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Application of a street categorization method to the study of urban noise: the Valladolid (Spain) study

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ABSTRACT

We describe the application of a categorization method for road traffic noise evaluation. The method assumes that urban noise is stratified according to a five-category classification of streets based only on their use as communication routes. The method has previously been shown to be valid for towns under 220 000 inhabitants, and in the present case is applied to study the urban noise in Valladolid (Spain), a town with a population of nearly 320 000 inhabitants. Novel mathematical tools in this field are used to analyze the method. We demonstrate the existence of a stratification of the streets sound levels. Thus, the categories defined seem to be quite adequate for towns of this size range. Moreover, noise level predictive capacity of the method was also analyzed and an overall value for the predictive capacity of 80% was obtained. Thus, our method can be a simple, low-cost strategy to make a statistical evaluation of the traffic noise in a city.

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I. INTRODUCTION

Noise has been proven to be a public health problem (Bluhm *et al.*, 2004) because of its harmful effect on humans [physical (Ising *et al.*, 2003, 2004), psychological (Zannin *et al.*, 2003; Griefahn *et al.*, 2000), etc. (Fyhri and Klæboe, 2009)], as well as having many other repercussions [economic (Taylor *et al.*, 1982; Brons *et al.*, 2003), social (Fyhri and Klæboe, 2006), etc.]. Since people are increasingly living in urban areas, it is very important to characterize the noise in these agglomerations (Li *et al.*, 2002; Ali and Tamura, 2003) and to investigate the interaction between urban form, traffic and noise exposure (Tang and Wang, 2007). In the case of urban noise, traffic noise (TN), and mainly road traffic noise (RTN), is acknowledged as being the main contributor. For this reason, the evaluation of RTN in large agglomerations has been the most extensively studied contribution to overall noise levels (Ouis, 2001, 2002; Bluhm *et al.*, 2004; Jakovljevic *et al.*, 2009).

The purpose of a noise map is to show the distribution, values, evolution, sources, etc., of noise. There are two totally different approaches to constructing a noise map: *in situ* measurement of noise, or calculation of noise descriptors using data on environmental conditions and noise sources. In any case, *in situ* measurements will always be necessary, either as the fundamental data for a measurement-based noise map, or as input or control values in a calculation with the same objective.

For these *in situ* measurements, random sampling, usually by the superposition of a regular grid over a town map to choose sampling points, has been extensively used for noise mapping (Zannin *et al.*, 2001, 2002; Barrigón *et al.*, 2002a, 2011; Sommerhoff *et al.*, 2004). In seeking a strategy better suited to noise assessment based on *in situ* measurements, our research group proposed (Barrigón *et al.*, 2002b) a categorization method in which streets were classified into different categories according to their use as communication routes. The method has been applied with promising results to medium-sized towns (Barrigón *et al.*, 2005a, 2005b), showing its potential as simpler and less resource-consuming than grid-based experimental methods. A recent publication referring to this methodology shows other applications of the method (Barrigón *et al.*, 2010).

Previous noise studies of Valladolid had been carried out in the 1990s. One (Sánchez and González, 1992) was based on an existing town-planning analysis, and a more recent study (Martín *et al.*, 2006) principally focused on the annoyance due to noise determined by a survey questionnaire.

The main objectives of the present work can be summarized as follows:

- To apply the categorization method to more populous towns than those studied previously.
- To validate statistically the previous defined categories in large towns.
- To analyze in depth the statistical validity of the method.
- To study the predictive capacity of the method.

II. THE STUDY AREA

A. Location

Valladolid is the capital of the province of the same name, in the centre of the *Castilla y León* region, in the north-east of the Iberian Peninsula (coordinates: 41°39' N; 4°43' W), in the Central Plateau. The town's mean altitude is 691 m above sea level (a.s.l).

The area of the town is 37.02 km², and the total population is 315 000 inhabitants (year 2007), making it the 13th town in size in Spain by number of inhabitants.

B. Geographical description

Most of Valladolid's population live in a very flat area, the exception being the Parquesol district (25 900 inhabitants) which is on a hill that physically separates it from the other parts of the town.

There are two barriers in the town. One is a natural barrier – the River Pisuerga. It crosses the town from north-east to south-west. Eight three-lane bridges along a 3.7 km stretch concentrate the traffic flow between the two halves. The other is the railway which cuts the town into two. This division has been the root of serious problems of transport, because communication between the two areas is only possible through 9 bridge or tunnel crossings and 1 level-crossing along 5.3 km. Some of these crossings are two-lane and some are four-lane.

C. Town planning

The buildings of the town are varied in their types of construction. Buildings of between 8 and 15 storeys predominate, although some very old houses of no more than 3 storeys are common in the town centre, and there are semi-detached houses, bungalows, and single-family 2-storey houses in some peripheral zones.

The streets are heterogeneous. There are both narrow one-way streets with little traffic (although saturated at certain times of day) and wide avenues of up to three lanes per direction and traffic flows of up to 4000 vehicles/hour. The roadways are mainly asphalted and generally in good condition, although some are cobbled. The speed limit is at most 50 km/h in all the study area, although it is 80 km/h in certain sections of the surrounding ring-road.

In this city, neither airport nor industrial activity will affect the fundamental assumption that road traffic is the main noise source. The town's airport (Villanubla airport) is located 11 km away on a plateau at an altitude of 870 m a.s.l. Although rail traffic can become an important source of noise, the slow speed of the trains approaching or leaving the station, and their relative low frequency, make this contribution fairly irrelevant for the day as a whole. There is no significant industrial activity inside the study area (only small workshops) since the two largest industrial zones are outside residential areas.

III. METHODS

A. Categorization method

The categorization method is based on the widely accepted assumption that road traffic is the main noise source in most of a town's streets. Firstly, this implies that the results and validity of the method should by itself be correct only if no other significant noise sources are present, and secondly that, considered as a method of mapping, only a road traffic noise map can be obtained.

The definitions of the categories used in the present study are the same as have been used in a previous work (Barrigón *et al.*, 2005b) where you can find also a summary of the steps needed to follow in order to apply it..

B. Street categorization

The categorization of the town consists of classifying each street into one of the six categories. This step required approximately one week: one–two days of study on a map with the assistance of one of the town's residents, and four–five days of *in situ* study.

The resulting categorization of Valladolid is summarized in the map of Fig. 1. Grey levels from black to white represent the categories 1 to 5. Also shown is the limit of the area studied. Only streets with housing were considered. Roads outside the inhabited zone have been coloured for completeness and a better comprehension of the categorization method, but no measurements were made in them.

All the streets other than pedestrian, restricted-access, etc., not included in categories 1 to 4 were included in the type-5 category. Thus, from the list provided by the Town Council, which totals 997 streets, 659 belonged to category 5. The pedestrian, restricted-access, etc. streets were not considered because of the absence of RTN.

The distribution of the total street length by category is shown in Fig. 2. These are measured lengths for types 1 to 4, and an estimated length for type 5. Despite the many kilometres of type-1 streets in the map of Fig. 1, only a small fraction passes through residential areas. For that reason this category represents less than 20% of the total of types 1–4.

C. Sampling point selection

Once every street of the city had been assigned to one of the five categories, eleven points of streets belonging to each category were selected at random. After a careful analysis, we found that with this number of points we get a good compromise between the predictive ability of the method and the time required to carry out all measures. Two methods were used, one for the streets of categories 1 to 4, and the other for streets of category 5. For the streets of categories 1 to 4, the total street length was calculated, denoting by L_i the total length of category *i*. Using the "random" function, eleven values x_{ij} ($x_{ij} \in [0,L_i]$; i = 1, 2, 3, 4; j = 1, 2,…11) were selected for each category. Each value represented a point of a street, located with a precision of 1 m, and randomly distributed throughout the category. The only condition applied was that equivalent points (located on the same section of street with no intersection between them) were avoided. In the case of category 5, due to the large number of streets involved, another random strategy was used. Each administrative-level street was taken to be a single potential sampling point, with the actual measurement to be made in the middle of the segment that corresponded to the whole street. The actual measurement point locations are represented on the map of Fig. 1, superimposed on the street categorization.

D. Measurement equipment and procedure

In situ noise measurements were made on working days (Monday to Friday) from March 5th to May 11th 2007, on days corresponding to the typical continental climate of spring when the weather conditions were convenient (no rain or wet roads, and light winds producing saturation in the sound-lever meter always below 0.1% for each measurement). The day was taken to be that defined by European Directive 20002/49/EC (COM, 2002), from 7:00 a.m. to 7:00 p.m. This period was divided into four 3-hour periods in order to take a set of four independent measurements at each sampling point. With this objective, never more than one measurement per day was performed at each location and never in the same time interval.

All measurements were carried out following the ISO 1996-2 (ISO 1996-2, 2003) guidelines with the use of a 2238 Brüel & Kjæl type-1 sound-level meter, equipped with a tripod and windshield. Calibration was performed using a 4231 Brüel & Kjæl calibrator twice a day. Each measurement was fifteen minutes in duration [as is standard (Zannin *et al.*, 2002)]. The standard noise descriptors were recorded (L_{max}, L_1, L_5, L_{10}, L_{50}, L_{90}, L_{99}, etc.), but only the 15-minute $L_{A,eq}$ will be used to analyze the results in the present work, as this is the simplest and most widely accepted physical descriptor of noise, although some objections to its use have been raised (Can *et al.*, 2008).

IV. RESULTS

A. Initial analysis

The measurement sites were unaffected by noise from construction, the railway, or aircraft. Two points were located close to the railway, but separated from it by a 3 m high wall, which, together with the infrequent passage of trains and their slow speed (due to the closeness to the railway station), meant that train noise could be regarded as negligible. In the selection of the sampling points, care was taken to check that they were not close to construction sites, especially in the case of type 5 streets. Nevertheless, during the measurements, it was observed that at point 6 of category 3 (the point crossed out near the bottom of the map of Fig. 1) there was a high traffic flow of heavy trucks. This was due to the construction of a new south ring-road. As this situation was circumstantial and not representative of the normal conditions of this street, the sound levels measured at this point, although listed in Table 1, were eliminated from further consideration in the calculations.

A total of 220 15-minute measurements were taken. The results of the measurements are summarized in Table 1. The following conclusions were drawn from the analysis of the values obtained:

1) In general, the measurements are highly stable. Category 5 presents more variability, reflecting the effect of its varied architecture, location, etc.

2) The medians associated with each category show the expected increase in value with category. Figure 3a shows a synthesis of these results in the form of a box-and-whisker plot (Fawcett, 2006).

B. Statistical analysis

The experimental results were subjected to different statistical tests to test the basic hypothesis of the categorization method: that noise is stratified among the streets of the town according to their use, and that the proposed categorization allows this stratification to be distinguished.

The Kruskal-Wallis test and Wilcoxon-Mann-Whitney with Bonferroni correction test were applied to study the similarities and differences between the categories. These non-parametric tests were used instead of parametric tests since the small number of samples meant that the normality of the data was doubtful.

As a new approach in this kind of study, a Receiver Operating Characteristics (ROC) analysis or ROC curve (Hand and Till, 2001; Fawcett, 2006) was conducted to find the best class and analyze the predictive capacity of the categorization method. This method measures the ability of our classification method to discriminate between the different categories.

B.1. Kruskal-Wallis test

A Kruskal-Wallis one-way analysis by ranks is a non-parametric method for testing equality of population medians among groups. The results of this test were, for four degrees of freedom, K=46.24 and p-value=2.19×10^{-9} ($p\leq0.001$). This result shows that the samples come from different populations, i.e., that there is a significant difference between the means of each category.

B.2. Wilcoxon-Mann-Whitney test with Bonferroni correction

The Wilcoxon-Mann-Whitney test with Bonferroni correction showed that all the categories differ from each other, except categories 2 and 3 (Table 2).

The present results are coherent with those reported in a previous study (Barrigón *et al.*, 2005b). In particular, all the non-adjacent categories are distinguished, and only one pair of adjacent categories is not distinguished.

B.3. Area under the curve (AUC) of the ROC analysis

By means of a statistical analysis similar to that used in previous works, we have demonstrated that the category definitions allow one to test the existence in a town of more than 300 000 inhabitants of a noise structure than can be explained with the proposed categorization.

In order to study the categorization method in greater depth, we analyzed the differences among categories in the proposed structure. Although the equivalent levels of all the categories were different (except for categories 2 and 3 as was discussed in section B.2), if one takes all the sound levels corresponding to each category into account (Table 1), there appear to be values in some categories that lie in the range of values corresponding to adjacent categories. This overlap is also seen in Fig. 3b. To analyze these overlaps, we used the ROC technique, which, to the best of our knowledge, has not been applied before in this type of study. This technique will also help us to analyze the predictive capacity of the method. For a good explanation of ROC analysis and the generalization of the Area Under the Roc Curve (AUC) for multiple class classification, see the mentioned references (Hand and Till, 2001; Fawcett, 2006).

Here, we generalized the area under the ROC curve for a 5-category classification. Each choice of a set of category limits defines a vertex in the ROC plot. The set which maximizes the sensitivity (power to identify a positive or true classification) and minimizes the nonspecificity (power to identify a negative or false classification) is chosen as the category definer. The results of this optimization process are presented in Table 3, giving the limits defining each category, its amplitude, and the AUC, p-value, and the Bonferroni adjusted p-value for each consecutive pair of strata or categories, and the sensitivity, nonspecificity, and predictive value of each category.

One observes that the application of this data analysis technique yields five strata (one corresponding to each category), with their upper and lower values. With respect to the amplitudes of the strata, two of them (2 and 3, the same pair that the Wilcoxon-Mann-Whitney test could not distinguish) have amplitudes near 3 dB(A), while two others have amplitudes near 5 dB(A), and one an amplitude near 15 dB(A), with this stratum being that corresponding to the least noisy streets of the town.

The marks of the strata are very close to the mean equivalent levels obtained for categories 2, 3, and 4, and fairly close for the other two categories (1 and 5). This proximity is indicative of internal coherence of the category method.

The ROC analysis sensitivity is a measure of the capacity of including the previously assigned streets in the stratum. The results presented in Table 3 can be regarded as encouraging: the sensitivity in strata 4 and 5 is 100%, and in the other strata is 60% or greater. The overall sensitivity of the method is consequently about 80% – of a group of five streets, four will present sound values corresponding to the stratum to which they were assigned in the initial categorization of the town (prior to any measurements).

The nonspecificity is a measure of the proportion of the streets which were not initially assigned to a certain stratum but which the ROC analysis indicates belong to that stratum. As can be observed in Table 3, only for stratum 2 is the nonspecificity greater than 10%. For the rest of the strata, the values are lower, and even zero for stratum 5. This indicates that, according to the ROC analysis, none of the streets assigned to categories 1 to 4 actually belongs to category 5. The overall nonspecificity was 20.4%, consistent with the overall sensitivity obtained. This means that on average only one out of five streets is assigned by the ROC analysis to a stratum different from that to which it was assigned in the categorization. One notes that 60% of this nonspecificity comes from stratum 2.

With respect to the predictive value of the different strata, this parameter represents the proportion of the streets that are assigned by the ROC analysis to the stratum to which they were initially assigned, relative to the total number of streets that the ROC analysis considers belongs to this stratum. The results given in Table 3 show that, except for stratum 2, the predictive values are greater than 75% (100% for stratum 5). The overall predictive value is 80%.

V. CONCLUSIONS.

We have described the construction of a traffic noise map for the entire residential part of a town of 320 000 inhabitants (Valladolid, Spain) using the street categorization method.

The obtained results demonstrate the existence of a stratification of the sound levels of the streets of Valladolid – a stratification obtained from the definition of the five categories. Thus, the applicability of the method has been proved in a city with 50% increase in size over the previous most populous town analyzed.

An ROC analysis gave a predictive value of about 80% or greater for all the strata except one. It also indicated, on the basis of the amplitudes obtained for strata 2 and 3 that, for this town, these two categories could be merged in order to obtain predictive values greater than were obtained in the present study. It should be noted that, in such a case, the amplitude would remain at a value below 5 dB(A). On the contrary, the amplitude and predictive value of stratum 5 indicate that this category could be split into subcategories which, while maintaining the high predictive value, could allow the amplitude to be reduced.

An overall value for the predictive capacity of 80% was obtained.

Further studies are necessary to inquire in greater detail into the proposed method for the study of noise in towns in order to take advantage of the great potential that the categorization method shows: in one hand, we can estimate with only a few measures the noise distribution in a city; these estimated values can be compared with those proceeding from modelling results. And, in the other hand, with the verification of the existence of a stratification of urban noise, our method can help users of predictive noise software to validate their results with a few measures.

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Figure captions

Figure 1. City area studied (dashed gray line), the excluded industrial zones, street categorization, and noise measurement points.

Figure 2. Total length of streets belonging to a category.

Figure 3. (a) Box-and-whisker diagram by categories. (b) Disjoint categories as a result of the ROC analysis.

TABLE 1. Values of the 15-minute measurements: $L_{A,eq}$, range, and standard deviation for each measurement point, and logarithmic mean, range, and standard deviation for each category. Point 6 of category 3 (shadow cells) was eliminated from further consideration in the calculations, as explained in the main body of the paper.

		Point number											Category value
Category		1	2	3	4	5	6	7	8	9	10	11	
1	7:00-10:00	74.4	75.4	73.4	74.4	74.7	73.1	75.9	75.4	74.7	77.7	80.4	
	10:00-13:00	72.8	74.2	72.9	74.4	75.3	72.1	76.0	76.1	73.8	76.9	71.6	
	13:00-16:00	73.7	75.0	71.9	74.1	74.3	73.1	76.9	74.1	73.9	78.4	79.8	
	16:00-19:00	77.4	74.5	73.2	75.2	75.1	74.0	75.7	74.7	72.8	74.6	79.9	
	$L_{A,eq}$(dB)	74.9	74.8	72.9	74.5	74.9	73.1	76.2	75.1	73.9	77.1	79.0	75.5
	range (dB)	4.6	1.2	1.5	1.1	1.0	1.9	1.2	2.0	1.9	3.8	8.8	6.1
	σ_{n-1} (dB)	2.0	0.5	0.7	0.5	0.4	0.8	0.5	0.9	0.8	1.7	4.2	1.8
2	7:00-10:00	70.9	74.1	70.9	73.8	73.6	70.2	75.5	74.8	72.0	74.2	72.7	
	10:00-13:00	70.0	73.6	71.0	73.3	74.5	69.4	75.1	75.0	72.0	74.0	71.9	
	13:00-16:00	70.3	72.4	71.1	74.9	73.1	67.9	74.0	74.8	72.7	75.3	71.1	
	16:00-19:00	70.0	73.6	70.7	73.5	72.8	70.2	71.6	74.4	72.8	73.8	73.2	
	$L_{A,eq}$(dB)	70.3	73.5	70.9	73.9	73.5	69.5	74.3	74.8	72.4	74.4	72.3	73.0
	range (dB)	0.9	1.7	0.4	1.6	1.7	2.3	3.9	0.6	0.8	1.5	2.1	5.2
	σ_{n-1} (dB)	0.4	0.7	0.2	0.7	0.7	1.1	1.8	0.3	0.4	0.7	0.9	1.8
3	7:00-10:00	71.2	70.4	73.9	71.3	71.4	75.6	70.6	71.6	73.9	73.4	71.7	
	10:00-13:00	70.7	67.3	71.7	70.7	73.0	74.3	72.1	71.5	72.8	71.4	70.1	
	13:00-16:00	70.9	68.4	71.6	71.6	69.7	74.2	71.1	72.4	73.5	72.3	71.7	
	16:00-19:00	70.6	68.9	73.0	71.1	69.5	75.0	68.7	70.6	73.5	71.9	71.7	
	$L_{A,eq}$(dB)	70.9	68.9	72.7	71.2	71.1	74.8	70.8	71.6	73.4	72.3	71.4	71.6
	range (dB)	0.6	3.1	2.3	0.9	3.5	1.4	3.4	1.8	1.1	2.0	1.6	4.5
	σ_{n-1} (dB)	0.3	1.3	1.1	0.4	1.6	0.7	1.4	0.7	0.5	0.9	0.8	1.2
4	7:00-10:00	65.0	66.7	69.1	69.8	68.5	68.9	72.2	68.6	72.0	68.4	67.8	

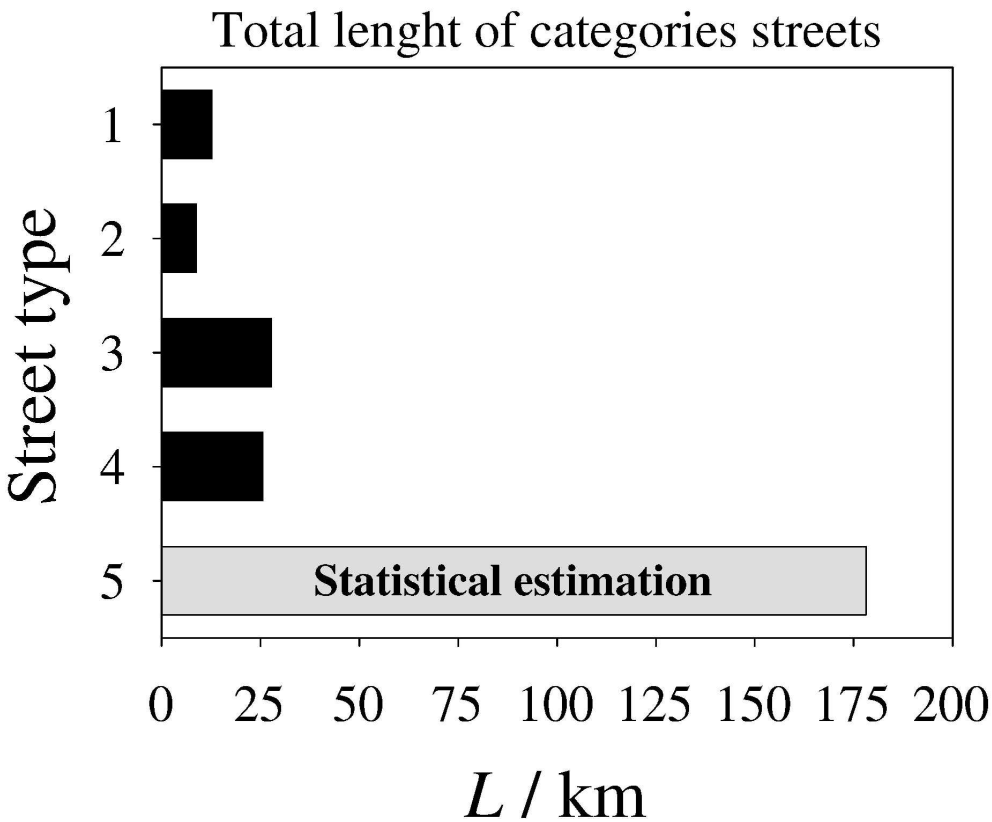
	10:00-13:00	65.8	68.1	67.0	66.7	66.4	68.9	69.4	70.3	71.9	66.9	68.3	
	13:00-16:00	68.9	67.8	68.1	68.8	67.6	68.1	69.8	68.9	67.5	65.8	68.8	
	16:00-19:00	65.5	67.3	67.3	68.1	65.4	69.0	68.9	68.0	69.9	66.9	67.4	
	$L_{A,eq}$(dB)	66.6	67.5	68.0	68.5	67.1	68.7	70.3	69.0	70.7	67.1	68.1	68.5
	range (dB)	3.9	1.4	2.1	3.1	3.1	0.9	3.3	2.3	4.5	2.6	1.4	4.1
	σ_{n-1} (dB)	1.8	0.6	0.9	1.3	1.4	0.4	1.5	1.0	2.1	1.1	0.6	1.3
5	7:00-10:00	58.4	67.3	66.3	48.6	61.9	62.7	61.1	53.8	64.3	53.6	61.7	
	10:00-13:00	57.6	62.9	60.7	50.6	62.8	56.3	60.3	51.8	61.0	57.1	60.5	
	13:00-16:00	58.8	62.0	62.6	49.8	59.4	58.8	62.4	55.9	52.3	52.4	59.9	
	16:00-19:00	58.6	62.8	61.9	51.3	60.2	56.3	60.5	63.0	63.7	59.0	62.3	
	$L_{A,eq}$(dB)	58.4	64.3	63.4	50.2	61.3	59.4	61.2	58.4	62.1	56.3	61.2	60.8
	range (dB)	1.2	5.3	5.6	2.7	3.4	6.4	2.1	11.2	12.0	6.6	2.4	14.1
	σ_{n-1} (dB)	0.5	2.4	2.4	1.2	1.6	3.0	0.9	4.9	5.5	3.1	1.1	3.9

TABLE 2. Homogeneous groups in terms of Wilcoxon-Mann-Whitney test.

	Medians (dBA)				
Stratum	1	2	3	4	5
Homogeneous group 1	74.9				
Homogeneous group 2		73.5	71.3		
Homogeneous group 3				68.1	
Homogeneous group 4					61.2

TABLE 3. ROC analysis results.

Stratum	**1**		**2**		**3**		**4**		**5**	**all**
Mark	76.7		73.2		71.3		68.1		57.8	
Upper limit	79.0		74.5		71.9		70.7		65.5	
Lower limit	74.5		71.9		70.7		65.5		50.2	
Amplitude	4.5		2.5		1.2		5.3		15.3	
AUC		0.86		0.73		0.97		1.00		
p-value		0.003		0.085		<0.001		<0.001		
Bonferroni ajusted		0.013		0.34		<0.001		<0.001		
Sensitivity (nº)	8		7		6		11		11	43
Sensitivity (%)	72.7		63.6		60.0		100		100	79.7
Nonspecificity (nº)	1		6		1		3		0	11
Nonspecificity (%)	2.3		14.0		2.3		7.0		0	20.4
Predictive value	88.9%		53.9%		85.7%		78.6%		100%	79.6%



157x141mm (600 x 600 DPI)

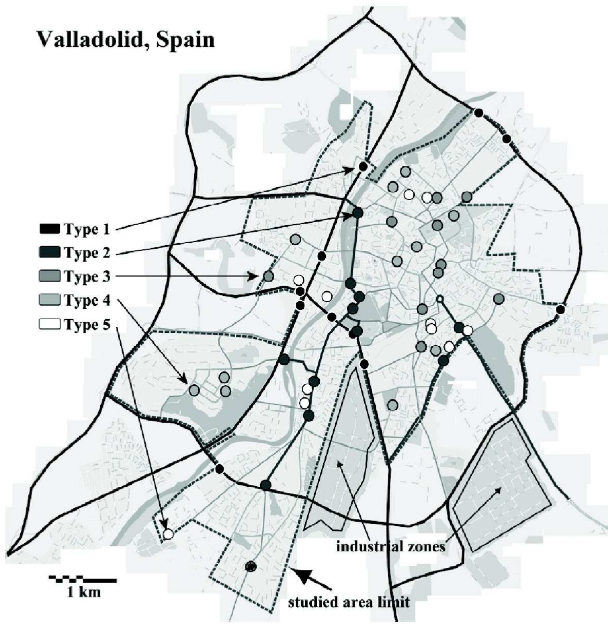
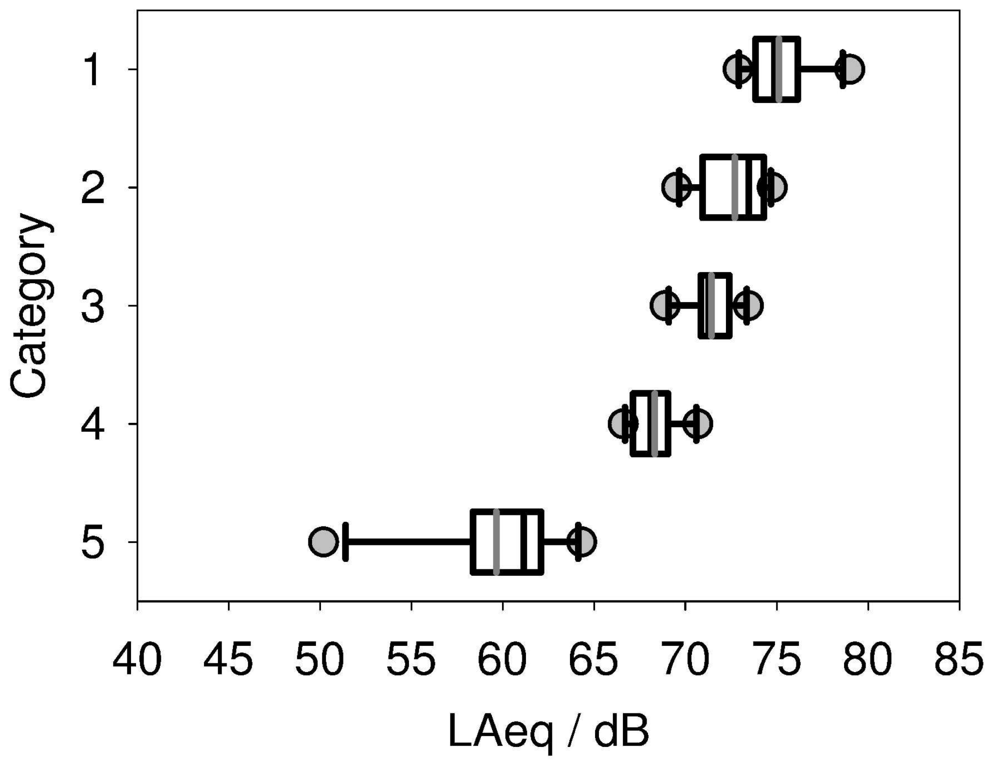
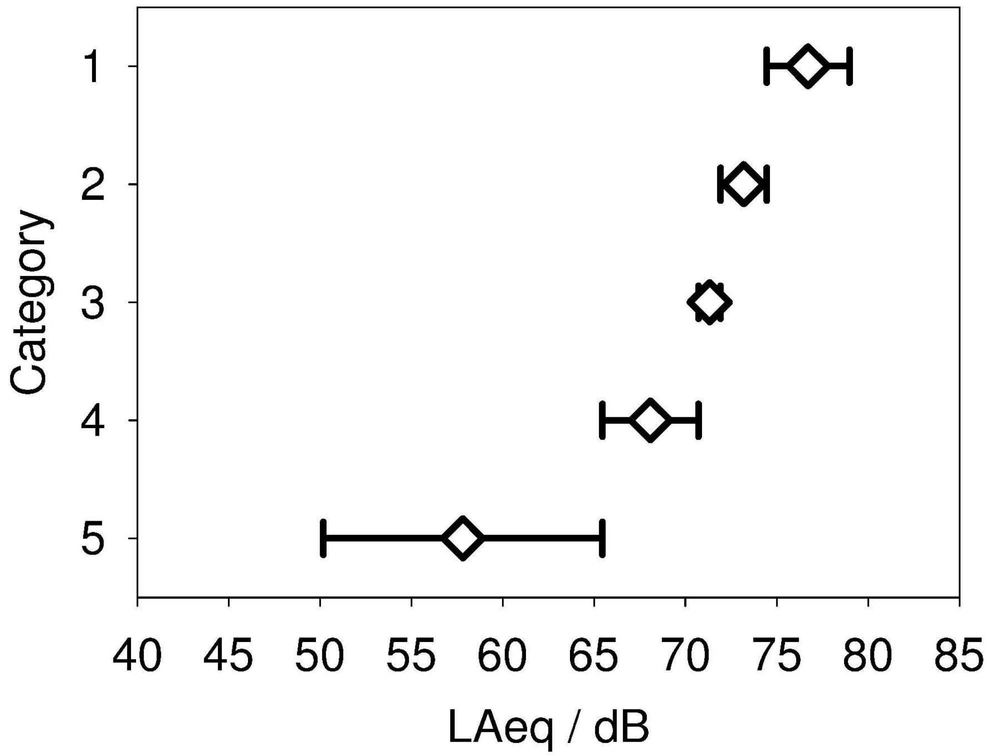


Figure 1. City area studied (dashed gray line), the excluded industrial zones, street categorization, and noise measurement points.
209x297mm (600 x 600 DPI)



152x127mm (600 x 600 DPI)



152x127mm (600 x 600 DPI)