Article

Descriptors and Indicators of the Acoustic Environment in Andorra and Escaldes-Engordany

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Abstract: Noise pollution is one of the growing issues in our cities. Every day the streets are full of vehicles of all kinds and works using noisy machinery; it seems difficult to find a quiet area that away from this acoustic environment. Nowadays, multiple studies are being carried out in the area of engineering in order to be able to attenuate the causes of this noise pollution, in order to improve citizens' lifes. Nevertheless, are only cars the cause of the noise in the city? Are there other noise sources that may affect the quality of life of the citizens? What defines a city as heavily polluted or not? Maybe it can be assumed that truck noise is annyoing and that it contributes to noise pollution, while the sound of birds does not and it is pleasant for people. This paper pretends to analyze the physical parameters that allow us to define if any sound causes annoyance, taking into account its acoustic environment. In order to do this, a specific case will be analysed; we will study three locations measured in Andorra La Vella and Escaldes-Engordany. The audio recordings will be studied deeply, and compared one to the other using data from two different days and all day schedule. We will finally evaluate the annoyance of each location usign parameters as loudness, sharpness and roughness, and taking into account both day and time, as well as giving details about the several types of sound labelled in that recordings.

Keywords: noise annoyance; acoustic environment; indicators and descriptors; recording campaign

1. Introduction

Noise is nowadays one of the main environmental people's health concerns [1,2], and lately several studies show that its impact on social and economic aspects is a fact [3]. Having an overview of several studies that have analyzed the causes and consequences of this matter, we can find the quantification of healthy life-years lost in Europe due to the environmental noise [4], but also the analysis of health impacts related to urban environments and transport planning [5] and even the new environmental noise guidelines in Europe [6]. Despite the fact that the regulations mentioned above correspond to countries of the European Union, there are other countries that are also making progress in analyzing the acoustic environment in detail, even identifying acoustic events in large cities such as New York City [7]. Not only the noise level (defined as equivalent level L_{Aeq}), but also the type of noise are very relevant to draw conclusions from the impact of it on people's lives.

The Actuatech Foundation and the Andorra Sustainability Observatory (OBSA) had a clear interest in determining the type of noise that existed in the streets of Andorra la Vella and Escaldes-Engordany [8]. With this idea in mind, some time ago we started a joint project to observe and characterise the different types of noise existing at three specific points in the two cities, with the aim of categorising all the audible sounds at these points into four categories: Traffic, People, City and Works [8]. For this purpose, samples of raw acoustic data were recorded at these locations for two days to be studied and labelled, as well as the final part of visualization of the types of noise [9].

Most of the studies focus on defining the relation between objective acoustic measurements and the annoyance they cause, as we can find in [10], leaving other acoustical characteristics that represent human perception, e.g., loudness or sharpness [11]. In this paper, we conduct a first approach to evaluate soundscape [12,13] descriptors and indicators over the data collected in Andorra la Vella and Escaldes-Engordany, by means of the psychoacoustic annoyance (PA) calculations, defined by Fastl and Zwicker in [11,14].

The paper is structured as follows. Section 2 describes the procedure followed in this work: the database is described in 2.1, the soundscape indicators are defined in 2.2 and the evaluation of the indicators is explained in 2.3. In Section 3, the results obtained for the Andorran dataset evaluation are presented and in Section 4 the conclusions are highlighted.

2. Methods

This section details the recording campaign of Andorra La Vella and Escaldes-Engordany. The acoustic parameters to be used (loudness, loudness fluctuation, sharpness and roughness) are also defined, and finally the Psycoacoustic Annoyance (PA) is defined from the previous parameters.

2.1. Recording Campaing

As the most commons studies for the analysis of the soundscape, in order to define the soundscape of Andorra La Vella and Escaldes-Engordany, we have collected some pieces of raw acoustic audio (10 min each) in three different locations.

- Location A (LA): highways on the suburbs, it means, more traffic with high speed (Ctra. de l'Obac / Carrer de la Unió).
- Location B (LB): inside the city, pedestrians location (Av. Carlemany / Carrer de la Valira).
- Location C (LC): inside the city, a location with traffic and traffic lights (Av. Meritxell nº73).

The recording campaign took into account two different days: 21st of March of 2018, a diary day, and 15th of April of 2018, on weekend. 10 recordings were conducted for each location each day. For the quality of the Andorra environment, we have labelled each sound for each recording. Moreover, all sounds have been grouped as (1) traffic sounds, (2) works on city infrastructure, (3) city sounds and (4) sounds made by people. The reader is referred to [8] for more details about the recording campaign and the labelling process of the data.

2.2. Soundscape Indicators: Psycoachoustic Parameters

The final goal of this preliminary study is to analyze all sounds with objective metrics that can approach the human perception. For this purpose, we will use the psychoacoustic parameters enumerated by Zwicker [11]:

- Loudness (I1): intensity perceived by human ear. It is related with dislike concept. It is calculated as the equivalence with a sinusoidal sound of 1 kHz and sound intensity of 40dB.

$$N_t = 2^{\left(\frac{L_N - 40}{10}\right)} \tag{1}$$

Where N_t is loudness (sones) and L_N reference sound loudness (phons).

- Loudness fluctuation (I2): non-stationary intensity perceived. It is the non-stationary loudness, it is calculated in function of the amplitude and the frequency in low frequencies (approximately 4Hz).

$$F = \frac{\Delta L}{\frac{f_{mod}}{4} + \frac{4}{f_{mod}}} \tag{2}$$

- Sharpness (I3): signal spectrum. It is calculated based on a specific loudness in high frequencies.

$$S = 0,11 \cdot \frac{\int_0^{24Bark} N'(z)g(z)zdz}{\ln\left(\frac{N}{sone \cdot 20} + 1\right)} \tag{3}$$

where N is the loudness value, $N'(z)$ is the specific loudness and $g(z) = e^{0,171z}$.

- Roughness (I4): dissonance, equivalent to the frequency decomposition of the ear bands. It depends on the modulation effect. It is based on frequency decomposition according to the same bands of the ear, roughness is the addition of these total values.

$$R = 0,3 \cdot f_{mod} \int_0^{2Bark} \Delta L_E(z) dz \quad (4)$$

where ΔL_E the modulation depth y f_{mod} modulation frequency.

2.3. Soundscape Descriptor: Psycoacoustic annoyance

Zwicker and Fastl [11,14] defined the psychoacoustic annoyance in function of four of the psychoacoustic parameters: loudness, loudness fluctuation, sharpness and roughness:

$$PA = N \cdot \left(1 + \sqrt{w_s^2 + w_{FR}^2}\right) \quad (5)$$

where

$$\begin{aligned} w_{FR}^2 &= \frac{2,18}{N^{2,18}} \cdot (0,4 \cdot F + 0,6 \cdot R) \\ w_s^2 &= \begin{pmatrix} (S - 1,75) \cdot 0,75 \cdot \log(N + 10), & S > 1,75 \\ 0 \quad S \leq 1.75 \end{pmatrix} \end{aligned} \quad (6)$$

where F is the loudness fluctuation, R roughness, S sharpness and N loudness.

Table 1 shows the PA grading values. The first column indicates the ponderation (percent) for each grading [15] and the second one is the equivalent value for the PA values that evaluates the acoustic environment.

Table 1. Psychoacoustic Annoyance Grading [15].

Interval %	Interval (PA)	Grade of PA
0-3,6	31,05 - 31,58	Not at all
3,6 - 23,55	31,58 - 34,52	Slight
23,55 - 58,62	34,52 - 39,68	Moderate
58,62 - 89,77	39,68 - 44-27	High
89,77 - 100	44,27 - 45,77	Very High

3. Results

This section reviews the results of the preliminary evaluation of the PA over the data collected in Andorra La Vella and Escaldes-Engordany [8]. As we can observe in Figure 1 and 2, which correspond to the PA distribution per day and per typology of noise and the PA distribution per location and per typology of noise (respectively), the higher results are depicted for traffic and work (when looking at the noise typology), and location A is the most annoying of the three locations where the recordings were conducted. Another relevant result is that, as it can be observed in Figure 1, the 15th of April is a less acoustic annoying day; this is a conclusion that can be associated with the fact that it was a weekend day, and that both traffic and works presented lower L_{Aeq}. Another result shown in Figure 2 is that Location C is the most balanced in terms of annoyance. It presents medium values for the four types of noise, while the other two locations (A and B), show clearly higher values for all the four (in the case of Location A) and mainly for traffic and work (in the case of Location B).

Figure 3 and 4 present the results of PA per location (A, B and C) in function of the time of the day of the recordings. The first timestamp recorded is 8:03 am in the morning, and the last one is 19:30 pm in the evening. Especially clear in Location A (see Figure 3), the first hours corresponding to rush hour

Figure 1. PA distribution per day and per typology of sound

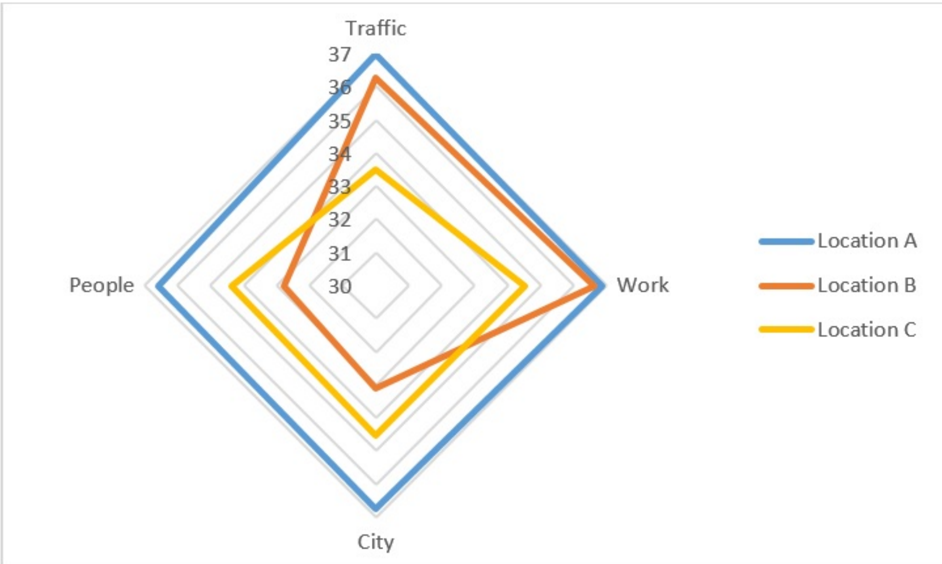

Figure 2. PA distribution per location and typology of sound

of traffic are the most annoying of all the measurements. Figure 4, corresponding to a weekend day, the annoyance increases as the afternoon becomes the evening, which can be explained by the people and traffic around due to commercial reasons.

4. Discussion and Conclusions

In this work a first approximation to the evaluation of descriptors of PA for the acoustic data measured in Andorra la Vella and Escaldes Engordany has been carried out. The results are encouraging, as they provide a broader view of what is happening in the three measurement sites, much farther than the analysis based on L_{Aeq}. The results of the evaluations are very clear especially in location A, where it was already assumed that there would be high level of noise during almost the whole day, mainly due to traffic. Location B also presents concerning results in terms of traffic and people noise, and location C is the most stable in terms of the annoyance caused by the four defined noise types. These preliminary results encourage us to work with broader psychoacoustic indicators

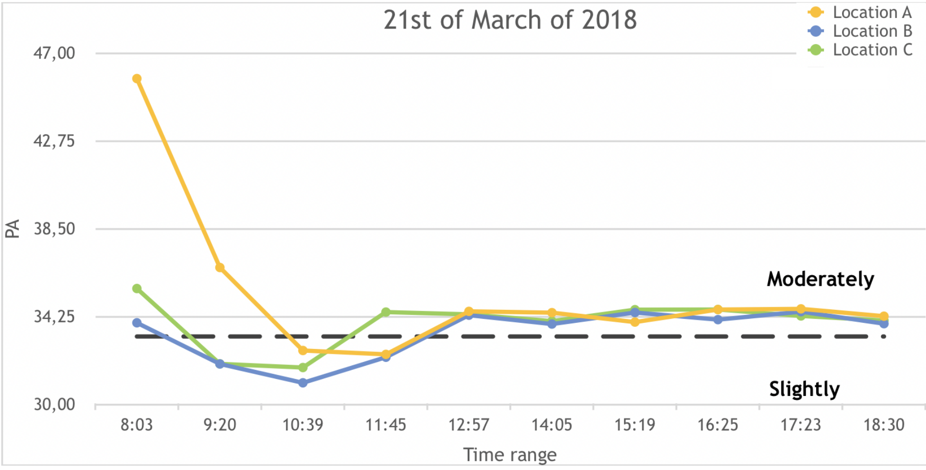

Figure 3. PA distribution per location for 21st of March of 2018

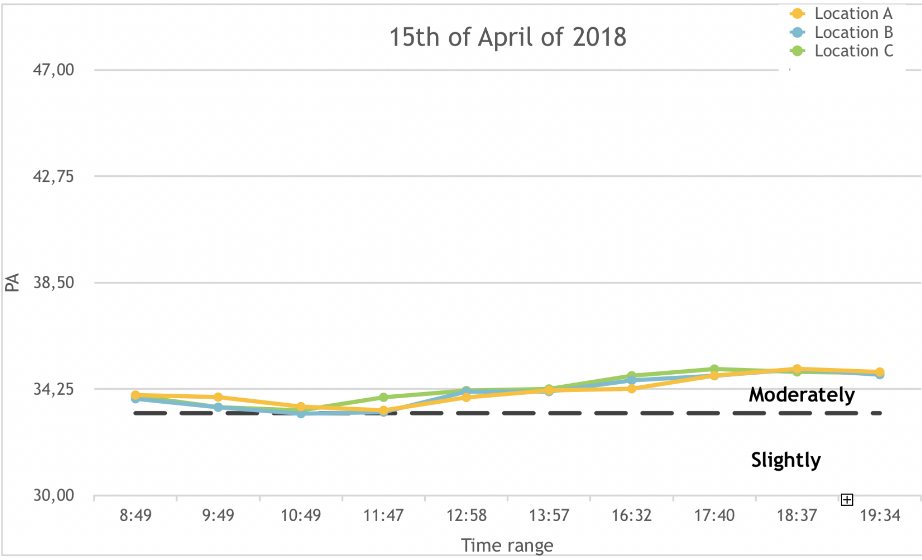

Figure 4. PA distribution per location for 15th of April of 2018

and to approach the concept of soundscape and citizens' perception in order to advance further in the acoustic definition of these three sites under test.

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Abbreviations

The following abbreviations are used in this manuscript:

L_{Aeq}	Equivalent Level
OBSA	Observatori de la Sostenibilitat d'Andorra
PA	Psychoacoustic Annoyance

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