Evaluating critical noise disturbance zones in a mid-sized city

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Abstract

Urban growth is continuously applying pressure over resources, infrastructures and facilities, affecting negatively the standard of living in cities. In this context, evaluating and monitoring the urban environmental quality has become a main issue particularly important when considered as a decision-support tool that contributes to more livable and sustainable cities.

Viana do Castelo is a mid-sized city located on the northwest Portuguese seaside, which undertook the challenge of developing an environmental program leading to the integration in a Healthy Cities European Network.

Within this program, the identification of urban noise levels and people exposure was considered a priority. The scientific toolbox adopted to develop the studies includes noise simulation models and a GIS platform.

Based on traffic data and site physical characteristics, acoustical maps were created and overlaid together with the land-use-based acoustic zoning and population distribution layers.

This combination was the basis for the identification of critical zones, both in terms of noise levels and people exposure to this kind of pollution.

This paper aims to present the approach, including the theoretical framework, and to discuss the results of a summer scenario of noise exposure in the city center.

1 Introduction

The Project Healthy Cities is, today, a worldwide movement, having on its basis the concept Health for All (HFA) in the year 2000 of the World Organization of Health and the strategies of the Letter of Ottawa which searched a way of testing the application of these principles in a local level.

In 1986 the World Health Organization (WHO) selected eleven cities in order to demonstrate that the new approaches in public health defended by HFA worked in practice. This is how the concept Healthy Cities was born.

Viana do Castelo is a mid-sized city located on the northwest Portuguese seaside, which undertook the challenge of developing an environmental program leading to the integration in a Healthy Cities European Network. Within this program, the identification of urban noise levels and people exposure was considered a priority.

In Portugal, environmental acoustical pollution noise is regulated since 2000 through a specific Noise Regulation (RLPS), published in Law 292/2000 of November 14^{th}[5]. This legislation forces the consideration of outdoor noise levels in the planning process, namely in the elaboration of zoning plans. Territory must be classified according to the land-use in two main classes: "sensitive areas", which have allocated existent or foreseen residential uses, as well as schools, hospitals, recreation and leisure; and "mixed areas", which overlap the uses of sensitive areas plus other ones like retail shops and services, parking, etc..

According to the provisions of the law, sensitive areas may not be exposed to an equivalent continuous sound level (A-weighted average sound level – *Leq*(A) or simply *Leq*), higher than 55 dB(A) in day-time (period between 7.00 a.m. and 9.00 p.m.) and 45 dB(A) in night-time (period between 9.00 p.m. and 7.00 a.m.); and mixed areas may not be exposed to a L_{Aeq} higher than 65 dB(A) in day-time and 55 dB(A) in night-time.

This paper aims evaluating critical noise disturbance zones in a mid-sized Portuguese city – Viana do Castelo. The scientific toolbox adopted to develop the studies includes noise simulation models and a GIS platform.

Based on traffic data and site physical characteristics, acoustical maps were created and overlaid together with the land-use and population distribution layers. This combination was the basis for the identification of critical zones, both in terms of noise levels and people exposure to this kind of pollution.

2 Road traffic noise

Noise caused by road traffic is the nuisance the most often cited by roadside residents. For existing roads, it is first of all necessary to define the magnitude of the problem. Actions required are then determined in relation to two different categories of noise limits, i.e. for day and for the night time. New infrastructure can improve the surrounding area by easing traffic flow on existing roads. Hence the construction of new roads can bring about environmental benefits through a better distribution of traffic flows in the network and the various associated transport systems. The quantitative evaluation of traffic noise levels is the basis on which noise control policies stand [6].

Traffic noise levels can be evaluated by two different means: measurements and prediction. The measurement method is only feasible when applied to existent situations; the prediction methods are used with advantage from the very start of the planning process to the final detailed design of noise abatement measures.

Prediction methods have proved to be very useful and applied in a wide range of noise situations. When a calculation method is used, a large number of scenarios can be greeted by introducing different traffic flows, several types of pavement, variable number of reception points, and noise abatement measures designs. By contrast, measurements results give information only about a very limited situation (the specific traffic and weather condition at the time the measurements are made).

There are available in the market numerous prediction noise models, which constitute an important toolbox in the simulation of the acoustic situation, as referred by Bertellino and Licitra [3].

The model adopted for this research, named New Method of Forecast of the Traffic Noise (NMPB 96) was developed in France in 1996. It is the method recommended by Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 [7], relating to the assessment and management of environmental noise. In this method, the acoustical calculation is done for each ray issued from the receptor which cuts a source line. If the angular step is sufficiently small (some degrees), one supposes that the topography represented by segments intersected by the ray doesn't vary in the angular cone; in other words that the propagation medium doesn't vary in the cone. In these conditions, the problem is restored to that of the calculation on a cross sectional cut between a punctual source and receptor. For this, it is necessary to define the acoustic power associated to the cross section, the attenuation by the geometric divergence (A_{div}), absorption by the air (A_{atm}), the diffraction (A_{dif}), the ground effects (A_{ground}) and the absorption by the vertical surfaces (A_{ref}) on which the ray has been reflected in the horizontal plane.

To evaluate the noise level for a long period, denominated long term (L_{LT}), the method take into account the meteorological conditions observed locally. This level L_{LT} is obtained by the sum of the energy contributions of the noise levels obtained for the homogeneous meteorological conditions (situation obtained when the vertical gradient of speed of the sound is null) and favourable (when that gradient is positive), weighted according to its relative occurrence in the study site. In the periods in that it happen unfavourable atmospheric conditions (situation when the vertical gradient of speed of the sound is negative) it is assumed by the method noise levels corresponding to homogeneous meteorological conditions. This assumption increases the real levels obtained in these propagation conditions, but provides an approach on the safety's side [2].

This way, in this method, the acoustic level for a long period is calculated according to eqn (1).

$$L_{LT} = 10\log\left(p \times 10^{\frac{L_{pF}}{10}} + (1-p) \times 10^{\frac{L_{pH}}{10}} \right) \tag{1}$$

$L_{p,H}$ is the long term noise level on a cross section with homogeneous meteorological conditions to sound propagation and is calculated from eqn (2).

$$L_{p,H} = LW - A_{div} - A_{atm} - A_{ground,H} - A_{dif,H} - A_{ref} \qquad (2)$$

$L_{p,F}$ is the long term noise level on a cross section with favourable meteorological conditions to sound propagation and is calculated from eqn (3).

$$L_{p,F} = LW - A_{div} - A_{atm} - A_{sol,F} - A_{dif,F} - A_{ref} \qquad (3)$$

where p is the occurrence of favourable meteorological conditions, varying from 0 to 1, and LW is the acoustic power per meter of traffic circulation line.

The calculation of the acoustic power per meter of the circulation lane LW is a function of traffic data (flow, percentage of heavy vehicles, speed), as well function of the typology of the road and the type of road surface [4].

To simplify the calculation and the data presentation, the traffic data relative to the two types of vehicles (light and heavy) are treated as a group in weighting the heavy flow by an acoustic equivalence factor between heavy and light vehicles.

The acoustic power per meter of traffic circulation lane is calculated from eqn (4).

$$LW = LW_{VL} + 10\log\left(\frac{flow + flow \times \%P \times (EQ-1)/100}{V_{50}}\right) - 30 \qquad (4)$$

where LW_{VL} is the acoustic power of a light vehicle, *flow* is the number of vehicles per hour per lane, *%P* is the percentage of heavy vehicles, and EQ is the light-heavy vehicles equivalence factor.

The acoustic power of a light vehicle is given by eqn (5).

$$LW_{VL} = 46 + 30\log V_{50} + C \qquad (5)$$

where V_{50} is the speed of the vehicles (assumed V_{50} = 30 if $V_{50} < 30$), and

$C = 0$ for fluid traffic;
$C = 2$ for interrupted traffic; and
$C = 3$ for accelerating traffic.

The light-heavy vehicle equivalence factor is given by Table 1, according to the French standard - NF S.31.085 [1].

Table 1. Light-heavy vehicle equivalence factors

EQ		Slope of the lane (%)				
		≤2	3	4	5	≥6
Speed (km/h)	120	4	5	5	6	6
	100	5	5	6	6	7
	80	7	9	10	11	12
	50	10	13	16	18	20

3 Evaluating critical noise disturbance zones in a mid-sized city

The study undertaken aimed evaluating critical noise disturbance zones in the Portuguese city of Viana do Castelo, located on the northwest seaside. This is a mid-sized city, which has a population of 36.544 inhabitants living in an overall area of 37,04 Km^2. The most remarkable noise source is a main road that crosses the city dividing it in two parts.

Based on traffic data and site physical characteristics, acoustical maps were created and overlaid together with the land-use-based acoustical zoning and population distribution layers. The scientific toolbox adopted to develop the studies included a noise simulation model and a GIS platform.

This combination was the basis for the identification of critical zones, both in terms of noise levels and people exposure to this kind of pollution.

3.1 Calculation of horizontal noise maps

Noise or acoustic maps represent the actual noise in a certain area and can be obtained through measurement methods and/or prediction methods. This last tool, i.e. the noise simulation model described in the previous section, was used in the present study.

The modeling of outdoor acoustic propagation in built up urban areas must integrate all the parameters which influence the propagation, among others, the topography, the site, the screens, the nature of the ground, and in certain cases the wind and the heterogeneousness of the atmosphere.

For the acoustic characterization of the sources, and considering that Viana do Castelo is a touristic seaside city, two traffic counting campaigns were carried out, one in winter time and another one in summer time, of which resulted the data for two scenarios. Each campaign included most of the city streets and traffic was counted round-the-clock in a typical week day.

A full survey, including topographic characteristics, location of reception points (points for which the noise is to be calculated), sound absorption characteristics of the ground, presence of natural and artificial barriers, and the specification of the emission sources (profil, cross section and pavements of streets) was carried out for the whole city.

Taking the data gathered, the noise simulation model was used to produce horizontal acoustic maps for winter and summer traffic-scenarios, both in terms of day-time and night-time. The following calculation parameters were adopted:

Height of the map: 1,50 m
Favourable meteorological conditions to sound propagation
Temperature: 15ºC; Humidity: 70%
Number of rays: 50; Propagation distance: 250m
Number of reflection: 5; Number of intersections: 99
Output: Leq(A) day-time and Leq(A) night-time
Road surface: variable; Average speed: variable

Due to space limitations in this article, only a small part of the city – downtown – is presented. For the same reason, the results presented are restricted to the summer scenario it is the most critical.

Figure 1 shows the noise maps obtained for day-time and night-time periods.

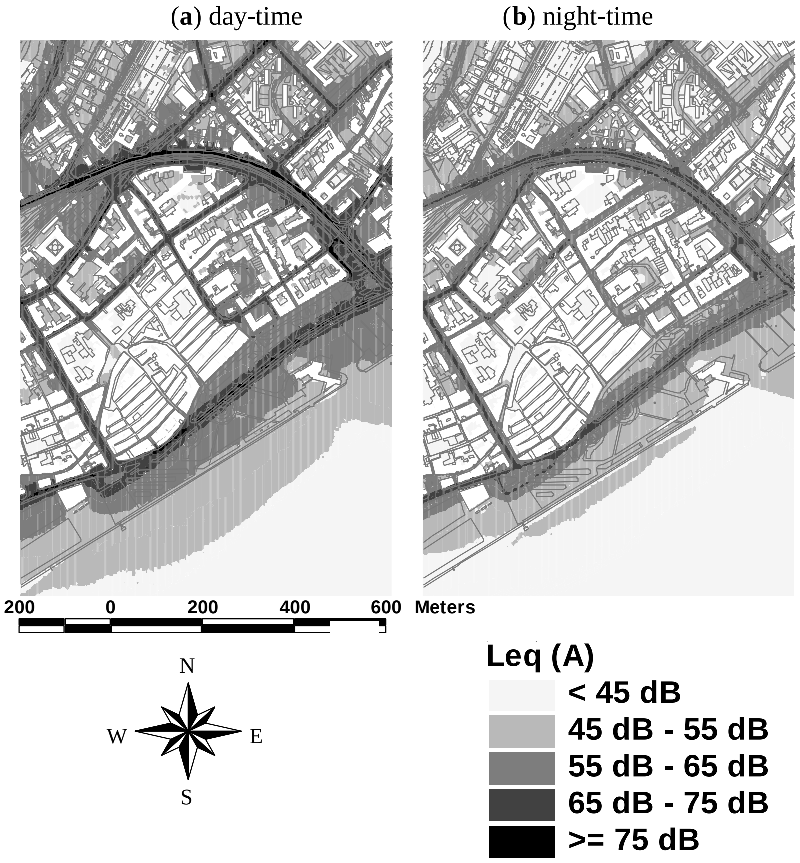

Figure 1: Noise Map - day and night

3.2 Overlay of noise maps on acoustic zoning

The acoustic zoning maps are set up standing on the land-use, existent and planned, according to national normatives, both in terms of methodology and reference values.

Typically, the acoustic zoning establishes areas in the territory to which day and night-time limit *Leq*(A) values are assigned, which means that there should be compatibility between this noise levels and the land-uses assigned to the areas.

Taking into account the land-uses assigned to the city areas by the Master Plan, and in agreement with the established in RLPS, the acoustic zoning map classifies the land in two classes: sensitive and mixed areas, for which the legal noise limits are the ones mentioned in the Introduction.

Figure 2 presents an extract of the acoustic zoning map of Viana do Castelo.

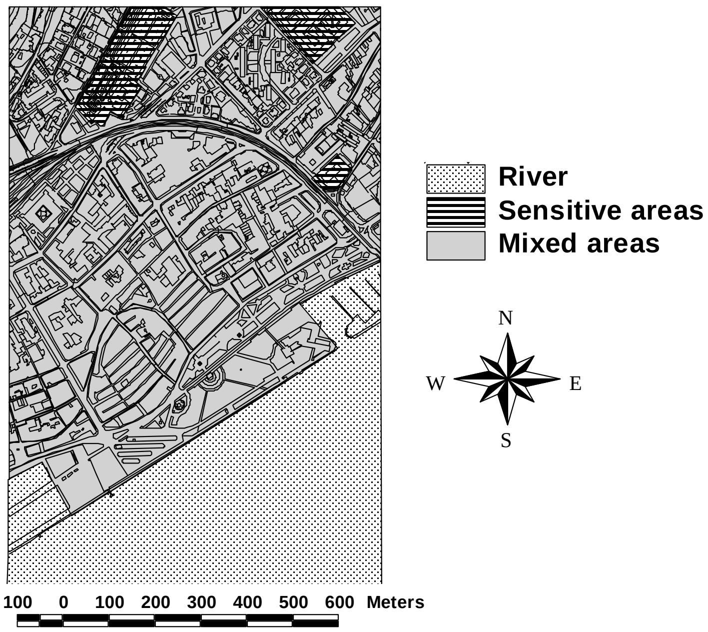

Figure 2: Acoustic zoning map

Noise maps and acoustic zoning were stored in GIS coverages and overlaid. This operation resulted in a map of *Leq*(A) deviations, where areas whose actual noise is higher and lower than the legal limits can be observed (Figure 3).

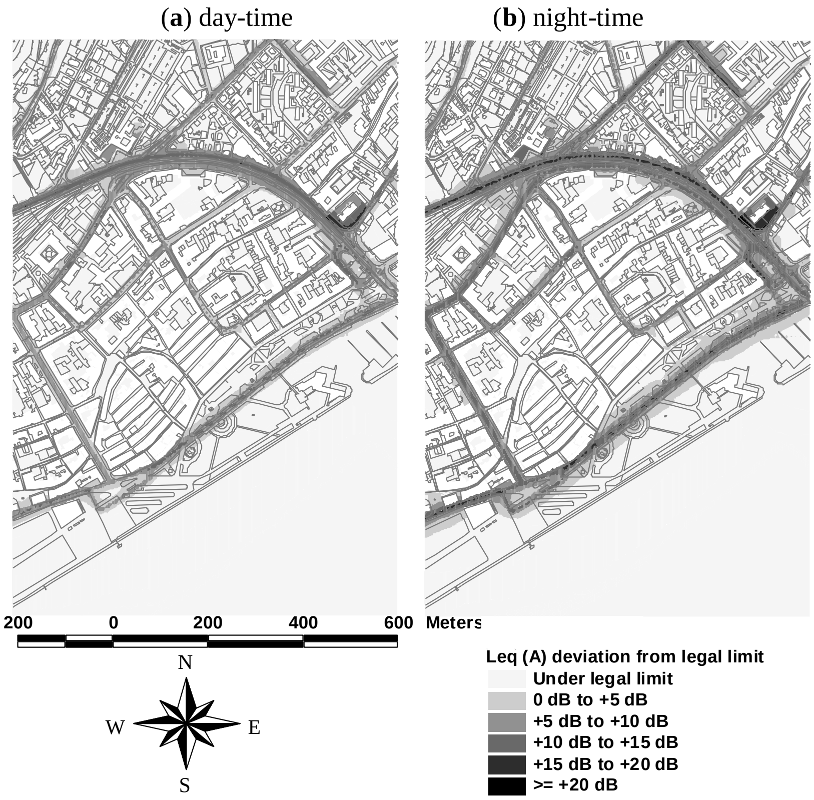

Figure 3: Overlay of noise maps on acoustic zoning – day and night

3.3 Overlay of noise maps on population

The 2001 population data obtained from the Census Bureau CENSO2001 and georeferenced to the smallest geographical spatial unit available – the census block – was stored in a topological GIS coverage and overlaid together with the noise maps in order to find out the percentage of people subjected to relevant ranges of *Leq*(A). For this purpose, a uniform distribution of the population within the blocks was assumed and the recommendations of the Directive 2002/49/CE [7] of the European Parliament, relative to the evaluation and administration of the environmental noise, were adopted. The results can be observed in Table 2.

Similar overlay was undertaken combining the population coverage and the *Leq*(A) deviations coverage, resulting in this case the number of people exposed to noise levels above and under the legal limits, in day and night periods (Table 3).

Table 2. Population exposed to noise – *Leq*(A) ranges

Ranges of *Leq* dB(A)	Population exposed to noise			
	Day		Night	
	Population	%	Population	%
]0 ; 35]	4	0.13	334	10.87
]35 ; 40]	221	7.19	592	19.27
]40 ; 45]	493	16.04	370	12.04
]45 ; 50]	417	13.57	370	12.04
]50 ; 55]	337	10.97	417	13.57
]55 ; 60]	353	11.49	379	12.34
]60 ; 65]	444	14.45	388	12.63
]65 ; 70]	411	13.37	204	6.64
]70 ; 75]	340	11.06	18	0.59
]75 ; 80]	53	1.72	0	0.00
]80 ; 85]	0	0.00	0	0.00

Table 3. Population exposed to noise - deviations to the legal limits

Leq Deviations to legal limits dB(A)	Population exposed to noise			
	Day		Night	
	Population	%	Population	%
]-30 ; -15]	1116	36.32	908	29.56
]-15 ; -10]	345	11.23	369	12.01
]-10 ; -5]	357	11.62	381	12.40
]-5 ; 0]	442	14.38	418	13.61
]0 ; +5]	409	13.31	379	12.34
]+5 ; +10]	342	11.13	384	12.50
]+10 ; +15]	59	1.92	205	6.67
]+15 ; +30]	3	0.10	26	0.85

3.4 Acoustic Criticality Zones

At this point, the acoustical *landscape* of the city, described by the noise maps and the acoustical zoning, can be weighted by the population in order to identify zones acoustically problematic, called acoustic criticality zones.

The index of acoustic criticality for a certain zone, denoted *C*, is given by the *Leq*(A) deviation to the legal limit in dB, *DL*, multiplied by the population living in that zone *Pop*:

$$C = Pop \times DL \tag{6}$$

The use of the deviation to the legal limit instead of the actual *Leq*(A) value is due to the fact that the first considers the legal limits adopted for Portugal by the RLPS.

The calculation of the index of acoustic criticality *C* for the study area, within the GIS environment, resulted in the maps of acoustic criticality for day and night periods presented in Figure 4.

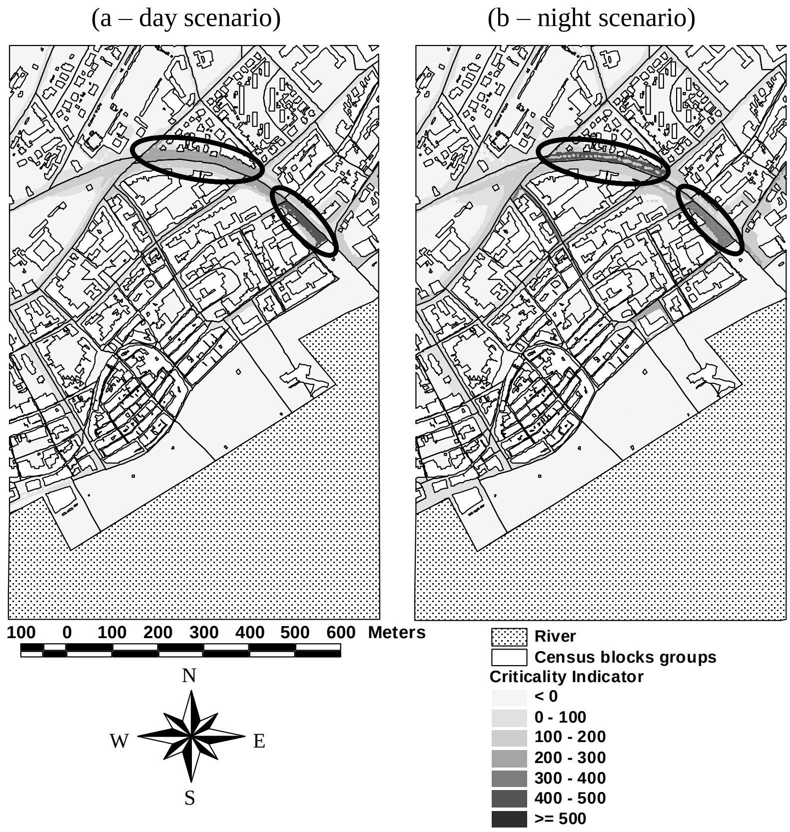

Figure 4: Map of acoustic criticality

4 Discussion and Conclusions

Results presented in Figures 1 and 3 show the existence of a ring around the historical downtown where noise levels are substantially over the legal limits. This ring includes the following streets: Avenida 25 de Abril (east-north), Rua dos Bombeiros Voluntários (north-west), Avenida dos Combatentes (west-south), and Avenida Marginal (south-east).

Legal deviations to the legal limits in this ring assume higher values at night when compared with day-time. This is due to the fact that Viana do Castelo is a leisure seaside city and Figure 3 reports the summer simulation.

The most critical point is on the west part of the ring road where a noise dark point is due to a high concentration of heavy traffic circulating next to a school, which is considered a sensitive area. At this point, *Leq* reach values of +15 dB over the day-time limit, and +20 dB over night-time limit.

Inversely, the acoustic climate within the historical center is quite good as it shows values clearly under the limits. This high quality acoustic atmosphere is due to the severe traffic limitations imposed by the municipality in this zone.

Overall, for the study area and during day-time, 26.2% of the population is exposed to a *Leq* over 65 dB; during night-time 32.3% of the people is exposed to a noise over 55 dB. When considering the legal limits for sensitive and mixed areas, the percentage of population above the limits is similar. Again, these values are considered high, especially the night ones, due the summer habits of this seaside city.

The noise and population values, combined through an acoustic criticality index, revealed the existence of two criticality zones, as shown in Figure 4. These zones should assume a first priority status when it comes to developing a noise mitigation plan.

5 References

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