

Article

Not peer-reviewed version

A Scalable Methodology Towards a European Noise-Barrier Database: The Case of Andalusian Highways (Spain)

[Rosa María Muñoz-Millán](#) , Carlos Castillo , [Laura Muñoz-Millán](#) , Rafael Pérez , [Antonio J. Cubero-Atienza](#) *

Posted Date: 17 March 2026

doi: 10.20944/preprints202603.1284.v1

Keywords: noise barriers; road traffic; GIS; environmental; spatial analysis; Andalusia



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a [Creative Commons CC BY 4.0 license](#), which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Article

A Scalable Methodology Towards a European Noise-Barrier Database: The Case of Andalusian Highways (Spain)

Rosa María Muñoz-Millán ¹, Carlos Castillo ¹, Laura Muñoz-Millán ², Rafael Pérez ¹ and Antonio J. Cubero-Atienza ^{1,*}

¹ Department of Rural Engineering, Civil Construction and Engineering Projects, University of Córdoba, Campus of Rabanales, Córdoba, Spain

² Department of Electronic and Computer Engineering, University of Córdoba, Campus of Rabanales, Córdoba, Spain

* Correspondence: ajcubero@uco.es

Abstract

Environmental noise is increasingly recognized as a major environmental development challenge, with road traffic identified as the dominant source of acoustic pollution across Europe. Noise barriers are among the most widely implemented mitigation strategies. However, their spatial distribution and adequacy remain poorly documented, limiting their effectiveness for sustainable territorial planning. This study develops the first georeferenced database of highway noise barriers in Andalusia (Spain) and applies a reproducible, transdisciplinary geospatial workflow integrating field surveys, remote-sensing tools, and Geographic Information Systems (GIS). A total of 110 barriers were mapped, classified by material, geometry, and surrounding land use, and analyzed in relation to dwellings, schools, and hospitals. Results show that 1.6% of the Andalusian highway network is currently protected by barriers, with strong territorial disparities: over 50% of all structures are concentrated along coastal metropolitan corridors, while extensive inland areas remain unprotected. Misalignments were also detected between barrier placement and officially reported high-exposure segments, indicating limited correspondence between infrastructural deployment and acoustic priorities. Beyond generating a comprehensive regional dataset, the methodology provides a scalable basis for national and European initiatives seeking to harmonize the mapping and assessment of noise-mitigation infrastructures. By offering an open-access, transferable framework, this work supports policy professionals, environmental managers, and planners in evaluating mitigation gaps and informing more equitable and sustainable transportation and land-use strategies.

Keywords: noise barriers; road traffic; GIS; environmental; spatial analysis; Andalusia

1. Introduction

The World Health Organization (WHO) identifies environmental noise as a growing public health issue, particularly in urban settings. It is estimated that in Western Europe, approximately one million healthy life years are lost annually due to traffic-related noise exposure [1]. Additionally, the organization describes practical noise mitigation techniques that are incorporated into multi-sectoral public policy frameworks such as acoustic barriers building insulation traffic restrictions and urban planning [1]. The European Environment Agency (EEA) estimates that in 2017 over 5 million people in the EU suffered from severe sleep disturbance and over 18 million people were extremely irritated by transportation noise [2]. The European Commission responded by adopting the Zero Pollution Action Plan which aims to cut the number of people impacted by transport noise by thirty percent by 2030 [3]. As a result, noise pollution can be regarded as one of the most important environmental problems and ought to be given top priority particularly in areas with dense populations [4].

Traffic noise is the leading source of acoustic pollution in urban environments, surpassing both rail and aircraft noise, and affects millions of people globally [5]. In the European Union, over 81 million citizens are exposed to noise levels exceeding 55 dB(A), which is estimated to cause around 10,000 premature deaths annually [6]. Regarding children and adolescents, the study by Newbury et al. [7] demonstrates that a considerably higher chance of developing anxiety between the ages of 13 and 24 is linked to increased exposure to environmental noise during early life stages. Numerous studies corroborate the link between noise and the development of various illnesses including those listed above. [8–10]. With regard to Andalusia, specifically the data that is currently available, shows that people consider noise to be a major environmental problem especially in urban areas that are impacted by traffic (Novale, 2016).

In response to the magnitude of the environmental noise impacts, acoustic regulation has gained increasing importance at the European, national, and regional levels. At the European level, Directive (EU) 2020/367 establishes standardized assessment methods for evaluating the harmful effects of environmental noise, facilitating cross-country comparability. All national and regional noise regulations originate from this overarching European directive. These European policies establish the need for the creation of noise maps. The EEA Noise Viewer and collaborative projects like Noise Planet, contribute to the visualization, analysis, and public participation in the development of noise maps. In Spain, the SICA system (Information System on Acoustic Pollution) centralizes data on strategic noise maps and action plans [3]. At the global scale, the average road density varies greatly among regions, with the highest values found in northwestern Europe and parts of South and East Asia, and the lowest in sparsely populated areas such as northern Canada, the Sahara, and the Amazon basin [12]. The strong correlation between road density and population observed in the Global Roads Inventory Project supports this interpretation. Europe continues to report the highest road network density, followed by East Asia and the Pacific [13].

According to the WHO and the EEA, traffic noise is the type of noise most perceived as a problem and noise barriers are one of the common solutions to control road traffic noise [14]. These structures function as physical obstacles placed between noise sources (such as highways) and human receivers, with the aim of interrupting or redirecting sound propagation. They are typically installed along road corridors to improve the acoustic environment for nearby residents. Despite their widespread application, their impact on community perception and overall noise annoyance remains insufficiently explored [15]. There is an increasing number of studies that demonstrate the reduction in dBA levels in areas where noise barriers have been installed, before and after installation [16–20]. Therefore, in the planning of new highway infrastructure, it is essential to assess whether the proposed route may negatively affect the surrounding acoustic environment [21]. Kastka et al. [22] study shows that after installing barriers, the relationship between noise level and annoyance weakens. According to Nilsson et al. [23] evaluation should not only focus on the reduction of dBA but also on frequency variation, as this factor also affects the annoyance generated.

Therefore, the installation of noise barriers reduces road traffic noise reaching the population living near highways and main roads. The acoustic performance of noise barriers is commonly assessed through the Insertion Loss (IL) parameter, defined as the difference in sound pressure levels before and after barrier installation, measured in situ according to ISO 10847:1997 [24]. This standard allows both direct and indirect methods, with the latter frequently applied to evaluate existing roadside barriers [16]. Complementary parameters such as sound insulation and absorption coefficients are determined using EN 1793-5 and EN 1793-6, including the Adrienne method, which enables in-situ testing under real sound field conditions [19]. Reported IL values typically range from 5 to 20 dB(A), although field studies indicate variable performance depending on barrier design, material, and installation context [16–20].

Compared to other aspects of environmental, research on noise barriers is still scarce, although in recent years there has been an increase in studies that concentrate on their type materials and acoustic performance [25–28]. However there is still a significant research gap regarding the actual

locations of noise barriers, whether or not their placement adheres to precise planning criteria and whether or not they are actually effective beyond isolated noise-reduction measurements [29].

Based on this gap, the general objective of this study was to spatially characterize the noise barriers installed along the Andalusian highway network and create the first step to a European Noise Barrier database. To achieve this, the following specific objectives were defined: (i) to locate and georeferenced sampled existing barriers, (ii) to classify them according to material, length and surrounding land use, (iii) to analyze their relationship with noise-sensitive areas and the most acoustically affected road sections, and (iv) to evaluate the coverage and effectiveness of current planning. The research aims to fill this existing gap and address.

2. Materials and Methods

2.1. Study Area

To date, there is no detailed or publicly accessible database of noise barrier locations at the European scale, only some reports describe barrier typologies or acoustic performance [30]. Given the impossibility of mapping all existing barriers across Europe (or even Spain), this study focuses on Andalusia (southern Spain) as a starting point, with the aim of developing a database that can later be scaled to broader contexts. This region covers more than 87,000 km² and is structured by a highway network connecting its main urban, industrial, and touristic centers [31]. Despite this infrastructure, no systematic information exists at the regional level, which makes it difficult to determine the numbers of barriers installed and their location (Figure1).

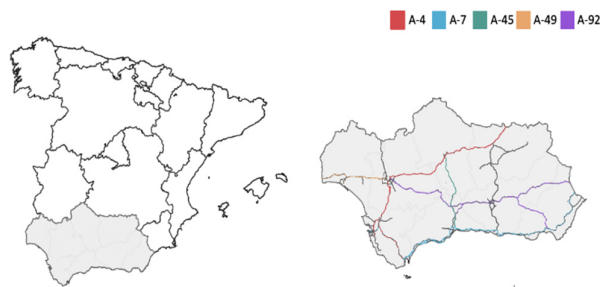


Figure 1. Study area in Andalusia (Spain), showing the highway network analyzed.

2.2. Methodological Framework

The workflow followed in this research is summarized in Figure 2. This illustrates the sequential process adopted to identify, classify, and analyze roadside noise barriers in Andalusia.

The methodological framework presented in this section is based on the first three steps: data collection, database development and Geographic Information System (GIS) analysis. The methodology followed to obtain, process, and analyze the data are described in detail: Identification and collection of primary and secondary information, construction of a consistent spatial database, and the application of GIS.

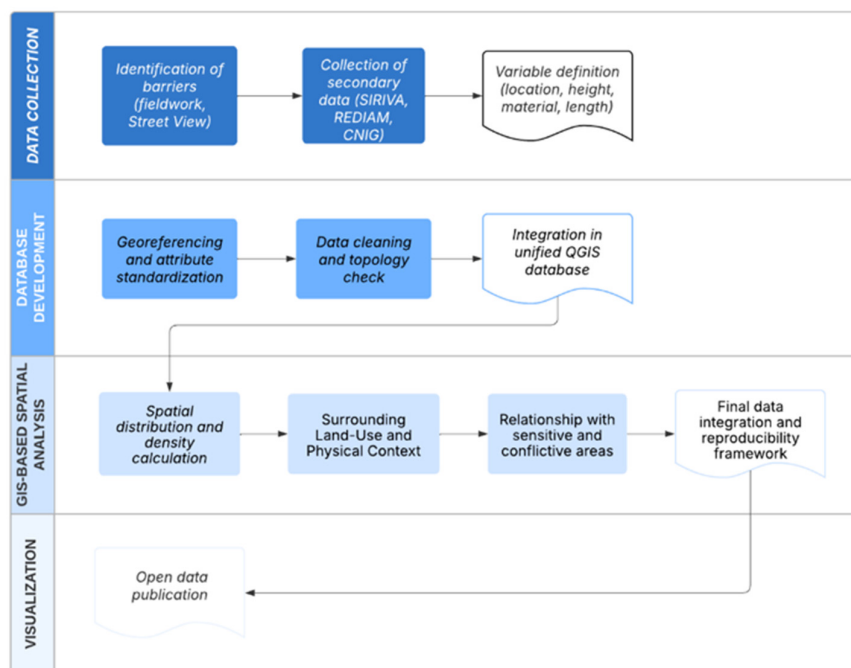


Figure 2. Workflow diagram of the research methodology.

2.3. Data Collection

2.3.1. Identification of Barriers: Fieldwork and Google Street View

In order to guarantee thorough coverage of the Andalusian highway network, noise barriers were identified and verified using a combination of direct field observation, GPS-based localization and methodical virtual inspection using Google Street View imagery. This process combined in situ validation with online visual documentation.

An official data request was submitted to the Andalusian regional administration; however, no official registry of existing roadside noise barriers was available at the time of the study. Therefore, to gather primary data, a direct field observation was conducted. This involved four field trips spread over four non-consecutive days, covering approximately 1845 km of regional highways—248 km of motorways and 1597 km of highways—by car. Each survey involved the manual identification and recording of barriers (road name and kilometric point, length and material when distinguishable), and the land use surrounding them. Table 2 summarizes the four field trips conducted across the Andalusian highway network, covering a total of approximately 1,845 km of roads through both inland and coastal corridors.

Table 1. Summary of fieldwork campaigns for noise barrier identification.

Field trip	Route description	Approx. distance (km)	Area covered
1	Córdoba—Jaén—Granada—Almería	≈800	Eastern Andalusia
2	Córdoba—Sevilla—Huelva	≈700	Western Andalusia
3	Coastal corridor between Gibraltar and Málaga	≈180	Southern coast
4	Coastal corridor between Gibraltar and Cádiz	≈165	Cádiz coast
Total	—	≈1,845 km	—

During this process a preliminary georeferenced inventory was created. Google Earth and Street View, which offered supplementary visual data, were used to methodically confirm and supplement all field observations and location. Google Earth was also used to measure the lengths of the noise

barriers. Figure 3 displays the steps for field identification, virtual inspection and length measurement in Google Earth, serving as an illustration of this workflow.

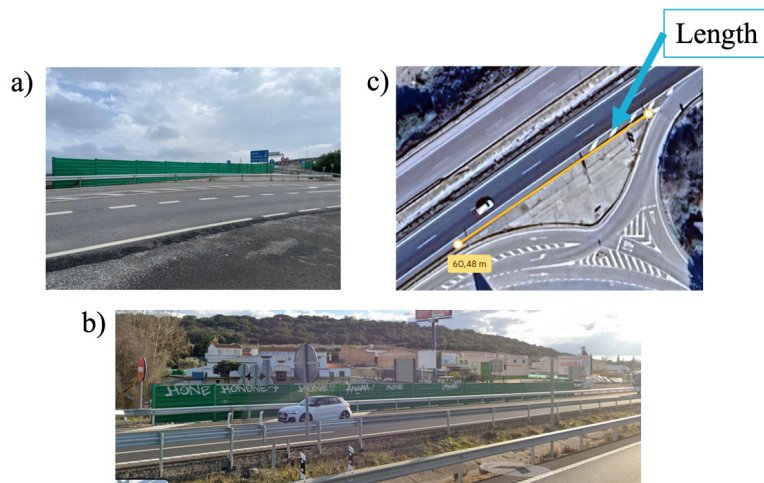


Figure 3. Workflow followed to determine the length of noise barriers, combining field observation and Google Earth tools. (a) Field survey by car observation. (b) Google Street View inspection. (c) Length measurement in Google Earth.

2.3.2. Collection of Secondary Data

Complementary data were obtained from several official and publicly accessible repositories to supplement the primary data gathered during fieldwork. In order to locate, categorize and analyze the current noise barriers within the Andalusian highway network, these datasets offered extra spatial and contextual information:

SIRIVA (Sistema de Información de Ruido Viario de Andalucía) [*Andalusian Road Noise Information System*] (2018), which contains strategic noise maps, acoustic action plans, and information on conflictive noise points published by the Andalusian Regional Government.

“Plan de Acción contra la Contaminación Acústica generada por los Grandes Ejes Viarios de la Junta de Andalucía” [*Action Plan Against Acoustic Pollution Generated by Major Road Axes of the Andalusian Regional Government*] (hereafter referred to as the *Action Plan*) which provides detailed information on the regional acoustic management framework. It also includes the prioritization of high-exposure corridors and the identification of mitigation measures implemented in previous planning cycles. However, it does not specify whether such measures have been installed, nor do they include the precise location of existing barriers. For this reason, the georeferenced database developed in this study was compared with the areas identified in these maps as being at higher risk of noise exposure, allowing the barrier inventory to be contextualized within the broader regional planning framework.

REDIAM (Red de Información Ambiental de Andalucía) [*Andalusian Environmental Information Network*], which provides protected natural areas, and other environmental layers relevant for contextual analysis.

CNIG (Centro Nacional de Información Geográfica) [*National Centre for Geographic Information*] which supplies the official cartography of Spain, including the national road network (MTN25), orthophotos, and administrative boundaries and land-use data.

Each dataset was processed in QGIS 3.34 [32] after being downloaded in vector or raster format (SHP GPKG or TIFF). To guarantee spatial consistency and compatibility with the primary field data all analyses were carried out using the same coordinate reference system (UTM Zone 30N). These sources offered the contextual framework needed to examine Andalusia barrier systems, spatial

coverage, proximity relationships and environmental exposure. Table 2 summarizes the primary repositories consulted, the types of information obtained, file formats and their particular application in this study.

Table 2. Sources of secondary data and type of information obtained.

Source / Repository	Type of information obtained	Format	Use in this study
SIRIVA	Strategic noise maps and acoustic action plans.	PDF	Identification of high-exposure road segments
Action Plan	Conflictive noise points	PDF	Conflictive noise points framework for noise barrier planning
REDIAM	Environmental (protected areas, hydrology, etc.)	SHP, GPKG	Environmental context
CNIG	Administrative boundaries (municipalities, provinces, autonomous communities, Spain); highway network; land-use types; 2022 orthophotos (WMS service)	SHP, GPKG, WMS	Geometric reference for aligning barrier locations, spatial analysis, and visual mapping

¹ (SIRIVA—Sistema de Información de Ruido Viario de Andalucía [Andalusian Road Noise Information System]; “Action Plan—Plan de Acción contra la Contaminación Acústica generada por los Grandes Ejes Viarios de la Junta de Andalucía [Action Plan Against Acoustic Pollution Generated by Major Road Axes of the Andalusian Regional Government]; REDIAM—Red de Información Ambiental de Andalucía) [Andalusian Environmental Information Network]; CNIG—Centro Nacional de Información Geográfica [National Centre for Geographic Information]).

2.3.3. Variable Definition

To allow comparison and analysis, a standardized set of spatial and descriptive variables was used to characterize each identified noise barrier. It’s worth noting that only the primary variables - those that were directly gathered or defined during data collection and database development - are covered in this section. Later in the study, variables derived from GIS-based spatial analysis were incorporated, like barrier density, proximity to sensitive areas or intersection with conflictive noise points, are introduced as the outcome of further geoprocessing operations carried out on this original dataset. The initial database included three main descriptive fields: **length (m)**, a numerical variable; **type of material** (concrete, metal, wood, or composite), a categorical variable; and **location details** (road name and kilometer point), used as reference identifiers.

2.3. Database Development

The geospatial database was developed in QGIS 3.34 using a common reference system (EPSG:25830—ETRS89 / UTM 30N). The layers from CNIG were loaded to provide spatial context: (1) Administrative boundaries: provinces and municipalities. (2) Land use maps: urban, industrial, agricultural, transport-related, etc. (3) Protected natural areas: natural and regional parks. (REDIAM). (4) Orthophotos: a web map service (WMS (2022)) imagery service was added to provide aerial verification of barrier locations and surrounding contexts. (5) Official highway network. The corresponding geographical coordinates from each kilometric point (of each highway) were retrieved from Google Maps, allowing each barrier to be georeferenced and added as a point feature in QGIS with its descriptive and contextual attributes stored in an associated attribute table.

To confirm that every point was situated accurately along the official road network supplied by CNIG, a topology check was carried out. Using orthophotos and satellite imagery from the 2022 CNIG WMS service inconsistencies were manually examined. This process resulted in a unified

spatial database displaying the Andalusian highway network together with the exact locations of the identified noise barriers, forming the initial dataset used for subsequent spatial analyses.

2.4. GIS-Based Spatial Analysis

2.4.1. Spatial Distribution

The georeferenced database of noise barriers have been consolidated so a series of spatial and descriptive analyses were performed to quantify their distribution and characteristics across the Andalusian highway network. The identification of regions with higher infrastructure concentration was made possible by these metrics which offered both absolute and relative indicators of protection coverage. The outputs of these analyses were integrated with the field-recorded attributes (height, length, and material). A structured table was compiled, in which each barrier was characterized by its geographic position, administrative location, material, dimensions, land-use context, and distance to sensitive areas. Overall, this analysis of spatial distribution provided the basis for later evaluations.

2.4.2. Surrounding Land-Use and Physical Context

Land-use layers from CNIG were spatially intersected with the noise barriers in order to describe the environmental setting of each noise barrier. This allowed the differentiation between urban, industrial, agricultural and natural areas and the classification of barriers based on the predominant surrounding environment. The database was also checked for barriers within or next to protected land by comparing it with the protected areas layer (REDIAM). Each barrier was visually examined in QGIS and Google Maps to improve the interpretation of these results. Orthophotos and satellite imagery were used to confirm the immediate context. Additional information such as proximity to residential buildings, service areas or agricultural facilities was discovered due to this manual validation.

Each barrier surrounding area was classified according to their land use using the official Land Cover dataset (2022) available by CNIG. These land-uses were included in CORINE Land use (CLC) categories which were modified by splitting the artificial surfaces class into two separate groups: urban areas and industrial/service areas in order to better represent the spatial and functional heterogeneity of the Andalusian highway network. This distinction was significant because despite being in the same CLC level-1 category, they represent very different territorial contexts with regard to environmental function and human exposure. A manual qualitative classification based on direct visual inspection of orthophotos and field observations was conducted in addition to the CORINE-based quantitative analysis to characterize the immediate functional context of each barrier. This comparison was performed to assess whether the land-use information provided by the CNIG dataset (CORINE Land Cover) accurately represents the actual environment surrounding the barriers. For this purpose, each barrier was individually inspected to verify the real land-use type visible on aerial imagery and during fieldwork.

2.4.3. Relationship with Sensitive and Conflictive Areas

Layers representing sensitive land uses and conflicting noise points were used in the proximity and overlay analyses to evaluate the functional adequacy of noise barrier location. The conflicting noise points specified in the Action Plan were compared with the georeferenced barrier dataset. The following circumstances are used in this plan to define an urgent action scenario: (1) SVRA (*Sistema de Valoración del Ruido Ambiental* [Environmental Noise Assessment System] (night) > 200, (2) the presence of sensitive buildings affected beyond AQO (Acoustic Quality Objectives (specified in Decree 50/2025, of February 24)); (3) citizen noise complaints located within road sections coinciding with the urgent scenario. The plan identifies 79 conflicting points based on these criteria, though some of them overlap spatially due to their close proximity. To assess their coincidence with current noise barriers and determinate whether noise barriers have been put in the most acoustically crucial areas, these points were digitalized and imported into QGIS.

Finally, the road segments examined in the SIRIVA (which identify the highway corridors assessed by the Andalusian Regional Government in its strategic noise studies) were contrasted with the barrier dataset. This comparison made it possible to ascertain whether study corridors with barriers are situated along the same road segments that are formally monitored for noise exposure.

2.4.4. Descriptive Indicators

To complement the spatial and contextual analyses, a series of quantitative indicators were defined to summarize the main structural and territorial characteristics of the Andalusian noise-barrier network. Concentration indices: To assess the degree of inequality in the distribution of barriers among provinces, two complementary concentration metrics were used:

1. Herfindahl–Hirschman Index (HHI)

$$HHI = \sum_{i=1}^n s_i^2 ; s_i^2 = \frac{n_i}{N} , \quad (1)$$

Where s_i represents the proportion of barriers located in province i with respect to the total number of barriers; n_i is the number of barriers located in province i ; And N is the total number of barriers identified in the study area. This metric provides a numerical measure of how evenly or unevenly the barriers are distributed across provinces. Values close to zero indicate a more even distribution among all territories, whereas increasing values (approximately $>0.18-0.25$) reflect moderate to high concentration in a reduced number of provinces.

2. Gini coefficient (G)

$$G = \frac{\sum_{i=1}^n \sum_{j=1}^n |x_i - x_j|}{2n^2 \bar{x}} , \quad (2)$$

Where x_i is the number of barriers in province i , n is the total number of provinces, and \bar{x} their mean. This provides a complementary measure of inequality in spatial distribution. Values closer to 0 indicate perfect equality, whereas values above 0.4 reflect marked inequality in the allocation of noise barriers.

2.4.5. Final Data Integration

Every spatial and contextual variable produced by the GIS analyses was combined into a single geospatial database. Field-recorded characteristics like length and material are combined with the derived spatial variables obtained through GIS operations. An extensive dataset detailing each barriers physical attributes and environmental context was created as a result of this integration. This serves as the analytical foundation for the spatial interpretation and statistical assessment presented in Section 3 (*Results*).

Apart from its immediate analytical value the database was designed to guarantee transparency scalability and reproducibility. Its design make simple to update with fresh field data from other regions of Spain or even integrate it into more extensive European-scale projects. The final dataset will be made publicly accessible via a repository guaranteeing open access to the data. This configuration ensures compatibility with non-relational data systems and facilitates the retrieval and analysis of large and heterogeneous records. This database structure is conceived as the foundation for an extendable national and, in the future, European-wide database of noise barriers, enabling standardized mapping and long-term monitoring of mitigation infrastructure.

A summary of all primary and derived variables included in the geospatial database—together with their source, units, and analytical purpose—is presented in Table 3.

It is important to note that some contextual observations were not stored as formal variables in the database. Instead, they were recorded manually after visual comparison of layers in QGIS. These include: (1) Whether the barrier is located near a conflictive noise point (2) Whether it lies along a road corridor analyzed in SIRIVA. (3) The density grid cell used for visual interpretation of concentration patterns.

Table 3. Primary and derived variables included in the geospatial database.

Variable	Description	Unit	Source / Method	Type	Use in analysis
Road name	Identifier of the highway where the barrier is located	—	Field observation	Primary	Location reference
Kilometric point (PK)	Kilometer marker where the barrier was identified	km	Field observation	Primary	Georeferencing reference
Coordinates (X, Y)	Geographical position of each barrier in EPSG:25830	m	Derived from Google Maps	Derived	Spatial positioning
Length	Estimated longitudinal extent of the barrier	m	Measurement in Google Earth	Derived	Density and length aggregation
Material	Dominant construction material	—	Field / Street View inspection	Primary	Typology classification
Province / Municipality	Administrative location of each barrier	—	Spatial join with CNIG boundaries	Derived	Aggregation by territory
Land-use type	Surrounding environment	—	Intersection with layers	Derived	Environmental context
Protected area	Whether the barrier is located within or near protected zones	—	Overlay with REDIAM protected areas	Derived	Environmental sensitivity

3. Results and Discussion

3.1. Distribution and Density of the Road Infrastructure

Spain has one of the largest motorway networks in Europe, with a total length of 17,668 km and an average density of 34.9 km per 1,000 km². This figure places the country close to the European average for highly developed transport systems such as Germany (36.9 km/1,000 km²). According to official data from the “*Centro de Información de Carreteras*” of the Spanish Ministry of Transport and Sustainable Mobility, the internal distribution of the Spanish motorway network shows marked territorial contrasts. The Community of Madrid stands out as the most densely developed region reflecting its strong concentration of national traffic corridors and the radial structure around the capital. In contrast, Andalusia—despite being the region with the largest total motorway length (1,845 km)—ranks tenth in density (21.1 km/1,000 km²), mainly due to its extensive surface area and predominantly interprovincial road system. For comparing with other European countries, motorway length data were obtained from the World Road Statistics Data Warehouse, and national surface area figures from the World Bank database, as summarized in Table 1 which lists the ten European countries with the highest motorway density. These territorial variations are particularly relevant when analyzing the distribution and adequacy of roadside noise barriers. The extent and density of the road network directly influence both, the spatial exposure to traffic noise and the planning criteria used to implement mitigation infrastructures across regions such as Andalusia.

Table 4. Highway density (km per 1,000 km²) in Europe.

Country	Region (if applicable)	Motorway or Highway (km)	Area (km ²)	Density (km / 1,000 km ²)	Rank (Spain)
Netherlands	—	2,793	41,540	67.2	—
Belgium	—	1,763	30,689	57.4	—
Switzerland	—	2,259	41,291	54.7	—
Germany	—	13,210	357,680	36.9	—
Spain	—	17,668	505,976	34.9	—

	Madrid	640.3	8,028	79.8	1
	Andalusia	1,845.2	87,597	21.1	10
Portugal	—	3,113	92,230	33.8	—
Austria	—	2,250	83,879	26.8	—
Italy	—	7,561	302,070	25.0	—
France	—	11,752	606,410	19.4	—
U.K.	—	3,749	243,610	15.4	—

3.2. Database Overview and Spatial Distribution of Noise Barrier

Along the Andalusian highway network 110 noise barriers were found (Figure 4), about 29 km in total. Considering that the total motorway length in Andalusia amounts to 1,845.2 km, this represents about 1.6% of the regional highway network currently protected by acoustic barriers. Disparities in infrastructure and demographic are reflected across the regions, with an uneven distribution of noise barriers.



Figure 4. Location of identified barriers along the regional highway network, derived from the geospatial database developed in Section 2.3.

This unequal geographic distribution can reflect Andalusia differences in infrastructure and population. Whereas interior provinces like Córdoba, Jaén or Almería exhibit fewer installations, barriers are concentrated along coastal and metropolitan corridors which correspond with the areas with the highest population density and therefore intensity of road traffic. The observed pattern indicates that barrier implementation has probably been prioritized in more urbanized and frequently traveled corridors leaving inland sectors relatively underrepresented even though this study does not include traffic data.

This spatial imbalance is supported by the descriptive breakdown by province (Figure 5). The majority of barriers are concentrated along the coastal and metropolitan corridors, particularly in the provinces of Málaga (32 barriers, \approx 8.98 km; 29.1%) and Cádiz (28 barriers, \approx 6.18 km; 25.5%), which together account for more than half of the total inventory (54.6%). Lower numbers were recorded in Seville (17 barriers, \approx 7 km; 15.8%) and Granada (19 barriers, \approx 4.0 km; 12.8%), while Almería (8 barriers; 7.3%), Córdoba (5 barriers; 4.6%), and Jaén (1 barrier; 0.9%) showed marginal presence. Regarding material composition (Figure 6(b)), metal structures represent 41% ($n = 45$) of the total sample, followed by composite panels 27% ($n = 30$), concrete walls 23% ($n = 25$), and polycarbonate barriers 12% ($n = 13$), with a negligible presence of wood panels ($< 1\%$). These values were calculated from the total inventory ($n = 110$). The overall dataset is summarized in Figure 6c, indicating both the number of barriers and their combined linear extent (\approx 29 km).

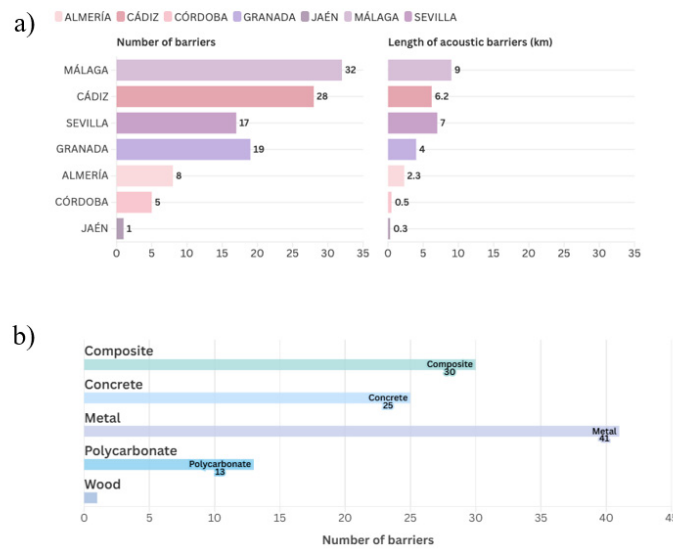


Figure 5. Composition of the Andalusian noise barrier inventory. (a) Number and total length of barriers by province. (b) Distribution by material type.

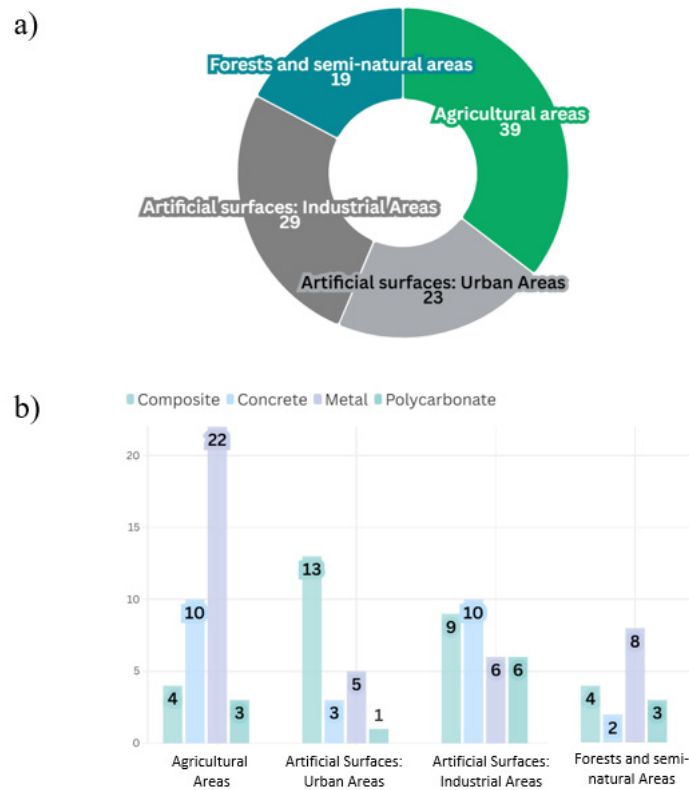


Figure 6. Distribution of noise barriers by CORINE land cover categories and barrier materials. (a) Proportion of barriers by major land-cover category. (b) Material composition of barriers within each land-cover class.

Finally, an interactive version of the database is publicly available through a MongoDB web dashboard, allowing open-access visualization and filtering by material, location, and barrier length. The dataset can be explored online at **noise barrier database** (<https://figshare.com/s/3e4ad137a72da4c57fd8>), providing transparency, reproducibility, and facilitating future updates of the Andalusian noise-barrier repository.

3.3. Surrounding Land-Use and Physical Context

Figure 6a displays the outcomes of the modified classification of CORINE Land use. The majority of barriers (39 units, 35.4%) are found in or close to agricultural areas followed by urban areas (23 barriers, 20.9%) and industrial or service areas (29 barriers, 26.4%) and finally nineteen cases (17.3%) are barriers that are situated close to forests and semi-natural areas. This distribution suggests that rather than being found in environmentally noise-sensitive areas, these mitigation infrastructures are primarily found in productive or heavily populated corridors.

The prevalence of barriers close to inhabited or industrial zones may indicate that mitigation efforts have tended to concentrate on human activity hotspots rather than environmentally vulnerable areas. Their closeness to industrial agricultural and urban areas may suggest a desire to preserve areas that see frequent human activity or commercial activity, while natural environments may receive relatively less attention due to their lower population and less exposure to public scrutiny. Mitigation efforts may have focused on these areas because they are more visible and subject to public pressure. The combination of land-use and material typologies (Figure 7b) also shows that while composite and concrete barriers are more evenly distributed between urban and industrial contexts, metal barriers are the most common across all land-use types especially within agricultural and industrial areas. These trends imply that the choice of materials may be more influenced by the type of infrastructure and the time frame of construction than by the surrounding environment.

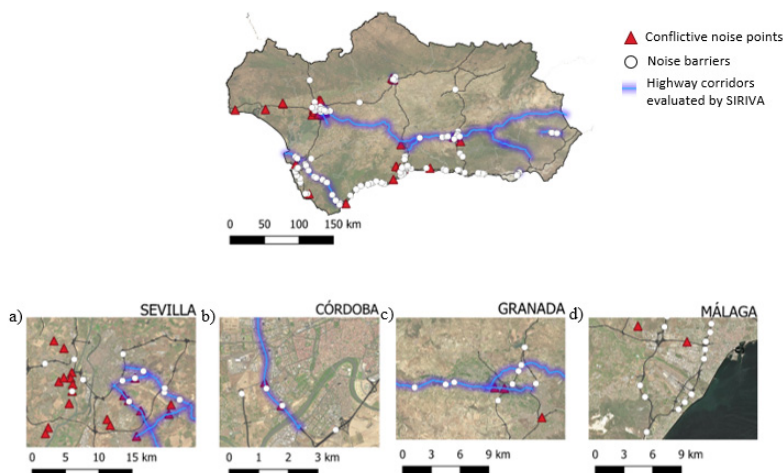


Figure 7. Spatial Distribution of Noise Barriers and Government-Reported Conflict Points in Andalusian Capitals.

The overlay with the REDIAM protected-area layer showed that only five barriers (4.5%) of the total cross areas that have been officially designated as protected. They are all found in Los Alcornocales Natural Park (Cádiz). This small overlap suggests that the Andalusian highway barrier network is currently barely present in environmentally sensitive areas.

The comparison between the observed classification and the CORINE dataset (Table 4) revealed marked discrepancies in the spatial distribution of barrier surroundings. Over half of the barriers (61.8%) were located in urban areas, while the CORINE data indicate that only about 20.9% of the territory near highways corresponds to urban land use, producing a positive deviation of +40.9

percentage points. Industrial and service areas accounted for 10.9% of the barriers compared to 26.4% in CORINE, suggesting that these sites are generally less associated with noise-sensitive receptors. Agricultural areas represented 23.6% of the observed barriers versus 35.5% in CORINE, and forests and semi-natural areas (including water bodies) 3.6% versus 17.3%, reflecting the limited presence of barriers in uninhabited or natural contexts. Overall, this manual verification shows that the actual surroundings of noise barriers differ substantially from the general land-use patterns recorded in CORINE, with barriers predominantly concentrated near populated and urbanized environments rather than proportionally distributed across all land-cover types.

Table 5. Comparison between observed classification and CORINE distribution.

Level 1 General type	Level-3	Observed (%)	CORINE (%)	Δ (%)	Examples from field observations
Urban areas	Continuous urban fabric; Discontinuous urban fabric;	61.8	20.9	+40.9	Cities/towns, urbanizations, service/rest area
Industrial / Service areas	Industrial or commercial units	10.9	26.4	-15.5	Industrial estates, hospital, educational center
Agricultural areas	Complex cultivation patterns; Olive groves; Pastures	23.6	35.5	-11.9	Empty fields, greenhouses, livestock, olive groves, abandoned plots
Forests and semi-natural areas (incl. water)	Bare rocks; Water bodies	3.6	17.3	-13.7	Cliffs, scenic viewpoint, lagoon

According to the comparison of field-based observations and CORINE classifications, the intricacy of the environments surrounding transportation corridors may not be adequately captured by extensive land-use datasets. The scale and generalization effects that are inherent in CORINE data may be the cause of the observed differences. Despite being subjective manual verification offers a more thorough view of each barriers immediate surroundings and can enhance regional analyses by enhancing official datasets. However, the interpretative nature of visual inspection and the lack of temporal data on land-use evolution limits this strategy.

Significant variations in the representation of the surrounding environments of noise barriers are found when comparing CORINE classifications with field-based observations. Barriers were more often linked to populated or built-up areas in the field-based classification than the CORINE data which has a tendency to generalize broad land-cover types. Given that manual inspection reflects the immediate human-scale context and CORINE maps capture dominant land uses at a regional scale, this disparity may be the consequence of different spatial resolutions and classification thresholds. Although it is impossible to verify this relationship without comprehensive demographic or acoustic data, the higher percentage of barriers identified close to inhabited or economically active zones may indicate that mitigation infrastructures are more frequently placed in areas where population presence and potential exposure are evident. All things considered; these findings highlight the importance of adding field verification to generalized datasets in order to gain a deeper understanding of the real-world context in which barriers are used.

3.4. Relationship with Sensitive and Conflictive Areas

The findings (Figure 7) demonstrate a limited spatial coincidence between conflict points formally identified in the Action Plan and current noise barriers. A total of seven barriers were found within these areas of reported exceedance: three in Seville, two in Córdoba, and two in Granada, while none were identified in Málaga. The implementation of barriers appears to be in line with the regional government noise-management priorities in highly urbanized road sections. The current distribution of mitigation structures however appears to have been influenced more by

infrastructural or visual factors than by acoustic exposure data as the overall number of coincidences is still low in comparison to the total number of barriers recorded (110).

Since the current study was specifically focused on motorways it is clear that all of the identified noise barriers are situated along these routes when contrasted with the SIRIVA corridors (highlighted in blue in Figure 8). Nonetheless, barriers are comparatively rare among the road segments that the Andalusian Regional Government has formally evaluated. In contrast, there is a higher concentration of barriers along coastal motorways especially those that are not part of the main SIRIVA-prioritized corridors. This spatial pattern indicates that the installation of noise barriers in Andalusia has been uneven with a greater emphasis on coastal routes that are frequently traveled than on the areas that have been formally assessed for environmental pollutants. The actual deployment of mitigation infrastructures and monitoring activities need to be better coordinated as indicated by this imbalance. These findings highlight the necessity of better integrating between acoustic monitoring frameworks (SIRIVA and Action Plans) and the actual deployment of mitigation measures. In order to guarantee that noise barriers are not only present along assessed roads but are also strategically placed in areas with the greatest acoustic impact and population exposure, future revisions of the regional noise strategy should give priority to those corridors where conflictive points continue to exist unprotected.

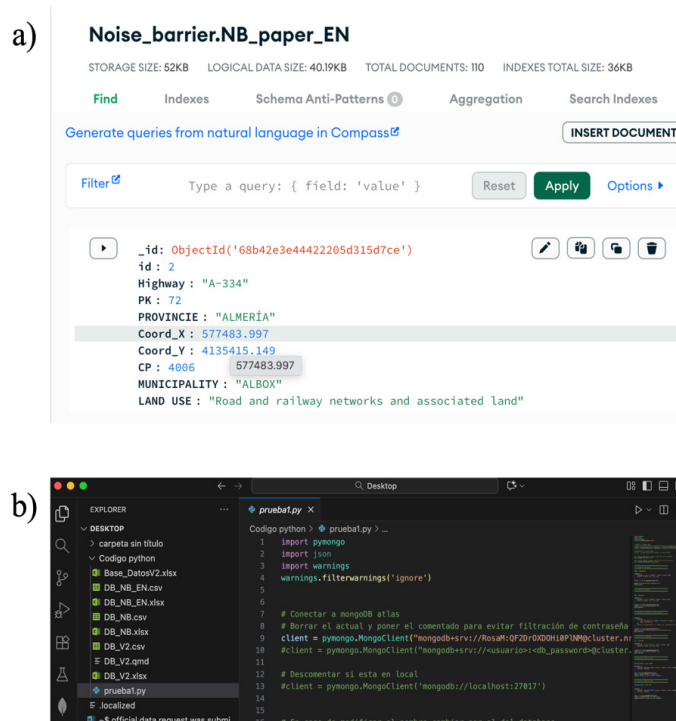


Figure 8. Workflow implementation in MongoDB and Python environment ((a) Query construction and data retrieval interface in MongoDB Compass.(b) Python script for database connection and query execution in Visual Studio Code.

The lack of correlation between conflictive points and existing barriers might suggest that the locations designated as acoustically problematic have not always been directly associated with the placement of mitigation infrastructure. Other factors might have affected the placement of barriers such as project timing, technical viability or aesthetic considerations. The limited overlap may also be a result of variations in traffic patterns or between the Action Plans reference periods and the current field observations. More thorough temporal and acoustic data would be needed to verify these aspects.

3.5. Descriptive and Quantitative Analysis

A total of 87 barriers (79.1%) are located along the coastal and metropolitan corridors of Málaga, Cádiz, Granada, and Almería, while only 23 (20.9%) are found in inland provinces such as Seville, Córdoba, or Jaén. This result confirms a strong geographical bias that favors areas with higher population densities, traffic volumes, and visual exposure, leaving interior corridors largely unprotected.

The provincial concentration indices reinforce this interpretation. The Herfindahl–Hirschman Index (HHI), based on the provincial share of barriers, is 0.211 ($\approx 2,106$ on the 0–10,000 scale), while the Gini coefficient (G) equals 0.466. Both values correspond to a moderate-to-high concentration, indicating that most noise barriers are clustered in a few provinces—chiefly Málaga, Cádiz, and Granada—which together contain more than 65% of the total inventory. These quantitative results align with the patterns observed in the density maps, confirming that mitigation infrastructure has been unevenly distributed across the territory.

Functional alignment between infrastructure and acoustic priorities was also assessed. Only 7 barriers (6.36%) coincide with officially reported conflictive road sections from the regional *Action Plan Against Acoustic Pollution*, with a 95% Wilson confidence interval of 3.1–12.6%. This limited correspondence reveals a weak relationship between identified acoustic problems and the actual implementation of mitigation measures. Furthermore, just 5 barriers (4.55%) intersect or border protected natural areas (95% CI: 2.0–10.2%), all of them located within *Los Alcornocales Natural Park* (Cádiz). The almost complete absence of barriers in ecologically sensitive zones suggests that environmental or landscape criteria have played a minor role in infrastructure placement decisions.

3.6. Data Accessibility and Reproducibility Framework

To ensure open access and transparency, the final geospatial database created via MongoDB has been made publicly available in a cloud repository (<https://figshare.com/s/25de397d558308475b2d>). The dataset combines the derived spatial variables generated by GIS processing with field-recorded attributes (location material length and contextual observations). To enable data filtering a complementary set of Python scripts (<https://figshare.com/s/bf52ad52b3adf809d8cb>) has been created in Google Collab linked with MongoDB. To run this code, you must link it to your MongoDB account where your database is located. This enables users to interactively explore the database or incorporate it into their own analytical workflows (Figure 8). This setup supports the long-term creation of a standardized inventory of roadside noise barriers in Spain by offering a repeatable framework that can be expanded with fresh field data or modified for use in different areas.

4. Study Limitations and Opportunities for Future Work

Several limitations should be acknowledged when interpreting the findings of this study. First the analysis does not include direct acoustic measurements or modeling outputs that would enable a quantitative evaluation of their efficacy, instead it is solely focused on the spatial identification and characterization of current noise barriers. This dataset does not allow conclusions about their acoustic performance under actual conditions despite offering a thorough overview of their location and characteristics. Furthermore, the categorization of nearby land uses and local contexts depended on accessible cartographic sources and visual inspection which could introduce uncertainties in heterogeneous or rapidly changing areas.

Future research could expand this work in several directions. To better assess the implications of barrier distribution for environmental justice a first step would be to integrate socioeconomic, demographic and detailed noise exposure datasets. Furthermore, conducting in-situ measurements or modelling the insertion loss of selected barriers would provide essential evidence on their actual acoustic performance and allow comparisons across typologies, materials and environmental contexts. Future developments of this research may involve establishing collaborations with other universities and research groups to expand the geographic coverage and methodological robustness

of the dataset. These collaborative efforts could support the preparation of national and European research proposals aimed at exploring the feasibility of creating a standardized database of noise barriers at regional, national, and eventually European scales. Such initiatives would allow the methodology introduced in this study to evolve into a broader, coordinated framework for mapping and assessing noise-mitigation infrastructure across territories.

5. Conclusions

By combining GIS processing field observations and open-source data this study offers the first georeferenced inventory and spatial analysis of noise barriers along the Andalusian highway network. Less than 1,6 percent of the highway network is made up of the 110 barriers that were found to exist totaling about 29 km in length. Even though there are many sensitive and heavily populated areas in Andalusia that are subject to traffic noise this scant coverage emphasizes how little infrastructure has been put in place to mitigate noise.

The majority of structures are centered in urban and peri-urban areas where visibility and public exposure are higher according to the spatial correlation between barrier locations and land-use patterns. On the other hand, the fact that large swaths of rural areas are still mainly unprotected indicates that the current barrier distribution and environmental sensitivity are out of sync. These results suggest that rather than using a methodical acoustic planning approach, mitigation efforts have probably given priority to the most noticeable areas perhaps as a result of social or regulatory pressure.

Beyond its descriptive value, this work develops a scalable and reproducible geospatial database that is made publicly available via a MongoDB cloud repository. The accompanying Python scripts promote transparency and long-term monitoring by enabling data visualization filtering and continuous updating. This open framework can be applied to other parts of Spain or incorporated into larger European projects that support evidence-based environmental planning and standardize data on noise mitigation.

Author Contributions: Rosa María Muñoz-Millán: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Visualization; Writing—original draft; Writing—review and editing. Carlos Castillo-Rodríguez: Conceptualization; Supervision; Writing—review and editing. Laura Muñoz-Millán: Software; Visualization; Writing—original draft. Rafael Pérez: Supervision; Investigation. Antonio J. Cubero-Atienza: Conceptualization; Supervision; Writing—review and editing

Funding: This research received no external funding

Data Availability Statement: The following supporting data can be downloaded at: <https://figshare.com/s/25de397d558308475b2d> DataBase S1: Noise Barrier Andalusia Dataset (2025); <https://figshare.com/s/bf52ad52b3adf809d8cb> Python scripts S1: Noise Barrier Andalusia—Python & Colab Reproducibility Scripts (2025); <https://figshare.com/s/3e4ad137a72da4c57fd8> Database S2: Noise Barrier Andalusia—Interactive Web Dashboard (2025)

Acknowledgments: The authors thank Andalusian Regional Government (Consejería de Fomento, Articulación del Territorio y Vivienda) who provided Additional information and data.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

GIS	Geographic Information System
WHO	World Health Organization
EEA	European Environment Agency
IL	Insertion Loss
GPS	Global Positioning System

SIRIVA	Sistema de Información de Ruido Viario de Andalucía [<i>Andalusian Road Noise Information System</i>]
REDIAM	Red de Información Ambiental de Andalucía [<i>Andalusian Environmental Information Network</i>]
CNIG	Centro Nacional de Información Geográfica [<i>National Centre for Geographic Information</i>]
WMS	Web Map Service
CLC	CORINE Land use (CLC)
SVRA	<i>Sistema de Valoración del Ruido Ambiental</i> [Environmental Noise Assessment System]
AQO	Acoustic Quality Objectives
HHI	Herfindahl–Hirschman Index
G	Gini coefficient

References

1. “Compendium of WHO and other UN guidance in health and environment, 2024 update.” Accessed: Aug. 16, 2025. [Online]. Available: <https://www.who.int/publications/i/item/9789240095380>
2. “European Environment Agency’s home page.” Accessed: Aug. 17, 2025. [Online]. Available: <https://www.eea.europa.eu/en>
3. by E. E. Agency, “The NOISE Observation & Information Service for Europe,” ArcGIS StoryMaps. Accessed: Aug. 17, 2025. [Online]. Available: <https://portal.discomap.eea.europa.eu/arcgis/apps/storymaps/stories/bee6c09cd15a4e0e9ed1df6e3fdbd873>
4. P. H. T. Zannin, E. O. Do Nascimento, E. C. Da Paz, and F. Do Valle, “Application of Artificial Neural Networks for Noise Barrier Optimization,” *Environments*, vol. 5, no. 12, p. 135, Dec. 2018, doi: 10.3390/environments5120135.
5. D. Montes González, G. Rey-Gozaló, and J. M. Barrigón Morillas, “Chapter 6—Environmental noise pollution and sources,” in *Nanotechnology to Monitor, Remedy, and Prevent Pollution*, M. Bilal, H. M. N. Iqbal, T. A. Nguyen, G. Yasin, and R. K. Gupta, Eds., in *Micro and Nano Technologies*, Elsevier, 2024, pp. 99–121. doi: 10.1016/B978-0-443-15660-1.00030-7.
6. B. S. Chauhan, N. Garg, and S. Tiwari, “Predictive noise annoyance and noise-induced health effects models for road traffic noise in NCT of Delhi, India,” *Noise Mapp.*, vol. 11, no. 1, Jan. 2024, doi: 10.1515/noise-2024-0008.
7. J. B. Newbury et al., “Air and Noise Pollution Exposure in Early Life and Mental Health From Adolescence to Young Adulthood,” *JAMA Netw. Open*, vol. 7, no. 5, p. e2412169, May 2024, doi: 10.1001/jamanetworkopen.2024.12169.
8. M. Basner et al., “Auditory and non-auditory effects of noise on health,” *The Lancet*, vol. 383, no. 9925, pp. 1325–1332, Apr. 2014, doi: 10.1016/S0140-6736(13)61613-X.
9. E. Orban et al., “Residential Road Traffic Noise and High Depressive Symptoms after Five Years of Follow-up: Results from the Heinz Nixdorf Recall Study,” *Environ. Health Perspect.*, vol. 124, no. 5, pp. 578–585, May 2016, doi: 10.1289/ehp.1409400.
10. K. B. Fuks, C. Wiggmann, H. Altug, and T. Schikowski, “Road Traffic Noise at the Residence, Annoyance, and Cognitive Function in Elderly Women,” *Int. J. Environ. Res. Public Health*, vol. 16, no. 10, p. 1790, Jan. 2019, doi: 10.3390/ijerph16101790.
11. novale, “Ruido y Salud—Observatorio de Salud y Medioambiente de Andalucía: OSMAN.” Accessed: Dec. 02, 2025. [Online]. Available: <https://www.osman.es/project/ruido-y-salud-2/>
12. J. R. Meijer, M. A. J. Huijbregts, K. C. G. J. Schotten, and A. M. Schipper, “Global patterns of current and future road infrastructure,” *Environ. Res. Lett.*, vol. 13, no. 6, p. 064006, May 2018, doi: 10.1088/1748-9326/aabd42.
13. T. Corbin, “International Road Federation,” Official Site of the International Road Federation. Accessed: Dec. 02, 2025. [Online]. Available: <https://www.irf.global/>
14. M. N. Tezel-Oguz, M. Marasli, D. Sari, N. Ozkurt, and S. S. Keskin, “Investigation of simultaneous effects of noise barriers on near-road noise and air pollutants,” *Sci. Total Environ.*, vol. 892, p. 164754, Sep. 2023, doi: 10.1016/j.scitotenv.2023.164754.
15. A. Barros, J. K. Kampen, and C. Vuysse, “Noise barriers as a mitigation measure for highway traffic noise: Empirical evidence from three study cases,” *J. Environ. Manage.*, vol. 367, p. 121963, Sep. 2024, doi: 10.1016/j.jenvman.2024.121963.

16. A. Jagniatinskis, B. Fiks, and M. Mickaitis, "Determination of Insertion Loss of Acoustic Barriers under Specific Conditions," *Procedia Eng.*, vol. 187, pp. 289–294, Jan. 2017, doi: 10.1016/j.proeng.2017.04.377.
17. P. Alam, K. Ahmad, S. S. Afsar, and N. Akhtar, "3D noise mapping for preselected locations of urban area with and without noise barriers: A case study of Delhi, India," *Noise Mapp.*, vol. 7, no. 1, pp. 74–83, Jan. 2020, doi: 10.1515/noise-2020-0006.
18. V. Laxmi, C. Thakre, and R. Vijay, "Evaluation of noise barriers based on geometries and materials: a review," *Environ. Sci. Pollut. Res.*, vol. 29, no. 2, pp. 1729–1745, Jan. 2022, doi: 10.1007/s11356-021-16944-2.
19. J. M. Martinez-Orozco and A. Barba, "Determination of Insertion Loss of noise barriers in Spanish roads," *Appl. Acoust.*, vol. 186, p. 108435, Jan. 2022, doi: 10.1016/j.apacoust.2021.108435.
20. X. Qin, W. Yang, Z. Zhang, and Z. Chen, "Research on the design and noise reduction performance of periodic noise barriers based on nested structure," *J. Clean. Prod.*, vol. 476, p. 143708, Oct. 2024, doi: 10.1016/j.jclepro.2024.143708.
21. K. Szopinska, M. Balawejder, and A. Warchol, "National legal regulations and location of noise barriers along the Polish highway," *Transp. Res. PART -Transp. Environ.*, vol. 109, p. 103359, Aug. 2022, doi: 10.1016/j.trd.2022.103359.
22. J. Kastka, E. Buchta, U. Ritterstaedt, R. Paulsen, and U. Mau, "The long term effect of noise protection barriers on the annoyance response of residents," *J. Sound Vib.*, vol. 184, no. 5, pp. 823–852, Aug. 1995, doi: 10.1006/jsvi.1995.0348.
23. M. E. Nilsson, M. Andéhn, and P. Lešna, "Evaluating roadside noise barriers using an annoyance-reduction criterion," *J. Acoust. Soc. Am.*, vol. 124, no. 6, pp. 3561–3567, Dec. 2008, doi: 10.1121/1.2997433.
24. A. Pultnerova, J. Simo, and J. Grecik, "Possibilities of Evaluating the Effectiveness of Noise Barriers in Slovakia," *Appl. Sci.-Basel*, vol. 11, no. 21, p. 10206, Nov. 2021, doi: 10.3390/app112110206.
25. H. Bendtsen, "Visual Principles for the Design of Noise Barriers," *Sci. Total Environ.*, vol. 147, pp. 67–71, May 1994.
26. D. Butkus, T. Janusevicius, and V. Askelovic, "Investigation of the variation of noise spectrum behind noise barriers made of different materials," in *9th International Conference Environmental Engineering (9th Icee) – Selected Papers*, D. Cygas and T. Tollazzi, Eds., Vilnius-40: Vilnius Gediminas Technical Univ Press, Technika, 2014. doi: 10.3846/enviro.2014.007.
27. I. Ramadan, T. Salah, and O. Alhariri, "Studying the Effect of Noise Barrier Characteristics on Traffic Noise in Urban Areas," *Civ. Environ. Eng.*, vol. 20, no. 2, pp. 824–836, Dec. 2024, doi: 10.2478/cee-2024-0061.
28. O. Yaroshchuk, V. Vyrozhemskiy, N. Kharytonova, and I. Rutkovska, "The Degradation Processes of Noise Barriers and Their Impact on the Acoustic Characteristics of These Facilities," in *Intelligent Transport Systems: Ecology, Safety, Quality, Comfort, Its Esqc 2024, Vol 2*, O. Slavinska, V. Danchuk, O. Kynytska, and O. Hulchak, Eds., in *Lecture Notes in Networks and Systems*, vol. 1336. Cham: Springer International Publishing Ag, 2025, pp. 50–60. doi: 10.1007/978-3-031-87379-9_5.
29. K. Zhang et al., "Using street view images to identify road noise barriers with ensemble classification model and geospatial analysis," *Sustain. Cities Soc.*, vol. 78, p. 103598, Mar. 2022, doi: 10.1016/j.scs.2021.103598.
30. "Conference of European Directors of Roads [CEDR]," Conference of European Directors of Roads [CEDR]. Accessed: Aug. 20, 2025. [Online]. Available: <https://www.cedr.eu/news-data/1380/Publication-of-three-Technical-Reports-on-noise>
31. "Longitud por CCAA, Provincia y tipo — Catálogo Oficial de Carreteras." Accessed: Aug. 20, 2025. [Online]. Available: <https://catalogorce.transportes.gob.es/longitud-ca-provincia-tipo>
32. "Spatial without Compromise · QGIS Web Site." Accessed: Dec. 02, 2025. [Online]. Available: <https://qgis.org/>

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.