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# Uncertainty evaluation of continuous noise sampling

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A B S T R A C T

An area of current interest and topic of multiple publications is the assessment of uncertainty in estimating long-term indicators from measurements made for periods of time of less than 1 year. In this work, these prior investigations have been used as a starting point.

Based on measurements made during one whole year at 26 sampling points with variables of urban and traffic characteristics, it was considered two aims related to uncertainty in the estimation of the annual $L_{den}$. The strength of this study is the large amount of data, which allows to simulate real measurements by sampling data from random days. Thus, it was studied in detail the predictive ability of the expressions proposed in the literature. Associated with this objective, then it was sought to evaluate the uncertainty associated with the estimation of annual $L_{den}$ when random days of sampling were much lower than a full year.

The results indicate the need for further progress in the theoretical determination of uncertainty. Second, the results made it able to estimate the uncertainty for the $L_{den}$ indicator based on the number days sampled randomly.



## 1. Introduction

Noise pollution poses serious risks to health and quality of life for large parts of the world population [1–5]. Many studies have been conducted over the last few decades on various aspects of noise pollution, including sources [6–8], sampling strategies [9–13], noise pollution levels [14–17], strategic noise map uncertainty [18–21], exposure levels [22,23], and physiological and psychological effects [24,25].

The European Community [26] suggests the use of noise maps as a major tool for assessing noise levels and their effects on humans. Such evaluations are required for devising noise pollution improvements or solutions.

European Directive 2002/49/EC recommends that noise assessments and an evaluation of noise pollution effects on the community be made over a long time interval, such as 1 year. This recommendation suggests that noise mapping measurements and sound field propagation models should use annual averages or other techniques with time periods on the order of 1 year. Naturally, the predictions should be compared with measurements representative of the entire year if it were possible.

Sound level measurements are therefore required either to confirm model predictions or to directly generate a noise map. Because of the costs and time needed for long-term measurements, it is common practice to obtain noise data over periods of minutes to hours [27–31], with some studies measuring noise over a whole day [32–35]. Noise measurements over periods longer than a day are rarely performed [36–38]. Generally, short-term noise measurements are extrapolated to the months or years required by the European Noise Directive 2002/49/EC. Therefore, studies that analyse the variability of sound indicators based on sound measurements that have been taken continuously for a year or more are required.

Several authors [39–41] have worked to find measurement strategies that would provide estimated average values of the $L_{den}$ index that provide acceptable values for $L_{den}^{(map)}$ (see Eq. (5)).

A research area related to noise measurements involves understanding the uncertainties associated with long-term noise estimates when they are generated based on short- or medium-term measurements. A recent theoretical paper [19] gives a mathematical expression to estimate the $L_{den}^{(map)}$ when the number of sampling days is much less than the 365 days of the year used for the $L_{den}$ index.

The goal of this paper is to confirm the theoretical analysis by providing a statistical comparison of estimated and "real" noise measurements. This comparison was conducted using a wide range of measurements over an entire year to obtain estimated annual values [19]; those estimates were then compared with actual long-term measurements which were taken at 26 points that had a variety of noise conditions on randomly selected days throughout the year.

In this paper, Section 2 describes the characterisation and location of measurement stations, Section 3 presents the experimental

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methodology, materials and methods, Section 4 presents the assessments of the results, and Section 5 contains the conclusions.

## 2. Characterisation and location of measurement stations

Environmental noise in cities is primarily derived from road traffic. Past research has shown that street noise depends on a number of factors, including land use [42], road type [43], social activities and socioeconomic factors [9], weather and the intrinsic attributes of the street itself, such as its geometry, the presence of obstacles to sound propagation and the type of pavement [37,44,45]. A wide variety of locations were considered for the measurement stations so as to ensure differing characteristics of urban and architectural environment, traffic flow and other factors.

Measurements were taken throughout 2006, at 26 different locations in Madrid. Table 1 and Fig. 2 contains relevant geographic characteristics for the measurement stations, while Table 2 summarises relevant meteorological characteristics for the stations. The data were obtained from the Spanish Meteorological Agency website [46]. All measurements had an integration interval of 1 min.

Stations that had lost more than 5% of the measurement days during the analysed year were discarded to avoid introducing uncertainties associated with the total time of measurement when calculating $L_{den}$.

## 3. Methodology

Twenty-six statistical noise analysers from *Brüel & Kjær* models *4441* and *4435* were used for environmental sound monitoring. The analysers were operated continuously during the year 2006. The measured parameter was the continuous equivalent A-weighted noise level integrated every hour ($L_{Aeq,1h}$) for all months of 2006. The $L_{den}$ indices were calculated and averaged from the hourly $L_{Aeq}$ results, as shown in Fig. 1.

Acoustic parameter $L_{den}$ is calculated using Eq. (1) [26]:

$$L_{den} = 10\log\frac{1}{24}\left\{12\times10^{\frac{L_{day}}{10}} + 4\times10^{\frac{L_{evening}+5}{10}} + 8\times10^{\frac{L_{night}+10}{10}}\right\} \quad (1)$$

Because $L_{den}$ should be based on all the days of a year, the calculation of $L_{day}$, $L_{evining}$ and $L_{night}$, as performed using Eqs. (2)–(4), should use $n$ to represent every day in the year.

$$L_{day} = 10\log\left\{\frac{1}{n}\sum_{i=1}^{n}10^{\frac{L_{day}^{(i)}}{10}}\right\} \quad (2)$$

$$L_{evening} = 10\log\left\{\frac{1}{n}\sum_{i=1}^{n}10^{\frac{L_{evening}^{(i)}}{10}}\right\} \quad (3)$$

**Table 2**
Meteorological characteristics of the city where the stations were located.

| City | Annual minimum mean maximum (°C) | July minimum mean maximum (°C) | Precip. annual: total–max. July: (total–max.) (mm) | Weather averages |
|---|---|---|---|---|
| Madrid | 9.37<br>14.34<br>19.29 | 17.96<br>24.52<br>31.06 | 37.10–13.35<br>(11.41–7.44) | 1920–2011 |

**Table 1**
Main features of the environmental sound monitoring stations.

| City population area density | Measurement station number | Geographical location | Traffic | Street category[a] [31,47] | Coordinates GPS latitude–longitude | |
|---|---|---|---|---|---|---|
| Madrid 3,255,944 inhab. 605,77 km$^2$ 5,374,86 inhab./km$^2$ | 1 | *Plaza del Carmen – Tres Cruces* | Medium | 3 | 40.419208 | −3.703172 |
| | 2 | *c/Princesa – Plaza de España* | Intense | 2 | 40.423992 | −3.712333 |
| | 3 | *Avda. Betanzos – c/Monforte de Lemos* | Intense | 2 | 40.478228 | −3.711542 |
| | 4 | *Plaza Dr. Marañón – c/Miguel Ángel* | Intense | 1 | 40.442500 | −3.689444 |
| | 5 | *Plaza Marqués de Salamanca* | Intense | 2 | 40.430833 | −3.679167 |
| | 6 | *c/Alcalá – c/O'Donell* | Intense | 1 | 40.421564 | −3.682319 |
| | 7 | *Paseo de las Delicias – c/Canarias* | Intense | 1 | 40.425556 | −3.681111 |
| | 8 | *Avda. de Pablo Iglesias – P. de S. Francisco de Sales* | Medium | 3 | 40.445542 | −3.707128 |
| | 9 | *Avda. Ramón y Cajal – c/Príncipe de Vergara* | Intense | 2 | 40.451472 | −3.677353 |
| | 10 | *Dr. Gómez Ulla – Jardines Eva Duarte de Perón* | Intense | 2 | 40.428753 | −3.668833 |
| | 11 | *c/Arroyo del Olivar – c/Río Grande* | Medium | 3 | 40.388150 | −3.651522 |
| | 12 | *Plaza Fernández Ladreda – c/Marcelo Usera* | Intense | 1 | 40.389444 | −3.716111 |
| | 13 | *Plaza de Castilla – c/Agustín de Foxá* | Intense | 2 | 40.465556 | −3.688611 |
| | 14 | *c/Vizconde de los Asilos – c/Arturo Soria* | Light | 4 | 40.440047 | −3.639233 |
| | 15 | *Glorieta Marqués de Vadillo – c/ Antonio Leiva* | Light | 4 | 40.394778 | −3.731833 |
| | 16 | *Paseo de Extremadura – c/Francisco Brizuela* | Medium | 3 | 40.399167 | −3.714444 |
| | 17 | *Avda. de Moratalaz – c/Camino de Vinateros* | Medium | 3 | 40.407956 | −3.645294 |
| | 18 | *Plaza de Cristo Rey – c/Isaac Peral* | Intense | 2 | 40.439722 | −3.716389 |
| | 19 | *Puerta de Toledo – Paseo Pontones* | Medium | 3 | 40.407500 | −3.709444 |
| | 20 | End of *c/Alcalá* (*Canillejas*) | Intense | 2 | 40.449167 | −3.608333 |
| | 21 | *Casa de Campo* (Near the cable bar) | Pedestrian | 6 | 40.419356 | −3.747344 |
| | 22 | *c/Riaño* | Light | 4 | 40.462500 | −3.580556 |
| | 23 | *c/Júpiter* | Light | 4 | 40.476928 | −3.580028 |
| | 24 | *Avda. de la Aviación* | Medium | 3 | 40.376111 | −3.776639 |
| | 25 | *Avda. de la Guardia* | Light | 4 | 40.518056 | −3.774611 |
| | 26 | *Ribera del Sena s/n* | Intense | 2 | 40.461667 | −3.615250 |

[a] Streets categories go from 1 'Main city roads' to 6 'pedestrian roads'. The definitions for the different categories can be found in [25,40].