STUDY ON ENVIRONMENTAL NOISE POLLUTION IN THREE AREAS OF THE CITY OF SANTIAGO DE CALI - COLOMBIA

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This article presents the results of a research project to identify the environmental noise pollution in three areas in the city of Santiago de Cali – Colombia. This project was developed by the University of San Buenaventura Medellin by request of the environmental authority of the city "Corporación Autónoma Regional del Valle del Cauca" (CVC), given that these areas were identified as the most affected by environmental noise sources. This project involved the characterization of the environmental noise sources in each zone, noise mapping in order to quantify the noise levels and the estimation of the people affected by noise at different heights. Based on the environmental noise simulations, the facade exposure levels of the dwellings in each zone were estimated, taking into consideration the noise generated by both traffic and leisure establishments. The contribution of each noise source was assessed with the purpose of determining the predominant noise source in the zones. The results obtained in each area showed that the traffic was the dominant environmental noise source affecting the population in the city of Santiago de Cali.

Keywords: environmental noise, affected population.

1. Introduction

This article presents the results of a research project developed to join technical and economical efforts in order to strengthen the environmental noise management in the city of Santiago de Cali – Colombia. The outcomes of the project relate the description and assessment of environmental noise through noise mapping in three different areas. The areas had two major environmental noise sources: road traffic and leisure establishments. The three zones were modelled using a geographical information database adapted for environmental noise prediction in the software Noise prediction software ®. Information related to noise source characterization, road traffic and leisure establishment was collected following international and national standards. Two types of noise maps were obtained: noise maps at 4-meter height and façade noise maps.

Other aspect took into account was the estimate of population affected by environmental noise considering official estimations of population and number of dwellings in each zone. This information was used to quantify the percentage of affected people by different noise levels. A comparison was made between the affected population obtained with the 4-meter height noise map and the façade noise map at different heights. In the simulation, day and night periods were considered in order to assess the environmental noise using the A-weighted equivalent continuous sound pressure level.

2. Methodology

This research was conducted in three areas of the city of Santiago de Cali – Colombia with the purpose of identifying affected population by environmental noise. The evaluation was done using noise maps and Strategic Noise Maps (SNM) following national and international standards and guidelines. The modelling and simulation was carried out through Geographic Information Systems and environmental noise prediction software. The environmental authority of the city "Corporación Autónoma Regional del Valle del Cauca" (CVC, by its acronym in Spanish) chose the areas of the study given that the predominant environmental noise sources were traffic and leisure establishments.

The project consisted of three stages, in the first one the technical requirements and specifications for noise mapping were established. The second stage aimed to evaluate the georeferenced and cartographic information necessary for environmental noise simulations. Finally, environmental noise simulations through sound prediction methods were carried out to obtain noise maps at 4-meters height, strategic noise maps and data related to affected people by different noise levels at specific heights in all the zones.

2.1 Technical Information for noise mapping

The first step in the project was given by the collection of information from the local authority, in order to construct the noise maps models identifying useful georeferenced and cartographic data. This information was classified to characterise environmental noise sources, sound propagation and receivers in the noise models. Table 1 shows required information according to the mentioned classification, which was used with the purpose of matching the attributes in the environmental noise prediction software.

Table 1: Required information classification for environmental noise modelling as noise source, propagation or receivers.

Data type	Description
Environmental noise source	Streets
	Traffic lights
	Mass transport systems stations
	Mass transport systems routes
	Leisure establishments
Propagation	Contour lines
	Buildings
Receivers	Land uses
	Area delimitation
	Population

In order to obtain the information of Table 1, it was required to carry on collection campaigns in each area. The data acquisition strategies were adapted from the "Good practice guide for strategic noise mapping and the production of associated data on noise exposure" of the European Commission Working Group Assessment of Exposure to Noise WGAE [1]. In addition, a methodology to characterize road traffic flow and average speed of motorcycles and light and heavy vehicles was developed. The noise emission generated by leisure establishments was also characterized. These buildings were considered as industrial buildings whose main noise sources are the sound system and community noise inside them. In order to include their noise emission in the prediction software, the sound power was estimated from sound pressure level measurements following an adaptation of the ISO 8297 standard [2].

2.2 Assessment of georeferenced information

The geodata used in the environmental noise prediction model was obtained from the official Geographic Information System (GIS) of the Santiago de Cali city's government [3]. The available information was used to design a geodatabase for the construction of environmental noise models, adjusting the data according to the good practice guidelines and the attribute requirements of the noise prediction software. The geographic information was adapted in the noise model to include road nomenclature and hierarchy, the average traffic speed, traffic lights, mass transport systems and their stations, railways, buildings and neighbourhoods, level curves, land uses and city limits.

2.2.1 Cartographic information for noise mapping

This stage involved the collection, review and edition of the primary and secondary information: the definition of the structure of the geodatabase, GIS project creation and the elaboration of reports for the environmental authority (CVC). The structure of the GIS with all the data related to the project is shown in Fig. 1.

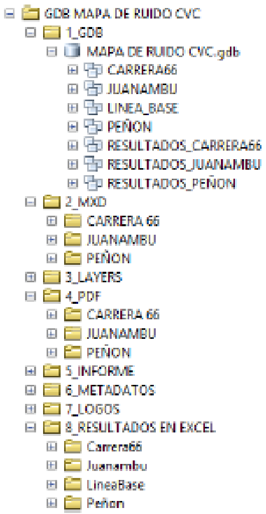

Figure 1: Geodatabase structure of GIS noise model (data in Spanish).

The structured directory shown in Fig. 1 compiles the input and output information which facilitates the documentary management for the assessment of noise pollution caused by environmental noise sources. The information is organized by topic so that the access is clear and accurate. The purpose of the structure is to renovate management processes of the environmental authority related to environmental noise assessment in these areas.

2.2.2 Acquisition of non-available data

An update campaign to obtain non-available data was carried out in order to match properly the geodata and the attributes of the calculation method for environmental noise prediction in the noise prediction software. The methodologies for obtaining the data were based on the good practice guide of the European Commission Working Group Assessment of Exposure to Noise [1].

Traffic flow was determined from the vehicle counting at street crossings in all the zones. The traffic composition was divided into two categories: heavy and light (including motorcycles) vehicles for day and night periods. The counting was performed during 5 minutes at each street crossing and then the amount of vehicles per day and night was estimated. Also, a methodology was proposed with a colour code according to the number of vehicles (light and heavy) per count. The Table 2 shows the colour code for a vehicle count 2 minutes time lap.The traffic flow in two-way streets was included as the sum of vehicles of each kind in each way. The average traffic speed was assigned according to the speed limit for every street in the city. The street surface was assumed as dense asphalt (totally reflective).

Table 2: Colour code according to number of vehicles

Number of vehicles in count	Colour	Range of vehicles per day
-		Pedestrians
0, 1		< 4.000 (low)
2-7 (Streets with low traffic)		< 4.000 (high)
8-16		4.001-8.000
17-32		8.001-16.000
33-64		16.001-32.000
65-128		32.001-64.000
129-254		64.001-128.000

The number of floors of the buildings was determined by counting them in each area. The floor height was established as 2.5 meters for every building. Construction-free zones were identified as green areas or parking lots. For the first case, the areas were catalogued as totally absorbent and without absorption for the second one. An estimation of the amount of people for each residential building was calculated from the number of inhabitants per dwelling and the number of dwellings per building. This data was obtained from statistics of the city's government article "Cali en Cifras"[3]. Table 3 shows the data for the estimations of population and assignation to residential buildings.

Table 3: Population estimates for 2015 per commune where the study zones belong to. Taken from [4].

Comuna	Study zone	Population estimates 2015 (inhabitants)	Area (m^2)	Dwelling density (Dwelling /m2)
2	Juanambú	114651	11313000	0.0033
3	Peñón	46400	3704000	0.0037
17	Carrera 66	139665	12556000	0.0036

The number of inhabitants per building was calculated using Eq. (1). The effective area was obtained by multiplying the building area times the number of floors. Equation (2) was used to estimate the number of dwellings per building. These information was then assigned as an attribute in the GIS.

$$Number\ of\ inhabitants\ per\ building = \frac{N.inhabitants\ Comuna * effective\ area}{Area\ of\ the\ Comuna} \quad (1)$$

$$N.dwellings\ per\ building = dwelling\ density \left[\frac{Viv}{m^2}\right] * Building\ area \quad (2)$$

3. Environmental noise prediction

The layers needed for the simulation were imported to Noise prediction software from the geodatabase. Shapefiles associated to buildings, leisure establishments, streets, contour lines (digital ground model), land uses and land absorption characteristics were selected for the simulation. The attributes for the calculation method were contained in each shapefile.

The project in the prediction software and the calculation parameters were configured according to the Colombian noise policy [4], the ISO 1996 standard [5] and the European directive [6]. Two periods were considered: day (7:00 – 21:00) and night (21:00 – 7:00). The land uses in the software were adapted to include the classification of the Colombian legislation as sectors and subsectors [4].

A calculation method for each environmental noise source was determined. For traffic noise the NMPB- Routes- 96 method was chosen. For leisure establishments the sound power levels per one-third octave bands were obtained using sound pressure level measurements following the ISO 8297 standard. The sound power levels were calculated using the option Full sphere: point source radiating in full space. The obtained values were assigned to the outside façade of the establishment as a superficial noise source. The emission of the leisure establishments over time was configured through the histogram in the prediction software. The assessment of environmental noise levels by each source and their combination was done using the equivalent continuous sound pressure level (Leq). Table 4 shows the noise index for day and night.

Table 4: Environmental noise indexes used in the project.

Type	ID	Name	limit	Interval (hours)	Amount of hours
Leq	LeqD	LeqDia	LeqD,lim	7-21	14
	LeqN	LeqNoche	LeqN,lim	21-7	10

The next step consisted of creating the digital ground model (DGM) from the contour lines shapefile. Once done, an elevation attributed was assigned to streets and buildings in order to locate them on the DMG. Additionally, the height of the buildings was calculated from the number of floors. To simulate different scenarios, three situations with specific geodata were created (see Table 5). The 3D model obtained after manually edited the data is shown in Fig. 2.

Table 5: Geodata used for each situation created in the software Noise prediction software.

Name of situation	Type of geodata used
Road traffic	Streets, buildings, contour lines, leisure establishments (without noise emission)
Leisure establishments	Buildings, contour lines, leisure establishments (with noise emission)
Leisure establishments and traffic	Streets, buildings, contour lines, leisure establishments (with noise emission)

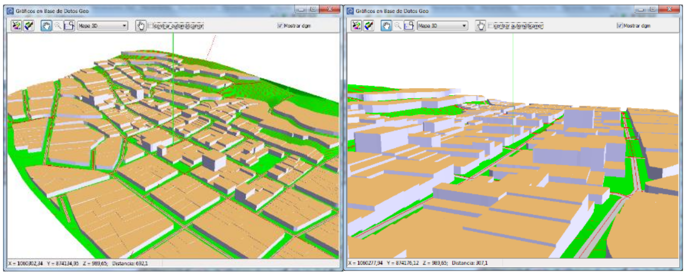

Figure 2: 3D model in Noise prediction software for the zone Carrera 66.

3.1 Noise maps parameters

Two kind of noise maps were calculated: grid noise map and façade noise maps. Both maps were obtained for day and night periods and for individual and combined environmental noise sources. The receivers for the grid map were located at 4-meter height over the DGM and with a 10-meter separation between them. For the façade noise maps all the building's surfaces were selected and the receivers were placed on the centre of the façade. Finally, noise level diagrams, tables for the assessment of environmental noise at different heights and the percentage of affected people at all heights and at different noise levels were calculated.

4. Results

Figure 3 shows the noise maps at 4-meter height for night in the zone Carrea 66. The façade noise maps for the same area are shown in Fig. 4. The maps are presented for individual and combined environmental noise sources (leisure establishments and traffic) for the LAeq noise index. Figure 5 shows the percentage of affected population at different noise levels for the Carrera 66.

Figure 3: Carrera 66, 4 meters noise maps of leisure establishments, road traffic and combined, from left to right.

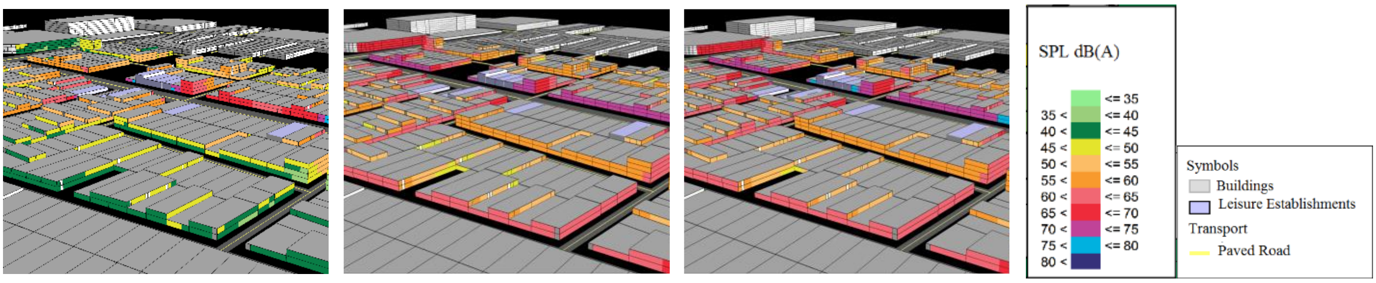

Figure 4: Carrera 66 façade noise maps of leisure establishments, road traffic and combined, from left to right.

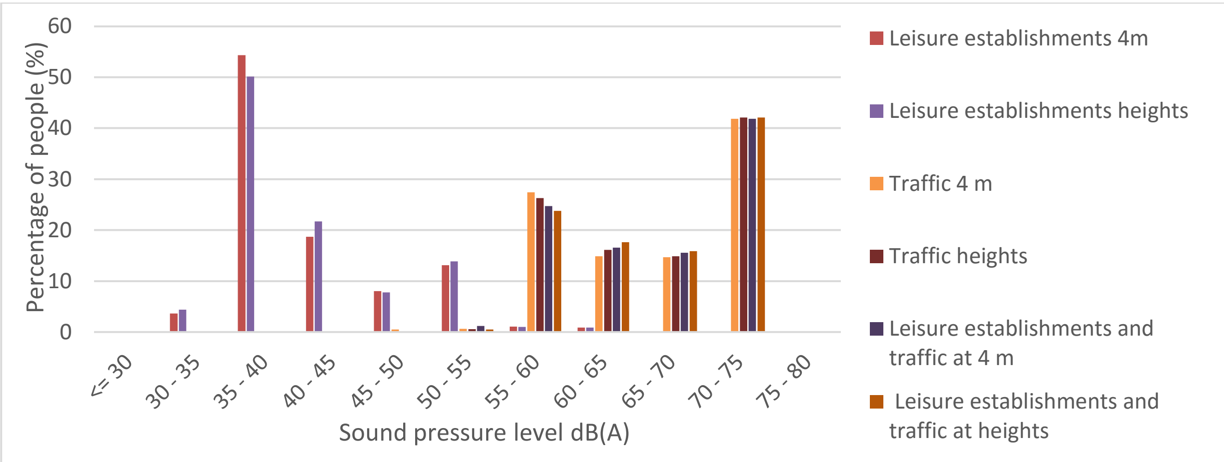

Figure 5. Percentage of affected people for environmental noise sources (LAeqN).

5. Discussion

Figure 3 shows that the environmental noise levels by the road traffic are greater than the ones generated by the leisure establishments by more than 10 dB. It can clearly be appreciated that the major contribution to the LAeqN is the emission by the traffic, in particular the streets with greater traffic flow despite the presence of the leisure establishments in these streets. Figure 4 presents the facade noise maps for the same area which show the environmental noise level at different heights. These levels allow to relate the noise problem with the people living at different heights in the city. It can be seen in Fig. 4 that the emission by road traffic is the most significant in the area. However, the façade noise maps evidence that the noise problem may increase at buildings distant from the noise sources, but because of their height have a direct path of propagation.

The percentage of people exposed for this zone is greater for noise levels between the intervals of 40 to 45 dBA and 70 to 75 dBA (see Fig. 5). The first interval corresponds to the percentage of people affected by mostly the sound emission of the leisure establishments. The second range could be the people affected by road traffic noise. According to the maximum permissible values for environmental noise in the Colombian legislation [4] this area presents a conflict level over 10 dB.

6. Conclusions

This research approached the environmental noise issue in three specific areas of the city of Santiago de Cali, Colombia. The study allowed to identify the required information for environmental noise prediction and noise mapping. The construction of a geographical database and a physical model simplified the access to the information for noise management. The database allows to edit, update and create new scenarios for environmental noise assessment and noise source characterization.

The results showed the population in the Carrera 66 area is exposed to noise level over the permissible limit values given in the Colombian legislation [4] and recommended by the WHO [7]. The road traffic is the greatest noise source and therefore the major contributor to the environmental noise levels. The percentage of affected people at different noise levels was determined at 4-meter and at different heights. The first approach may lead to overestimate the amount of inhabitants exposed to certain noise levels; and thus avoiding the correct identification the problem and the noise management in the area.

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