing the beach area. The current Mesones Park and its promenade at the foot of the Second Beach of El Sardinero could be altered in its physiognomy, relocating its route and giving up part of its surface area to the sandy stretch. In any case, these interventions will have to be analysed in depth as the uncertainty associated with the wave penetration line resulting from the rise in sea level and the associated extreme events are reduced (figure 5.55).

Figure 5.55. *Exposed areas and possible actions on the waterfront*
Source: CINCc (UC), 2024.

At the end of the promenade at Calle Manuel García Lago, next to the Hotel Chiqui, it is possible to **arrange the coastal space** between the cliff and the viewpoint with a structure of semi-natural pools distributed to reduce wave energy, taking advantage of the experience of projects in this line such as the European LIFE COSTAdapta project, which promotes the design of innovative and progressive systems of tidal pool-reef for the adaptation of the coast.

In the interior of the Bay, the coastline can be affected by the erosive action of waves, with winds from the south-southeast. The alternative of using protection solutions with hard infrastructures must be analysed in detail due to the implications of this type of intervention on the landscape. In the port area, it may be necessary to raise the height of the quays to avoid the penetration of waves in southerly wind storms.

Santander, as a coastal municipality, also requires strategies for the management of its coastal space connected to the ecosystem services offered by green areas. The **blue spaces**, both those associated with inland waters and marine waters, and the transitional spaces of the maritime-terrestrial public domain (estuaries, bays, coastal lagoons, coastal strip, breakwater areas, beaches, marshes, etc.) (hydrodiversity), are areas of unquestionable **heritage value** and a great resource as strategic blue infrastructure for the sustainable development[4] and **resilience** of Santander. In relation to EU community policies, such as blue growth or the blue economy, **incorporating them into current and future plans**, instruments and policies, should be proposed.

The municipality of Santander has several **sectors** in where blue spaces pose particular **potentialities and limitations** in the face of climate change:

1. **Northern cliff strip** with a high degree of naturalness and landscape value connecting with the peri-urban coastal countryside landscapes.
2. **Protected inner beaches,** the most used and valued natural space in the city (walking, playing, bathing, swimming, surfing, etc.), but also with notable threats in the context of current climate change.
3. **An urban seafront** where the natural elements, their components and dynamics have a notable influence on the many and intense uses that are made of this blue space.
4. **Inner rim of the bay and marshes** where industrial activity and other residential and commercial uses are interspersed with natural spaces.

[4] Sustainable development must be supported by promoting public awareness of the risks faced by green areas and the coastline through educational, training and cultural programmes in the framework of SDG 11 (Sustainable Cities and Communities), 13 (Climate Action) and 14 (Marine Environment) and the 2030 Agenda. Programmes such as the 'Sentinels Cantabria' initiative, or 'The Sea Starts Here. Don't throw rubbish into the sewer', an international initiative already present in other Spanish cities, or "Agents of Change: Geography and Education for Sustainability", which promotes sustainability contents among the different educational centres in Cantabria, are some examples of demonstrative actions that focus on the knowledge and conservation of this adaptive resource.

For the conservation and enhancement of the environmental quality and sustainable use of Santander's blue spaces, it will be necessary to develop a comprehensive **land-use planning instrument** for the enhancement of the seafront and to coordinate it with other recent projects such as the 'Plan Bahía', promoting the interconnection with the green ring and facilitating the creation of a 'Santander Blue Belt', with adaptation measures such as the creation of a **drainage and rainwater evacuation** system in the roads near the main beaches, especially flood areas (extendable to the rest of the seafront in the future), reducing spillages and improving water quality.

The **tourism potential** of blue spaces as an economic driver requires an in-depth analysis of the challenges posed by climate change, developing a blue tourism strategy that guarantees resilient use. Examples of this could be the evaluation of the retreat of the beaches of the municipality and their economic impact, or the analysis of the future evolution of the singular surf breaks of interest for surfing (the Vaca Gigante, or the historical breaks of El Sardinero), which could lead to the definition of a Surfing Reserve for Santander as a tourist asset.