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Abstract: Pollution associated to traffic can be considered one of the most relevant pollution sources in our cities; noise is one of the major components of traffic pollution; thus, efforts are necessary to search adequate noise assessment methods and low pollution city designs. Different methods have been proposed for the evaluation of noise in cities, including the categorization method, which is based on the functionality concept. Until now, this method has only been studied (with encouraging results) for short-term, diurnal measurements, but nocturnal noise presents a behavior clearly different on respect to the diurnal one. In this work 45 continuous measurements of approximately one week each in duration are statistically analyzed to identify differences between the proposed categories. The results show that the five proposed categories highlight the noise stratification of the studied city in each period of the day (day, evening, and night).
A comparison of the continuous measurements with previous short-term measurements indicates that the latter can be a good approximation of the former in diurnal period, reducing the resource expenditure for noise evaluation.
Annoyance estimated from the measured noise levels was compared with the response of population obtained from a questionnaire with good agreement.
The categorization method can yield good information about the distribution of a pollutant associated to traffic in our cities in each period of the day and, therefore, is a powerful tool for town planning and the design of pollution prevention policies.

Response to Reviewers: Answer to Reviewer #2:

1.- We agree with the reviewer that in a general noise study, noise measurement must be complemented with annoyance assessment. Thus, simultaneously to the analysis of sampling strategies for noise assessment, we have been working in the study of the response of population. In this line we developed some years ago a questionnaire to study this response (Barrigón Morillas JM, Vílchez Gómez R, Gómez Escobar V, Méndez Sierra JA, Tejeiro Vidal C, Alejandre Bueno L, Vaquero Martínez JM. Presentación de una encuesta para la realización de estudios sociales sobre el impacto del ruido urbano. Rev Española Acust 2002; 33:27-33). This questionnaire was used in the city of Cáceres as previously published (Barrigón Morillas JM, Gómez Escobar V, Méndez Sierra JA, Vílchez-Gómez R,

ANALYZING NOCTURNAL NOISE STRATIFICATION

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ABSTRACT

Pollution associated to traffic can be considered one of the most relevant pollution sources in our cities; noise is one of the major components of traffic pollution; thus, efforts are necessary to search adequate noise assessment methods and low pollution city designs. Different methods have been proposed for the evaluation of noise in cities, including the *categorization method*, which is based on the functionality concept. Until now, this method has only been studied (with encouraging results) for short-term, diurnal measurements, but nocturnal noise presents a behavior clearly different on respect to the diurnal one. In this work 45 continuous measurements of approximately one week each in duration are statistically analyzed to identify differences between the proposed categories. The results show that the five proposed categories highlight the noise stratification of the studied city in each period of the day (day, evening, and night).

A comparison of the continuous measurements with previous short-term measurements indicates that the latter can be a good approximation of the former in diurnal period, reducing the resource expenditure for noise evaluation.

Annoyance estimated from the measured noise levels was compared with the response of population obtained from a questionnaire with good agreement.

The *categorization method* can yield good information about the distribution of a pollutant associated to traffic in our cities in each period of the day and, therefore, is a powerful tool for town planning and the design of pollution prevention policies.

Keywords: urban pollution, noise sampling methods, urban planning, annoyance.

1. INTRODUCTION

Noise is one of the major urban pollutant, affecting the majority of the streets of modern cities, and it is present throughout almost all hours of the day (WHO, 1999). Thus, in the last decades, several noise studies have been conducted in different cities regarding different aspects of noise pollution, such as noise characteristics [sampling strategies (Barrigón Morillas, et al., 2005b; Romeu et al., 2011), uncertainty (Ausejo et al., 2011; Romeu et al., 2011, Torija and Ruiz, 2012; Barrigón and Prieto, 2014), sources (Zeng and Zhan, 2005; Yang et al., 2011), contamination levels (Arana, 2010; Ko et al., 2010), annoyance (Miedema and Oudshoorn, 2001; Kim et al., 2010; Paviotti and Vogiatzis, 2012), psychological effects of noise (Öhrström, 2004; Fyhri and Klæboe, 2009; Fyhri and Aasvang, 2010) and proposal of noise action plans (Naish, 2010; Vogiatzis and Remy, 2013). Road traffic is the primary origin of noise pollution and also of some other major city pollutants (Can et al., 2011b; Chen et al., 2008, Foraster et al., 2011; Su et al., 2008) which are the cause of different damaging effects on the citizens health and have influence also in the increase in house prices (Brandt and Maennig, 2011; Freitas et al., 2012; Lam and Chung, 2012).

In the analysis of the acoustic conditions of a given city or area, two different variables must be taken into consideration: spatial and temporal variation. Thus, sampling strategies can be classified according to these two variables.

Referring to the spatial variation, an adequate sampling strategy is dramatically important for noise mapping both for *in situ* measurements and for computational methods. Particularly, computational methods are recommended in different standards (ISO 1996-2, 2007) and legislations (COM, 2002). Nevertheless the recommended computation methods for road traffic noise need different kinds of *in situ* measurements: firstly, a wide traffic flow sampling through all the streets of the city in order to an adequate characterization of the sound source; secondly, noise measurements to calibrate the model and to check the precision of the estimated noise values (WG-AEN, 2007).

Therefore, it should be of great interest the development of a low cost method that could allow obtaining highly predictive results for *in situ* noise measurements. And, in addition, this method could allow an easy and efficient acquisition of traffic flows, and provide noise values for testing the accuracy of computational results. In example, Ausejo found an important decrease in the uncertainty of a computation noise model when the sampling strategy is improved and *in situ* measurements are carried out (Ausejo et al., 2011).

Based on the concept of functionality, a recently proposed group of category definitions has shown that it is possible to stratify the intensity of noise pollution in city streets: the *categorization method*. In previous studies, it was shown that these categories can highlight the stratification of urban noise (Barrigón Morillas et al., 2005b) and, recently, its applicability has been studied in urban centers ranging in size from 2,000 inhabitants to 700,000 (Rey Gozalo et al., 2013). The results show that, for even a fairly small number of measurements, the various strata (categories) are statistically significantly different. Thus, it was possible to precisely estimate noise levels in the unsampled streets. Consequently, the basis of the method and even the definition of categories could also be applied in such fields as urban planning or noise pollution control. Moreover, because traffic is also a source of other important pollutants, this method might extendable to such pollutants. Previous studies show the relationships between street noise and ambient air quality and their combined impacts on the surrounding environment (Kim et al., 2012) and how land use distribution determine the location of emission sources and the pattern of urban traffic, affecting urban air quality (Borrego et al., 2006).

Referring to the temporal variation, as also is indicated in the European Directive 2002/49/CE (COM, 2002) and some international standards (ISO 1996-2, 2007), noise indicators must be determined over a period of a year. This assessment can be easily performed using modern acoustical instrumentation, but noise-monitoring stations are quite expensive and can only be used at very specific locations. Thus, as an alternative, the most extended temporal strategy is recording measurements for less than a year and extrapolating them to obtain a year of data. The duration of these measurements can vary widely, from minutes to hours (Doygun and Gurun, 2008; Zannin et al. 2011; Romeu et al., 2011) to a whole day (Banerjee et al, 2008;

Onnu, 2000; Van Renterghem et al., 2012). Longer periods of time are rarely used (Alberola et al, 2005, Can et al., 2011a; Mioduszewski et al., 2011). Unfortunately, methods to assess the real day-evening-night sound level L_{Aden} from short-term measurements with the required precision have not yet been developed (Wolde, 2003). Thus, the extrapolation of these measurements to the year period can produce significant inaccuracies if the measurement period is not representative of the year period, as in the case of singular noise events (Prieto Gajardo et al., 2011). When the data used for the extrapolation are not representative of the entire year, errors of > 2 dBA can be produced (Bambrilla, 2001). We must consider that short-term measurements are usually carried out during the daytime, which generally has less variability than other periods of the day, such as nighttime.

Previously, the categorization method has only been applied to short-term diurnal measurements (thereby only yielding information about the day sound level L_{Ad}), focusing on showing that this method allows the identification of the noise stratification present in cities and villages (Barrigón Morillas et al., 2005b; Rey Gozalo et al., 2013). Despite the large number of cities and villages analyzed and the good results obtained, previous studies have not tested the validity of the method for continuous measurements or for other sound indicators commonly used in noise assessment, such as the evening sound level L_{Ae}, the night sound level L_{An}, and the day-evening-night sound level L_{Aden}.

The extension of the applicability of the categorization method to continuous measurements first requires proving that previous results obtained with short-term measurements are not statistically distinguishable from those obtained with continuous measurements in the same time period. Moreover, this confirmation does not guarantee the validity of the *categorization method* for unstudied periods of the day, such as the evening or night. The city of Cáceres (Spain) has been the site of a considerably high number of continuous measurements (of approximately one week each) and is used in this study to allow a deeper analysis of the applicability of the categorization method to continuous measurements. Moreover, this city has previously been studied in great detail using short-term measurements.

Nocturnal noise levels presents a behavior clearly different if compared with the diurnal one, both in temporal structure and in average values (Mioduszewski et al., 2011). Although there are some studies that relate diurnal noise levels with long-term indicators (which include the nocturnal period) (Schultz, 1978; Rey Gozalo et al., 2012), until now there are practically no jobs in which the stratification of nocturnal noise were proved. Previous studies nocturnal noise levels are estimated from its relationship with the whole day noise level (Jimenez et al, 2008), but the proposed categories presented significant differentiation problems. In addition to analyzing the stratification of the nocturnal noise values in the present work, it is examined whether these layers are the same as those proposed in previous works where, for diurnal period, significantly differences among them were observed. Therefore, the main objective of the present study is the evaluation of the application of the method to some sonorous categorization indicators (L_{Ad}, L_{Ae}, L_{An}, and L_{Aden}) obtained from continuous measurements.

Moreover, previous studies of Romeu, (Romeu et al., 2011) show the error in the estimation of day levels using short-term measurements in a classification of city streets in three groups: urban ring roads, main streets and ordinary streets. In the present work, we proposed five different categories and multiple comparison tests are carried out, in order to solve the different hypotheses. This kind of tests did not find significant differences in mean values of the categories proposed by Romeu (Jimenez et al., 2008). Thus, a secondary objective of the study is the evaluation of the possible differences in the application of this method to short-term and continuous measurements.

Finally, another secondary objective of the study is to analyze the ability of the categorization method to calculate the noise annoyance. To this effect, some mathematical equations have been proposed for determine annoyance due to traffic noise (Miedema and Vos, 1998; Miedema and Oudshoorn, 2001; Miedema et al., 2003); some of these equations are the basis of international standards or reports (ISO 1996-1, 2003; WHO, 2009), although some authors have found that these expressions cannot be totally appropriate in case of the existence of a high presence of noise traffic sources such as mopeds, scooters and motorbikes (Paviotti and

Vogiatzis, 2012). These annoyance estimations were compared with the results of some of the questions of a sociological study carried out in the studied city (Barrigón Morillas et al, 2005a).

Section 2 describes the method and the city where the measurements were carried out. Section 3 presents and discusses the results. Finally, Section 4 presents the most relevant conclusions.

2. METHODS

2.1. City studied

The present work was carried out in the city of Cáceres, the second largest town in Extremadura (a region in southwestern Spain). It has a population of approximately 95 000 inhabitants (increasing to over 110 000 during the teaching period due to the influx of over 10 000 students at the University of Extremadura and a large number of tourists). In recent years, the construction of a ring-road around the town has changed its traffic patterns, greatly reducing the number of heavy vehicles and, to a lesser extent, other vehicles that pass through the town. Industrial activities are of minor relevance and are concentrated mainly in the outskirts. The mean annual temperature and rainfall are 16.1℃ and 523 mm, respectively.

2.2. Sampling method

As previously mentioned, the categorization method was used in this study. The category definitions were the same described in previous works (Barrigón Morillas et al., 2005b, 2010; Rey Gozalo et al., 2013):

- *Type 1* includes those preferred streets whose function is to form connections with other Spanish towns and to interconnect those preferred streets. In general, these streets are indicated by a system of road signs.
- *Type 2* includes those streets that provide access to the major distribution nodes of the town. For the purpose of this study, a distribution node is considered to exist when at least four major streets meet. This definition does not include any possible nodes of preferred streets as defined in Type 1, above. This category also includes streets normally used as alternatives to Type 1 streets in the case of traffic saturation.

- *Type 3* includes streets that lead to regional roads, streets that provide access from those streets of Types 1 and 2 to centers of interest in the town (hospitals, shopping malls, etc.), and streets that clearly allow communication between streets of Types 1 and 2.
- *Type 4* includes all other streets that clearly allow communication between the three previously defined types of street, as well as the principal streets of the different districts of the town that were not included in the previously defined categories.
- *Type 5* comprises the rest of the streets of the town except pedestrian-only streets.
- *Type 6* comprises all the pedestrian-only streets.

As the assumption behind this method of street categorization is that traffic is the most important source of noise pollution, the sixth category was not included in the present study. In any case, pedestrian-only streets usually represent a very small percentage of all the streets in a city.

Once assigned the town's streets to these categories, several sampling points were required for each category. For the selection of these sampling points, different balconies were chosen, taking into consideration the category of the street, the access availability, their protection against vandalism and the non-equivalence with other balconies (equivalent balconies were those located on the same section of a street with no important intersection between them).

In Figure 1, the categorization of the different streets of the city and the locations of the sampling points are presented. A total number of 45 sampling points were used: 8 in Category 1, 8 in Category 2, 6 in Category 3, 8 in Category 4, and 15 in Category 5.

All measurements were performed following the ISO 1996-2 guidelines (ISO 1996-2, 1987, 2007) using 2236, 2238 or 2260 Brüel & Kjaer type I sound level meters. Each measurement lasted approximately one week, with data recorded every minute. A weighting was used in all measurements.

The monitoring stations were composed of a metallic box (to protect the sound level meter and the external battery), a 2-m spoke (to avoid the effect of the reflection of sound waves by the back wall), and an outdoor microphone kit (Brüel & Kjaer UA-1404) (to protect the microphone from adverse weather conditions). When possible, the monitoring stations were placed in different balconies or terraces located a height of 4 m (COM, 2002). Values obtained in balconies with a height higher than 4 m where were normalized to a height of 4 m as proposed in the "Guide du Bruit des Transports Terrestrial. Prévision sonores des niveaux" (CETUR, 1980) for streets with a U-shaped longitudinal profile and as described in the ISO 9613-2 standard (ISO 9613-2, 1996) for streets with an L-shaped longitudinal profile.

For the analysis for the secondary study objective, the comparison of continuous and short-term measurements, the short-term measurements used were those from a previous study of the city of Cáceres (Barrigón Morillas et al., 2011). These measurements were carried out on different days of the week (only workdays were studied) and during different periods of the day (at each sampling point, three measurements were distributed along the diurnal period). The sampling time for each measurement was 15 min. These short-term measurements were carried out in 2005 following the ISO 1996-2 guidelines (ISO 1996-2, 2007) using a 2238 Brüel & Kjaer type I sound level meter, with tripod and windshield, located 1 m from the curb and placed at a height of 1.5 m. Calibration was performed using a 4231 Brüel & Kjaer calibrator.

2.3. Calculation of the population annoyed by noise

To calculate the population annoyed by traffic noise two different methods were employed. Firstly, it was estimated as per some equations proposed by other authors and internationally validated. Thus, the percentages of annoyed (%A) and highly annoyed (%HA) population were estimated from L_{Aden} indicator with the following equations (Miedema and Oudshoorn, 2001; ISO 1996-1, 2003):

$$\%A = 0.0001795\,(L_{Aden} - 37)^3 + 0.0211\,(L_{Aden}-37)^2 + 0.5353\,(L_{Aden}-37) \quad (1)$$

$$\%HA = 0.0009868\,(L_{Aden} - 42)^3 - 0.01436\,(L_{Aden}-42)^2 + 0.5118\,(L_{Aden}-42) \quad (2)$$

Referring only to nocturnal noise, the percentages of citizens lowly sleep disturbed (%LSD), sleep disturbed (%SD) and highly sleep disturbed (%HSD) were estimated from the L_{An} indicator with the following equations (Miedema et al., 2003):

$$\%LSD = (-8.4) + 0.16\, L_{An} + 0.01081\, (L_{An})^2 \quad (3)$$

$$\%SD = 13.8 - 0.85\, L_{An} + 0.01670\, (L_{An})^2 \quad (4)$$

$$\%HSD = 20.8 - 1.05\, L_{An} + 0.01486\, (L_{An})^2 \quad (5)$$

Secondly, for the purpose of comparing the estimated annoyance with the response of population, results of a parallel sociological study were considered (only the answers corresponding to the questions referred to annoyance due to traffic and to alteration of sleep due to noise). A total of 390 subjects were randomly selected according to their residence following the categorization method. Consequently, the results can be classified according to the category of the street of the resident. The procedure was door-to-door, with the interviewer present. More information about the questionnaire and the survey can be found in previous works (Barrigón Morillas et al, 2002; 2005a).

2.4. Statistical analyses

The continuous equivalent sound level (L_{Aeq}) was chosen for the different statistical tests used to analyze the results and evaluate the quality of the category classification because L_{Aeq} is most commonly used in noise studies. Nevertheless, the sampling point locations are not similar and obtained values must to be normalized. Thus, to normalize these distances, for each measured L_{Aeq}, the sound power level by length unit (L_{Aw}) was calculated to allow a comparison. For corrections, the methods described in some ISO standards were considered (ISO 1996-2, 2007; ISO 9613-2, 1996). One order of reflection was considered; reflections on front of building were treated with the help of image sources, as used in several national calculation methods (EC, 2003).

After calculating the different sound power levels, the hypotheses of the statistical analyses were as follows:

- Null hypothesis (H_0): There are no significant differences between the L_{wx} values (dBA) of the different categories.
- Alternative hypothesis (H_1): There are significant differences between the L_{wx} values (dBA) of the different categories.

where x is the time period of the sound indicator considered: e.g., 7:00 to 19:00 for L_{Ad}, 19:00 to 23:00 for L_{Ae}, and 23:00 to 7:00 for L_{An}.

To address the previous hypotheses at a probability of at least 95%, that is, with a degree of significance (α) equal to 0.05, the nonparametric Kruskal-Wallis and Mann-Whitney U-tests were used (Mann and Whitney, 1947; Kruskal and Wallis, 1952; Holm, 1979). These nonparametric tests were used due to the small number of samples, which makes a normal distribution unlikely.

The Kruskal-Wallis test (Kruskal and Wallis, 1952) was used to compare the five categories to identify any significant differences. When such differences were found, as they were in all cities, as shown below, Mann-Whitney U-tests were used to compare pairs of categories. The Mann-Whitney U-test is a nonparametric test for assessing whether two independent samples or observations come from the same distribution. This test was used to compare pairs of separate categories within the same population. To avoid any errors due to the use of data from the same population rather than randomly selected data, the Holm correction was used (Holm, 1979).

In contrast to the previous statistical tests, we used the receiver operating characteristics (ROC) analysis to study the predictive capacity and other characteristics that refer to the classification capacity of this method (Hand and Till, 2001; Fawcett, 2006, Torija and Ruiz, 2012). ROC analysis allows us to calculate the sensibility (capacity to include previously assigned streets in the stratum), non-specificity (proportion of streets that were not initially assigned to a certain stratum but that the ROC analysis indicated belonged to that stratum), and predictive values (proportion of the streets that the ROC analysis assigned to a stratum that matched the categories to which they were initially assigned, relative to the total number of streets that the ROC analysis determined for the stratum) using the following equations:

$$sensibility = \frac{number\ of\ data\ classified\ correctly\ in\ category\ i}{number\ of\ data\ of\ the\ category\ i} \quad (6)$$

$$non-specificity = \frac{number\ of\ data\ classified\ incorrectly\ in\ category\ i}{number\ of\ data\ that\ no\ belongs\ to\ category\ i} \quad (7)$$

$$predictive\ value = \frac{number\ of\ data\ classified\ correctly\ in\ category\ i}{number\ of\ data\ that\ the\ ROC\ method\ includes\ in\ the\ category\ i} \quad (8)$$

Finally, for the comparison between short-term and continuous measurements, the Mann-Whitney U-test was used to assess whether the two groups of measurements come from the same distribution.

3. RESULTS AND DISCUSSION

3.1. Analysis of mean sound levels.

In Table I, the mean values of the different sonorous indicators are shown: L_{Ad}, L_{Ae}, L_{An}, and L_{Aden}. In all the sub-day periods studied [day (from 7 a.m to 7 p.m) (L_{Ad}), evening (from 7 p.m. to 11 p.m.) (L_{Ae}), and night (from 11 p.m. to 7 a.m.) (L_{An}) and over the whole day (L_{Aden})]. There is a clear tendency of noise levels to decrease as the category number increases, on both workdays and non-workdays, as well as considering all the measured days (global). For a more adequate comparison, from the different sonorous indicators, for the global period, the sound power levels were calculated according to the previously mentioned normalization. These global sound power levels (also shown in Table I) were used to evaluate the statistical hypothesis.

First, the Kruskal-Wallis test was used, indicating significant differences ($p \leq 0.001$) for all the sonorous indicators studied (Table II). Thus, the Mann-Whitney U-test with Holm correction was then applied to analyze the differences among category pairs (Table III). As shown in Table III, the Mann-Whitney U-test found significant differences ($p \leq 0.01$) among all pairs of categories studied for all sound indicators analyzed (except categories 1-2 in the evening period, where differences were significant with $p \leq 0.05$). This finding indicates that the stratification of noise levels observed in previous short-term diurnal measurements studies is also found for continuous measurements and is equally present in the evening and night periods. In all the studied temporal periods, the five categories defined in the categorization method highlight this stratification. Thus, the categorization method is a very powerful method for noise assessment, allowing the noise values of cities to be characterized using a reduced number of sampling points.

Finally, to corroborate the quality of the previous results and to obtain more information about the categorization method, the classification capacity of this method was studied via ROC analysis. The results of this analysis are shown in Figure 2. From the results shown in this table, we can note the following:

- Regarding the ROC sensitivity (%), which is a measure of the capacity to include previously assigned streets in the strata, all the categories have values at or above 87, 75, 93 and 100% for L_{Awd}, L_{Awe}, L_{Awn}, and L_{Awden}, respectively.
- Regarding the non-specificity (%), which measures the proportion of streets that were not initially assigned to a given stratum but that the ROC analysis indicates belong to that stratum, all the obtained values were below 2.8%.
- Finally, the predictive values of the different strata (which represent the proportion of the streets that the ROC analysis assigned to the stratum that matched the categories to which they were initially assigned, relative to the total number of streets that the ROC analysis determined for the stratum) are very good: at or above 86, 78, 89, and 100% for $L_{Awd,}$ L_{Awe}, L_{Awn}, and L_{Awden}, respectively.

Therefore, we see that in each of the three periods analyzed and in the overall indicator (L_{Aden}), the results showed a high predictive capacity. For the overall indicator the prediction capacity was 100% in all categories. For the different period indicators, the worst result was in the evening period (almost 80%) and the best in the night (almost 90%). In this respect, it should be noted that night period is the most difficult interval to be evaluated with short-term measurements because of its variability.

Thus, based on this high prediction capacity, this procedure seems to be very suitable for further applications, such as noise prediction and the design of environmental policy.

3.2. Comparison of short-term and continuous measurements.

As mentioned previously, previous studies of the categorization method used short-measurements in several villages or towns. It is therefore of great interest to analyze whether the results of this study from continuous measurement are similar to those obtained from short-term measurements. To this end, the results of this study were compared with the results obtained from short-term measurements carried for a methodology comparison study (Barrigón Morillas et al., 2011). For the present comparison, the values obtained from the short-term measurements were compared with the L_{Ad} values obtained from the continuous measurements after correcting these latter values to correspond to the location of the sound level meters used in the short-term measurements (1 m from the curb and a height of 1.5 m, as indicated previously).

In Table IV, the mean values of L_{Ad} obtained from the short-term and continuous measurements are presented. The results from continuous measurements are different from those presented in Table I due to the aforementioned correction. As observed, the standard deviation is lower for the continuous measurements, as could be expected. For each category, the results from both groups (short-term and continuous measurements) were compared using the Mann-Whitney U-test with the Holm correction. The p-values obtained using this test were 0.460, 0.696, 0.492, 0.203, and 0.807 for the groups of categories 1, 2, 3, 4, and 5, respectively. In all cases, these p-values correspond to non-significant differences ($p > 0.05$) among the two groups compared. These results indicate that the results obtained in the previous studies are good and that sampling procedures based on short-term measurements can give good approximations of the sound levels obtained in continuous measurements for diurnal period.

3.3. Analysis and comparison of the proportions of the population annoyed by noise

As mentioned previously, proportions of population annoyed by traffic noise were calculated from the measured sound levels (from L_{Aden} y L_{An} indicators); besides, the response of population was determined from the answers to the questionnaires. In Figure 3, the response of population for each category is shown join together with the lines corresponding to the previous equations for annoyance estimation [equations (1) to (5)]. As it can be seen, there is a common tendency in the response of population determined from the answers to the questionnaires and the annoyance predicted by the equations. Nevertheless in some cases, mainly in nocturnal period, there are some differences. Differences between response of population of each category and the estimated values are shown in Table V.

From these results we can conclude:

- There is a great similarity between %A and %HA predicted values and the obtained from the questionnaires (Figure 3A).
- Considering the values obtained for %A and %HA and the citizens living in each category (shown in Table V), values obtained for annoyance, although important, are lower than those obtained in other studies concerning other European cities (Martín et al., 2006; Paviotti and Vogiatzis, 2012).
- Values obtained for %LSD, %SD and %HSD indicator obtained from the questionnaires are generally lower than estimated.
- The L_{An} values higher than 40 dB in all the measured categories effect over sleep quality, well-being, environmental insomnia, complains... (WHO, 2009). Besides, in categories 1 to 4 (with near 34% of the city population) the L_{An} value higher than 50 dB implies possible effects on hypertension or myocardial infarction and, finally, in Category 1 (L_{An}>60 dB), psychic disorders (WHO, 2009).

4. CONCLUSIONS

It has been shown that there is a stratification of nocturnal noise levels, similar to this previously demonstrated for diurnal ones. The proposed categories enable to estimate this stratification.

The present study also shows that the categorization method is an adequate tool for noise assessment for all periods of the day, thus enabling the stratification of noise present in cities to be identified. Therefore, with a reduced number of sampling points, a quick characterization of the noise levels of cities can be achieved. Besides, a high degree of consistency was found between annoyance estimated from measured noise levels and the response of population.

A study of the sound level evolution during the sampling time and the results obtained from the continuous measurements carried out also lead to the following additional conclusions:

- The mean values of the analyzed sound indicators (L_{Ad}, L_{Ae}, L_{An}, and L_{Aden}) decrease as the number of the category increases. To create an adequate comparison, the sound power levels were calculated from these indicators. A comparison of sound power levels using the Kruskal-Wallis and Mann-Whitney U tests shows that the differences among values of categories are statistically significant for a confidence interval of 99%. This finding demonstrates the applicability of the categorization method to continuous measurements, as can be applied to all periods of the day.

- When analyzing the predictive values of different categories using ROC analysis, all the categories presented values above 78%, indicating a good predictive capacity for non-measured values. A 100% predictive capacity in all categories was obtained for the L_{Awden} indicator, and predictive capacities of 90% or higher were obtained for the night indicator (L_{Awn}).

- The comparison of the results obtained in this study to short-term measurement results reveals no statistically significant differences between the groups of measurements for the period compared (daytime). Thus, the urban stratification of noise evidenced in previous studies using the categorization method and short-term measurements has been validated by continuous measurements. This finding suggests that the results obtained from short-term measurements may be a good approximation, if the measurements are designed properly, to continuous measurements.

- The results of this work seem to indicate that the concept of functionality (the basis of the categorization method) enable us to obtain good information about the distribution of noise levels in our cities for all periods of the day, estimated annoyance due to noise and can therefore be a good tool for town planning and the design of pollution prevention policies for noise as well as other traffic-related pollutants.

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References

Alberola J, Flindell IH, Bullmore AJ. Variability in road traffic noise levels. Appl Acoust 2005; 66:1180-1195.

Arana M. Are urban noise pollution levels decreasing? J Acoust Soc Am 2010; 127:2107-2109.

Ausejo M, Recuero M, Asensio C, Pavón I. Reduction in calculated uncertainty of a noise map by improving the traffic model data through two phases. Acta Acust united Ac 2011; 97:761-768.

Banerjee D, Chakraborty SK, Bhattacharyya S, Gangopadhyay A. Modeling of road traffic noise in the industrial town of Asansol, India. Transport Res D-Tr E 2008; 13:539-541.

Barrigón Morillas JM, Vílchez Gómez R, Gómez Escobar V, Méndez Sierra JA, Tejeiro Vidal C, Alejandre Bueno L, Vaquero Martínez JM. Presentación de una encuesta para la realización de estudios sociales sobre el impacto del ruido urbano. Rev Española Acust 2002; 33:27-33. (in Spanish)

Barrigón Morillas JM, Gómez Escobar V, Méndez Sierra JA, Vílchez-Gómez R, Vaquero JM. Effect of leisure activity related noise in residential zones. Build Acoust 2005a; 4:265-276.

Barrigón Morillas JM, Gómez Escobar V, Méndez Sierra JA, Vílchez-Gómez R, Vaquero JM, Trujillo Carmona J. A categorization method applied to the study of urban road traffic noise. J Acoust Soc Am 2005b; 116:2844-2852.

Barrigón Morillas JM, Gómez Escobar V, Rey Gozalo G, Vílchez-Gómez R. Possible relation of noise levels in streets to the population of the municipalities in which they are located. J Acoust Soc Am 2010; 128:EL86-EL92.

Barrigón Morillas JM, Gómez Escobar V, Trujillo Carmona J, Méndez Sierra JA, Vílchez-Gómez R, Carmona del Río FJ. Analysis of the prediction capacity of a categorization method for urban noise assessment. Appl Acoust 2011; 72:760-771.

Barrigón Morillas JM, Prieto Gajardo C. Uncertainty evaluation of continuous noise sampling. Appl Acoust 2014; 75:27-36.

Borrego C, Martins H, Tchepel O, Salmim L, Monteiro A, Miranda AI. How urban structure can affect city sustainability from an air quality perspective. Environ Modell Softw 2006; 21:461-467.

Brambilla G. Physical assessment and rating of urban noise. In Environmental Urban Noise. Southampton WIT Press 2001: 15-61.

Brandt S, Maennig W. Road noise exposure and residential property prices: Evidence from Hamburg. Transport Res D-Tr E 2011; 16:23-30.

Can A, Van Renterghem T, Rademaker M, Dauwe S, Thomas P, De Baets B, Botteldooren D. Sampling approaches to predict urban street noise levels using fixed and temporary microphones. J Environ Monitor 2011a; 13:2710-2719.

Can A, Rademaker M, Van Renterghem T, Mishra V, Van Poppel M, Touhafi A, Theunis J, Botteldooren D. Correlation analysis of noise and ultrafine particle counts in a street canyon. Sci Total Environ 2011b; 409:564-572.

CETUR (Centre d'Etudes des Transports Urbains). Guide du Bruit des Transports Terrestres. Prévision des niveaux sonores. CETUR, France, 1980.

Chen H, Namdeo A, Bell MC. Classification of road traffic and roadside pollution concentrations for assessment of personal exposure. Environ Modell Softw 2008; 23:282-287.

COM. Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the Assessment and Management of Environmental Noise (END). Brussels: The European parliament and the Council of the European Union, Official Journal L 189:12-26; 2002.

Doygun H, Gurun DK. Analyzing and mapping spatial and temporal dynamics of urban traffic noise pollution: a case study in Kahramanmaras, Turkey. Environ Monit Assess 2008; 142:65-72.

EC (European Commission). Adaptation and revision of the interim noise computation methods for the purpose of strategic noise mapping. European Commission DG Environment, reference: B4-3040/2001/329750/MAR/C1; 2003.

Fawcett T. An introduction to ROC analysis. Pattern Recogn Lett 2006; 27:861-874.

Foraster M, Deltell A, Basagaña X, Medina-Ramón M, Aguilera I, Bouso L, Grau M, Künzli N. Local determinants of road traffic noise levels versus determinants of air pollution levels in a Mediterranean city. Environ Res 2011; 111:177-183.

Freitas E, Mendonça C, Santos JA, Murteira C, Ferreira JP. Traffic noise abatement: How different pavements, vehicle speeds and traffic densities affect annoyance levels. Transport Res D-Tr E 2012; 17:321-326.

Fyhri A. Aasvang GM. Noise, sleep and poor health: modeling the relationship between road traffic noise and cardiovascular problems. Sci Total Environ 2010; 408:4935-4942.

Hand DJ, Till RJ. A simple generalisation of the area under the ROC curve for multiple class classification problems. Mach Learn 2001; 45:171-186.

Holm S. A simple sequentially rejective multiple test procedure. Scand J Statist 1979; 6:65-70.

ISO 1996-1: 2003. Description, measurement and assessment of environmental noise. Part 1: Basis quantities and assessment procedures. Switzerland: International Organization for Standardization; 2003.

ISO 1996-2: 1987. Description and measurement of environmental noise. Part 2: Acquisition of data pertinent to land use. Switzerland: International Organization for Standardization; 1987.

ISO 1996-2: 2007. Description, measurement and assessment of environmental noise. Part 2: Determination of environmental noise levels. Switzerland: International Organization for Standardization; 2007.

ISO 9613-2: 1996. Attenuation of sound during propagation outdoors. Part 2: General method of calculation. Switzerland: International Organization for Standardization; 1996.

Kim J, Lim C, Hong J, Lee S. Noise-induced annoyance from transportation noise: short-term responses to a single noise source in a laboratory. J Acoust Soc Am 2010;127:804-814.

Jiménez S, Genescà M, Romeu J, Sanchez A. Estimation of night traffic noise levels. Acta Acust united Ac 2008; 94:563-567.

Kim KH, Ho DX, Brown RJC, Oh J-M, Park CJ, Ryu IC. Some insights into the relationship between urban air pollution and noise levels. Sci Total Environ 2012; 424:271-279.

Ko JH, Chang SI, Lee BC. Noise impact assessment by utilizing noise map and GIS: a case study in the city of Chungju, Republic of Korea. Appl Acoust 2010; 72:544-550.

Kruskal WH, Wallis WA. Use of ranks in one-criterion variance analysis. J Am Stat Assoc 1952; 47:583-621.

Lam K-C, Chung Y-TT. Exposure of urban populations to road traffic noise in Hong Kong Transport Res D-Tr E 2012; 17:466-472.

Mann HB, Whitney DR. On a test of whether one of two random variables is stochastically larger than the other. Ann Math Stat 1947; 18:50-60.

Miedema HME, Vos H. Exposure-response relationships for transportation noise. J Acoust Soc Am 1998, 104:3432-3445.

Miedema HME, Oudshoorn CGM. Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Persp 2001, 109:409-416.

Miedema HME, Passchier-Vermeer W, Vos H. Elements for a position paper on night-time transportation noise and sleep disturbance. Delft: TNO Inro; 2003.

Mioduszewski P, Ejsmont J, Grabowski J, Karpinski D. Noise map validation by continuous noise monitoring. Appl Acoust 2011; 72:582-589.

Naish D. A method of developing regional road traffic noise management strategies. Appl Acoust 2010; 71:640-652.

Öhrström E. Longitudinal surveys on effects of changes in road traffic noise annoyance, activity disturbances, and psycho-social wellbeing. J Acoust Soc Am 2004; 115:719-729.

Onuu MU. Road traffic noise in Nigeria: Measurements, analysis and evaluation of nuisance. J Sound Vib 2000; 233:391-405.

Paviotti M, Vogiatzis K. On the outdoor annoyance from scooter and motorbike noise in the urban environment. Sci Total Environ 2012; 430:223-230.

Prieto Gajardo C, Barrigón Morillas JM, Gómez Escobar V, Vílchez-Gómez R, Méndez Sierra JA, Carmona del Río FJ, Rey Gozalo G. Efectos del mundial de fútbol sobre los niveles sonoros de ruido. Cáceres: Proceeding of European Symposium on Environmental Acoustics and on Building Acoustically Sustainable; 2011.

Rey Gozalo G, Barrigón Morillas JM, Gómez Escobar V. Analysis of noise exposure in two small towns. Acta Acust united Ac 2012; 98:884-893.

Rey Gozalo G, Barrigón Morillas JM, Gómez Escobar V. Urban streets functionality as a tool for urban pollution management. Sci Total Environ 2013; 461-462:453-461.

Romeu J, Genescà T, Pàmies T, Jiménez S. Street categorization for the estimation of day levels using short-term measurements. Appl Acoust 2011; 72:569-577.

Schultz T. Synthesis of social surveys on noise annoyance. J Acoust Soc Am 1978; 64:337-405.

Su JG, Brauer M, Buzzelli M. Estimating urban morphometry at the neighborhood scale for improvement in modeling long-term average air pollution concentrations. Atmos Environ 2008; 42:7884-7893.

Torrija AJ, Ruiz DP. Using recorded sound spectra profile as input data for real-time short-term urban road-traffic-flow estimation. Sci Total Environ 2012; 435-436:270-279.

Van Renterghem T, Botteldooren D, Dekoninck L. Evolution of building façade road traffic noise levels in Flanders. Journal of Environmental Monitoring 2012; 14:677-686.

Vogiatzis K, Remy N. From environmental noise abatement to soundscape creation through strategic noise mapping in medium urban agglomeration in South Europe. Sci Total Environ 2013, http://dx.doi.org/10.1016/j.scitotenv.2013.07.098

WHO (World Health Organization). Guidelines for community noise. Geneva: WHO; 1999.

WHO (World Health Organization). Night noise guidelines for Europe. Copenhagen: WHO Regional Office for Europe; 2009.

WG-AEN (Working Group Assessment of Exposure to Noise), 2007. Good practice guide for strategic noise mapping and the production associated data on noise exposure. Brussels: WG-AEN, European Commission, Position Paper 2; 2007.

Wolde TT. The EU Noise Policy and the Related Research Needs. Acta Acust united Ac 2003; 89:735-742.

Yang D, Wang Z, Li B, Lou Y, Lian X. Quantitative measurement of pass-by noise radiated by vehicles running at high speeds. J Sound Vib 2011; 330:1352-1364.

Zannin PH, Queiroz de Sant'Ana D. Noise mapping at different stages of a freeway redevelopment project – A case study in Brazil. Appl Acoust 2011; 72:479-486.

Zeng X, Zhan Y. Development of a noise sources classification system based on new method for feature selection. Appl Acoust 2005; 65:1196-1205.

TABLE I. Average values and standard deviation of L_{Aeq} and L_{Aw} values of the different studied sonorous indicators. The results are shown separately for working and festive days and for each category.

Category	Indicator	$\overline{L_{Aeqx} \pm \sigma}$			$\overline{L_{Awx} \pm \sigma}$
		Workdays	Non-workdays	Global	Global
1	L_{Ad}/L_{Awd}	68.8±1.3	66.1±2.2	68.1±1.3	83.7±1.1
	L_{Ae}/L_{Awe}	68.0±1.9	66.9±1.9	67.6±1.9	83.2±1.4
	L_{An}/L_{Awn}	61.2±2.3	63.2±2.4	62.1±2.2	77.6±1.6
	L_{Aden}/L_{Awden}	70.7±1.4	70.6±2.2	70.8±1.6	86.3±1.1
2	L_{Ad}/L_{Awd}	66.8±1.9	65.2±2.9	66.5±2.1	81.5±1.7
	L_{Ae}/L_{Awe}	65.8±1.9	64.8±2.4	65.7±2.0	80.6±1.6
	L_{An}/L_{Awn}	58.6±2.3	59.0±2.3	58.9±2.0	73.9±1.4
	L_{Aden}/L_{Awden}	68.4±1.9	67.9±2.2	68.4±2.0	83.3±1.5
3	L_{Ad}/L_{Awd}	61.5±3.3	58.7±3.2	60.7±3.4	75.3±1.4
	L_{Ae}/L_{Awe}	61.3±3.2	60.2±2.8	60.9±3.1	75.6±1.2
	L_{An}/L_{Awn}	52.8±3.4	55.1±2.8	53.7±3.2	68.4±1.0
	L_{Aden}/L_{Awden}	63.1±3.3	63.0±2.8	63.1±3.2	77.8±1.1
4	L_{Ad}/L_{Awd}	60.5±2.2	57.6±2.1	59.6±2.1	72.3±0.6
	L_{Ae}/L_{Awe}	59.9±2.2	58.9±1.7	59.5±1.9	72.2±0.4
	L_{An}/L_{Awn}	51.8±1.8	54.1±1.9	52.8±1.8	65.5±1.1
	L_{Aden}/L_{Awden}	62.0±2.0	61.9±1.8	62.0±1.8	74.6±0.7
5	L_{Ad}/L_{Awd}	56.4±2.9	54.1±3.3	55.9±3.1	68.4±4.2
	L_{Ae}/L_{Awe}	56.0±3.8	54.9±3.6	55.7±3.7	68.2±4.5
	L_{An}/L_{Awn}	47.6±3.1	49.6±3.0	48.4±2.9	60.8±3.5
	L_{Aden}/L_{Awden}	58.2±2.8	58.0±2.9	58.1±2.8	70.6±3.7

TABLE II. Results of the Kruskal-Wallis test applied to the different sonorous indicators. (*), (**), and (***) indicate the grade of significance of the differences ($p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively). (n.s.) indicates a non-significant difference ($p > 0.05$).

Indicator	***P-value***
L_{Awd}	2.7E-08 (***)
L_{Awe}	2.9E-08 (***)
L_{Awn}	2.3E-08 (***)
L_{Awden}	2.1E-08 (***)

TABLE III. Results of the Mann-Whitney U-test applied to pairs of categories. (*), (**), and (***) indicate the level of significance of the differences ($p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively). (n.s.) indicates a non-significant difference ($p > 0.05$).

	Category	**1**	**2**	**3**	**4**
L_{Awd}	**2**	4.7E-03 (**)	-	-	-
	3	2.7E-03 (**)	2.7E-03 (**)	-	-
	4	9.3E-04 (***)	9.3E-04 (***)	2.7E-03 (**)	-
	5	4.1E-05 (***)	4.1E-05 (***)	2.6E-04 (***)	4.1E-05 (***)
	Category	**1**	**2**	**3**	**4**
L_{Awe}	**2**	1.5E-02 (*)	-	-	-
	3	2.7E-03 (**)	2.7E-03 (**)	-	-
	4	9.3E-04 (***)	9.3E-04 (***)	2.7E-03 (**)	-
	5	4.1E-05 (***)	4.1E-05 (***)	2.6E-04 (***)	4.1E-05 (***)
	Category	**1**	**2**	**3**	**4**
L_{Awn}	**2**	9.3E-04 (***)	-	-	-
	3	2.0E-03 (**)	2.0E-03 (**)	-	-
	4	9.3E-04 (***)	9.3E-04 (***)	2.0E-03 (**)	-
	5	4.1E-05 (***)	4.1E-05 (***)	2.6E-04 (***)	1.3E-04 (***)
	Category	**1**	**2**	**3**	**4**
L_{Awden}	**2**	9.3E-04 (***)	-	-	-
	3	2.0E-03 (**)	2.0E-03 (**)	-	-
	4	9.3E-04 (***)	9.3E-04 (***)	2.0E-03 (**)	-
	5	4.1E-05 (***)	4.1E-05 (***)	2.6E-04 (***)	4.1E-05 (***)

TABLE IV. Category mean values obtained from short-term and continuous measurements.

Category	Short-term L_{Ad}	Continuous L_{Ad}
1	73.6±2.7	72.9±1.9
2	70.9±2.4	69.8±2.0
3	68.2±3.1	66.7±1.4
4	65.8±2.9	64.8±0.8
5	59.8±5.1	60.4±3.6

TABLE V. Observed differences between the response of population determined from the answers to the questionnaires (X_e) and the estimated values from the proposed equations (X_r) (Miedema and Oudshoorn, 2001; Miedema et al., 2003). Percentage of citizens of each category is also shown.

Category	**% Citizens**	**Error ($\%A_r$ -$\%A_e$)**	**Error ($\%HA_r$ -$\%HA_e$)**	**Error ($\%LSD_r$ - $\%LSD_e$)**	**Error ($\%SD_r$ - $\%SD_e$)**	**Error ($\%HSD_r$ - $\%HSD_e$)**
1	4.8	2.4	1.3	-3.8	8.6	-5.6
2	6.2	-3.5	-1.7	-11.9	1.7	-3.8
3	7.2	1.5	8.3	2.6	8.3	-1.3
4	15.0	-13.2	12.0	-3.2	4.2	-3.3
5	66.9	-0.9	1.0	8.2	0.8	-0.7

FIGURE CAPTIONS

Figure 1. Street categorization of the city of Cáceres and location of the sampling points.

Figure 2. Results of ROC analysis for the different sonorous indicators

Figure 3. Percentages annoyance indicators obtained from the proposed equations (Miedema and Oudshoorn, 2001; Miedema et al., 2003) and from the answers to the questionnaires (*). A) Percentages of annoyed (%A) and highly annoyed (%HA) population; B) Percentages of lowly sleep disturbed (%LSD), sleep disturbed (%SD) and highly sleep disturbed (%HSD) population.

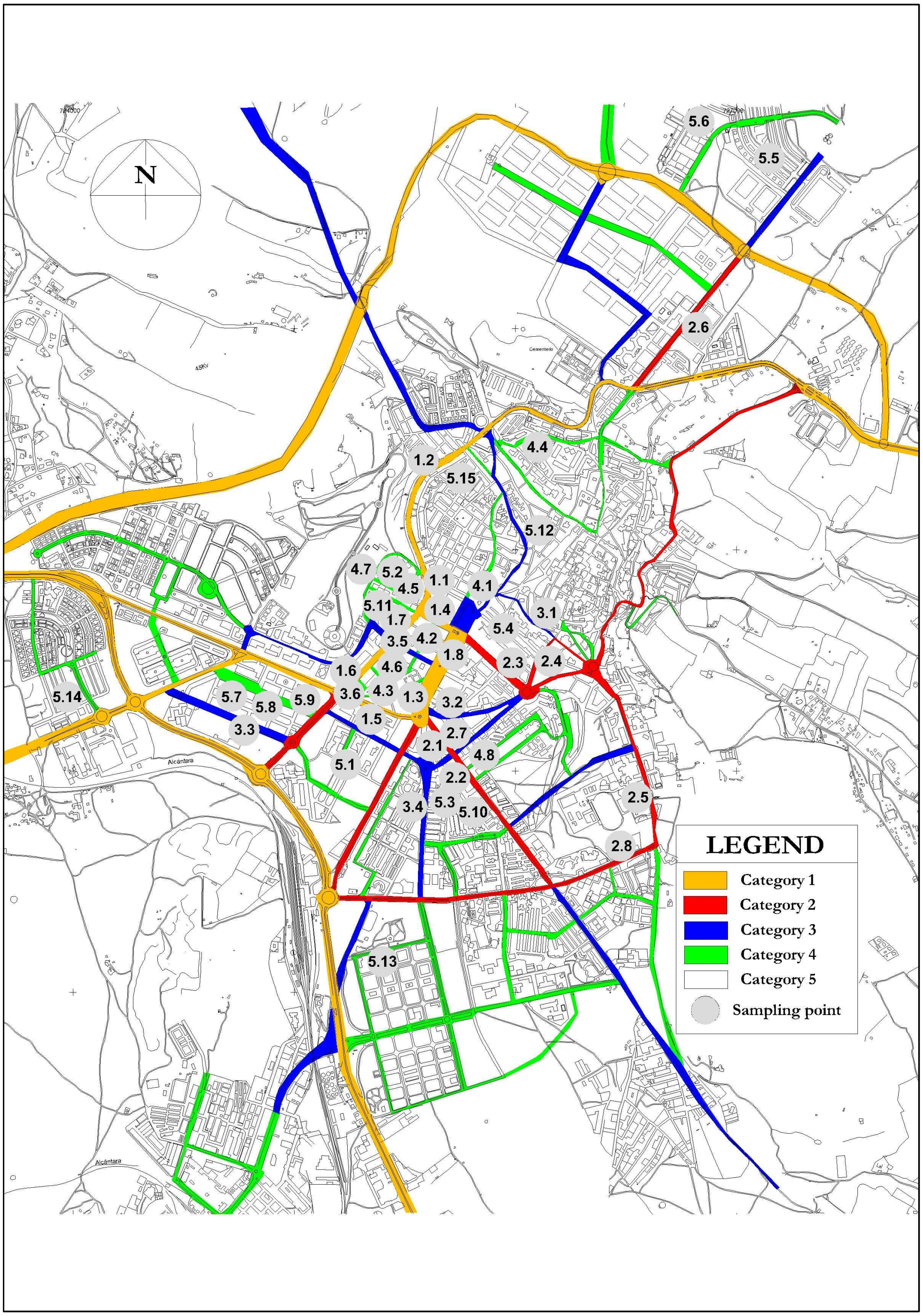

N
5.6
5.5
2.6
4.4
1.2
5.15
5.12
4.7
5.2
4.5
1.1
4.1
5.11
1.4
1.7
3.1
5.4
3.5
4.2
1.8
2.3
2.4
1.6
4.6
5.7
5.8
5.9
3.6
4.3
1.3
3.2
5.14
1.5
3.3
2.7
2.1
4.8
5.1
2.2
2.5
3.4
5.3
5.10
2.8
5.13
LEGEND
Category 1
Category 2
Category 3
Category 4
Category 5
Sampling point

Figure 1

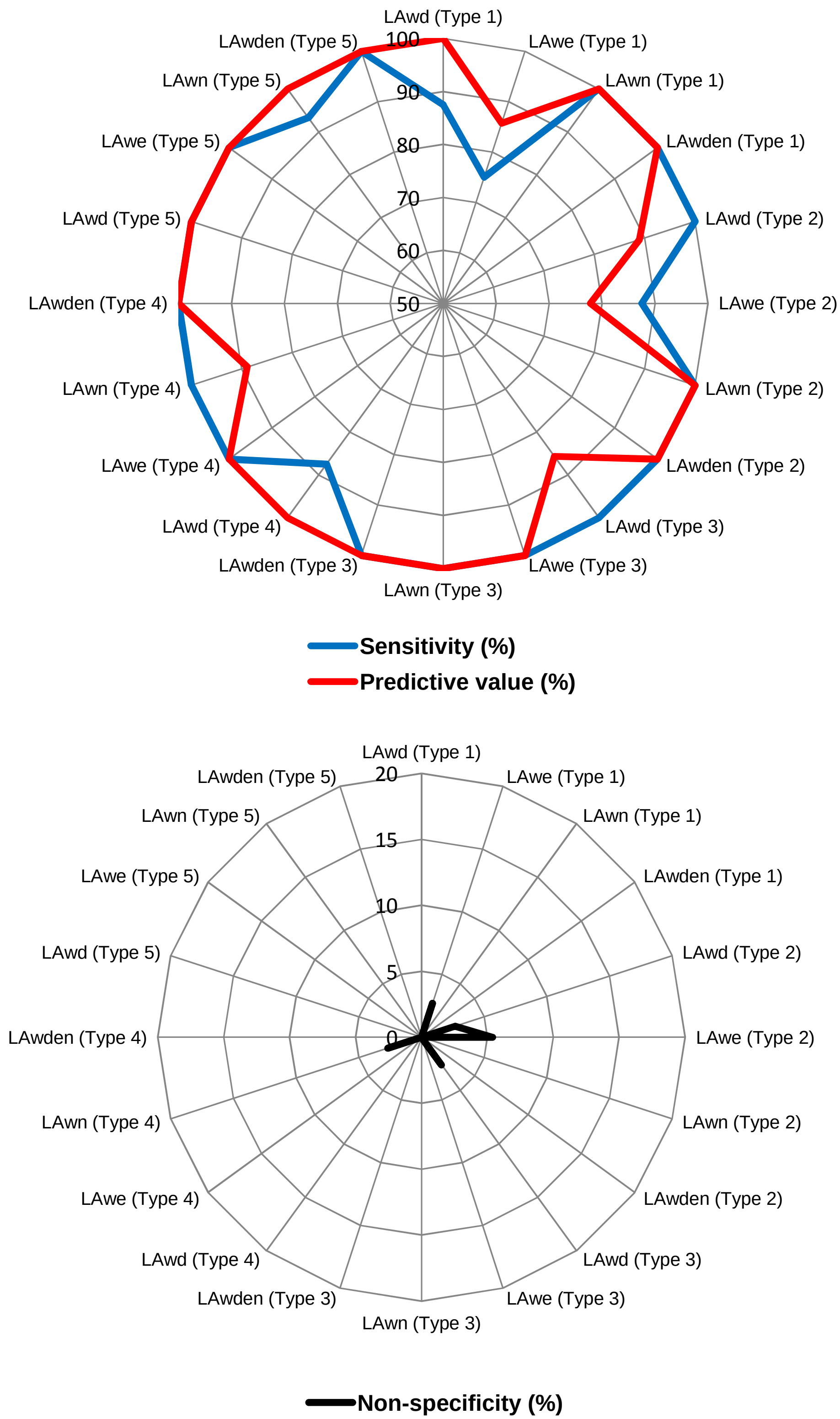
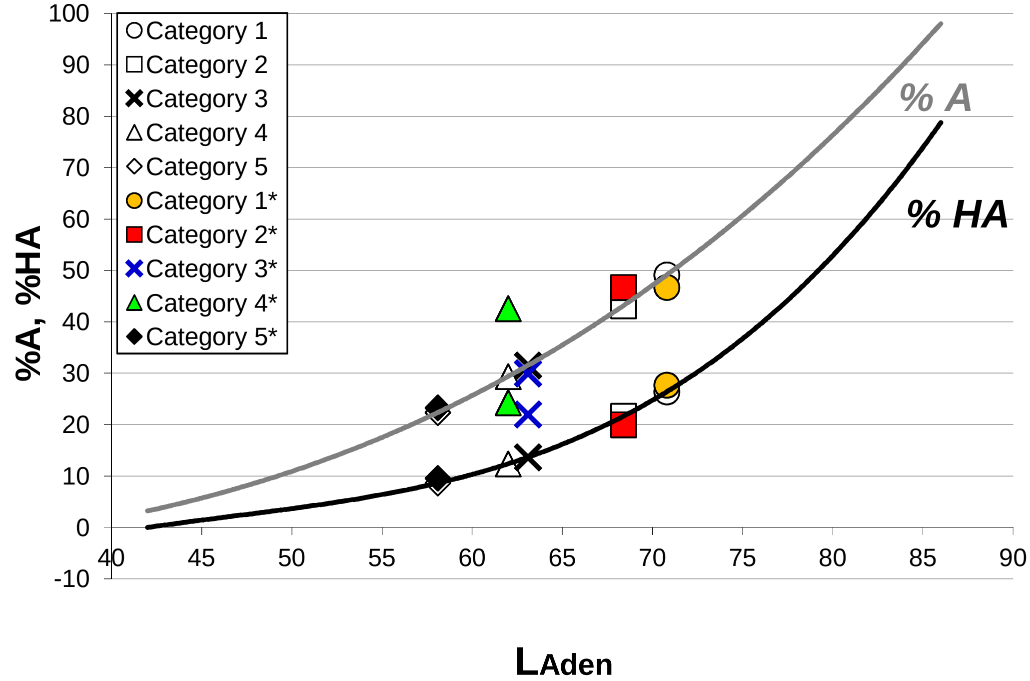

LAwd (Type 1)
LAwe (Type 1)
LAwn (Type 1)
LAwden (Type 1)
LAwd (Type 2)
LAwe (Type 2)
LAwn (Type 2)
LAwden (Type 2)
LAwd (Type 3)
LAwe (Type 3)
LAwn (Type 3)
LAwden (Type 3)
LAwd (Type 4)
LAwe (Type 4)
LAwn (Type 4)
LAwden (Type 4)
LAwd (Type 5)
LAwe (Type 5)
LAwn (Type 5)
LAwden (Type 5)
100
90
80
70
60
50
Sensitivity (%)
Predictive value (%)
20
15
10
5
0
Non-specificity (%)

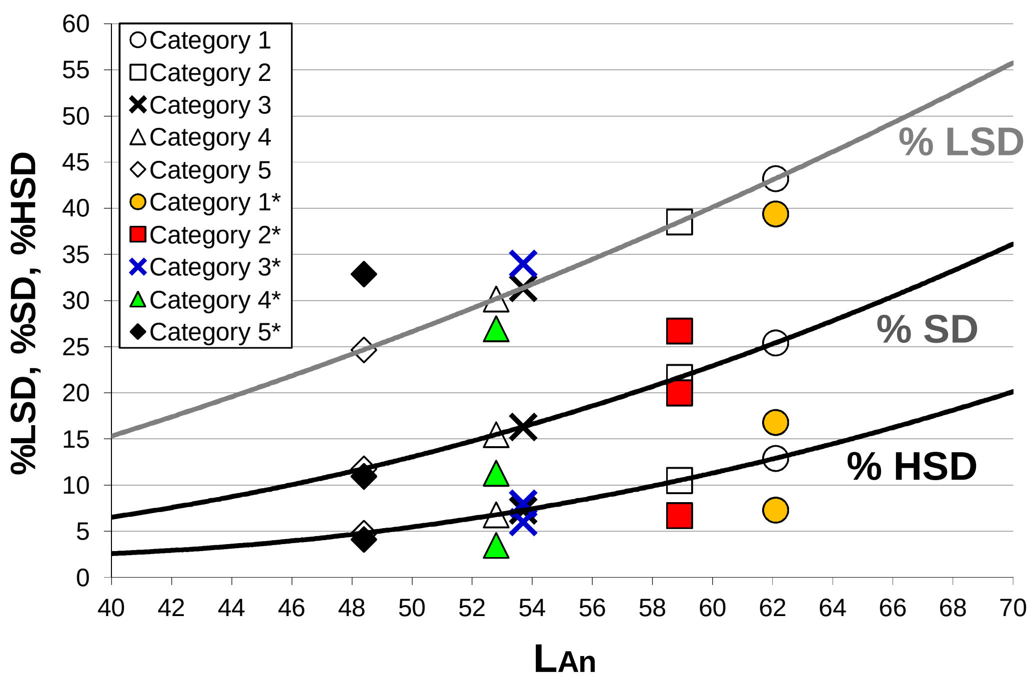
Figure 2

A)



Category 1
Category 2
Category 3
Category 4
Category 5
Category 1*
Category 2*
Category 3*
Category 4*
Category 5*
% A
% HA
%A, %HA
100
90
80
70
60
50
40
30
20
10
0
-10
40
45
50
55
60
65
70
75
80
85
90
LAden

B)



Category 1
Category 2
Category 3
Category 4
Category 5
Category 1*
Category 2*
Category 3*
Category 4*
Category 5*
% LSD
% SD
% HSD
%LSD, %SD, %HSD
60
55
50
45
40
35
30
25
20
15
10
5
0
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
LAn

Figure 3