A system for evaluating the impact of noise pollution on the population's health

Sistema de apoio à avaliação de impactos da poluição sonora sobre a saúde pública

Sistema de apoyo a la evaluación del impacto del ruido sobre la salud pública

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Abstract

The aim of this study was to develop a support system for the evaluation of noise pollution, applied to the central urban area of Rio Claro, São Paulo State, Brazil. Data were obtained from noise measurements and interviews with the population, generating the following indicators: equivalent sound level (L_{eq}*), traffic noise index (*L_{TNI}*), and a participatory diagnosis (*D_p*), integrated through a fuzzy inference system (*FIS*). The proposed system allowed classifying the measurement points according to the degree of impact of noise pollution on the population's health (*I_{PS}*) in the study area. Impact was considered significant in 31.4% of the measurement points and very significant in 62.9%. The FIS can be adjusted to local conditions, allowing generalization and thus also supporting noise pollution evaluation and respective environmental noise management in other geographic areas.*

Fuzzy Logic; Sound Contamination; Noise Effects

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Introduction

Studies on the effects of noise have identified it as a public health problem and one of the forms of pollution that most affects people [1,2,3,4,5]. However, due to its physical nature (propagating without causing permanent alterations), noise evaluation can be complex and subjective, especially concerning its impacts on health, often with psychosomatic and social manifestations [6,7,8,9].

The integration of quantitative evaluation using field measurements and interviews with the population can thus serve as an alternative for the evaluation of environmental noise and its effects on health [10,11,12,13].

Sound measurements form the basis for an objective analysis, providing quantitative indicators of noise levels [10,14,15,16], while interviews allow a participatory diagnosis based on how the exposed population perceives the noise [17,18,19,20,21,22].

Environmental noise evaluation is thus important for verifying noise levels, assessing compliance with maximum permitted levels, detecting evidence of health impacts, and providing orientation on prevention and control measures [12,15,19,20].

This study aimed to develop a support system for the evaluation of impacts of noise pollution (SIPS) on the population's health, based on a case study in Rio Claro, São Paulo State, Brazil.

Materials and methods

The system's input variables were equivalent sound level (L_{eq}), traffic noise index (L_{TNI}), and participatory diagnosis (D_p). The output variable was the impact of noise pollution on health (I_{PS}).

To demonstrate the performance of the proposed system, an application was performed using data collected in 2007 in the central urban area of Rio Claro, a medium-sized city with 192,000d inhabitants, located 173km from the state capital (Prefeitura de Rio Claro. Síntese da leitura técnica do diagnóstico ambiental de Rio Claro, 2006. http://www.prefeiturarc.sp.gov.br/siterc2/iss/download.php, accessed on 16/Jan/2015; Fundação Sistema Estadual de Análise de Dados. Perfil municipal. http://produtos.seade.gov.br/produtos/perfil/perfilMunEstado.php, accessed on 16/Jan/2015). The downtown area of Rio Claro includes the headquarters of the municipal government, and although there are numerous residences, the area is occupied mainly by commercial activities and is thus classified as a mixed-use area.

Development of the model

To deal with the imprecision associated with reading noise levels (L_{eq} and L_{TNI}) and the inherent uncertainty and subjectivity of interviews with the population (D_p), a fuzzy inference system (FIS) was constructed with the MatLab software (MathWorks, Natick, USA).

Constructed on the basis of expert consultation and expertise, the FIS simulates human reasoning to support decisions based on a given condition [23,24], such as diagnoses and monitoring in the health area [25,26,27,28,29,30,31]. Construction of the FIS thus involves four principal stages: fuzzification, construction of the rules set, inference, and defuzzification [32].

Fuzzification involved modeling the input and output variables using fuzzy sets, developed from reference values in the literature. In this sense, the linguistic classification of the variable L_{eq} was based on Guedes et al. [33], as well as the Standards of Reference (*Nível de Critério de Avaliação* – NCA) of the Brazilian Association of Technical Standards (ABNT) [34] and Langdon & Scholes [35] for L_{TNI}.

The point of reference in the study area was 60 dB(A) [34]. According to Guedes et al. [33], places can be considered slightly noisy when L_{eq} is less than or equal to 65 dB(A), noisy between 65 and 75 dB(A), and very noisy when greater than 75 dB(A).

According to Langdon & Scholes [35], the expected degree of annoyance is low L_{TNI} for less than 65 dB(A), medium from 75 to 65 dB(A), high between 90 and 75 dB(A), and very high when greater than 90 dB(A).

In fuzzification of the D_p, the percentage of interviewees who felt that noise pollution had affected their health was proposed as the criterion for defining the low, medium, and high degrees of perceived noise, and gradual transition between classes was based on the margin of error estimated by the Krejcie & Morgan method [36], described below. Thus, for a margin of error of ±d, the region of uncertainty was defined around the limit (L) in the range [L-d, L+d].

Finally, the output variable was proposed by means of linguistic classes pertaining to the significance of the I_{PS}, namely the following degrees of impact: insignificant (I), scarcely significant (SS), significant (S), very significant (VS), and extremely significant (ES).

Next, expert consultation was used to develop the rules set and included an urban planning architect with expertise in environmental comfort research, a physicist, and two engineers with expertise in studies on the diagnosis of noise pollution. Inference was developed with the Mamdani method, which establishes a fuzzy relationship *R(v,u)* that maps the degree of association between the input *(v)* and output parameters *(u)*. In this study, inference occurred according to rules that relate the evaluation criteria (L_{eq}, L_{TNI}, and D_p) to antecedents (A_j) and the significance of the impact as consequences (C_j), as expressed in equation (1):

$$R(v,u) = max_{1 \leq j \leq r}\left(\varphi_{R_j}(v,u)\right) = max_{1 \leq j \leq r}[\varphi_{A_j}(v) \wedge \varphi_{C_j}(u)] \qquad (1)$$

Meanwhile, defuzzification was performed by the centroid method, which establishes compatibility *φB(u)* between output *(u)* and the concept modeled by fuzzy set *B*, as shown in equation (2):

$$G(B) = \sum_{j=0}^{n} u_j \varphi B(u_j) / \sum_{j=0}^{n} \varphi B(u_j) \qquad (2)$$

Next, the defuzzified values were linearly normalized for the range [0, 10] by means of equation (3):

$$I_{PS} = 10(x - x_{min} / x_{max} - x_{min}) \qquad (3)$$

Where: *x*, generated value in the defuzzification; x_{min}, lowest generated value in the defuzzification; x_{max}, highest generated value in the defuzzification.

A scale was proposed in this range to classify the significance of the I_{PS} in which I: [0, 2[, SS: [2, 4[, S: [4, 6[, VS: [6, 8[and ES: [8, 10].

Noise level measurements

Data on sound measurements were collected in the study by Mochizuki [5], using a digital sound pressure meter, Instrutherm brand, model DEC-470, class 2 (Instrutherm, São Paulo, Brazil), calibrated and adjusted to operating in the weighting circuit dB(A), best adjusted to the human ear's sensitivity.

The sampling perimeter was demarcated by streets 1 and 7 and avenues 9 and 10, totaling 54 blocks, in which the measurement points were located at the intersections of streets and avenues, distributed evenly in a grid consisting of 35 points (Figure 1).

Considering the critical periods observed in other studies [37], pretests were performed on Thursdays and Saturdays from 8:00 to 09:00, 11:00 to 12:00, 12:00 to 13:00, 14:30 to 15:30 (Saturday only), 17:00 to 18:00, and 18:00 to 19:00. Based on this procedure, the period selected was Saturdays from 12:00 to 13:00, aimed at assessing the most critical situation observed in the pretests.

Measurements under the influence of atypical sources were avoided, i.e., noisy events that were uncharacteristic of the location, such as temporary or occasional construction work and natural phenomena like thunder and heavy rainfall. In the absence of these sources, measurements were taken at points 1.2 meters aboveground and at least 2 meters from rebounding surfaces, through 30 sound pressure level readings at 10-second intervals at each of the points, always preventing the effect of wind on the microphone by using a shield.

This procedure was performed twice non-consecutively at each sampling point to attenuate atypical readings. Based on these measurements, the target indicators were L_{eq}(A) and L_{TNI}(A), shown by equations (4) and (5), respectively [35,38,39]:

$$L_{eq}(A) = 10\,log\left(\frac{1}{n}\sum_{i=1}^{n} f_i 10^{0,1L_i}\right) \qquad (4)$$

Where: L_{eq}(A), noise level with energy equivalent A from the target period; f_i, frequency of readings with intensity L_i; L_i, instantaneous noise level read at each time interval, adopted as 10 seconds.

$$L_{TNI}(A) = 4(L_{10} - L_{90}) + L_{90} - 30 \qquad (5)$$

Where: L_{TNI}(A), level evaluated by the traffic noise index; L_{10}, noise level exceeded 10% of the time; L_{90}, noise level exceeded 90% of the time.

The results of these indices were analyzed and interpreted according to NBR 10,151 standard (2000) for noise evaluation in inhabited areas, aimed at community comfort [36] and taking parameters from the literature into account.

Participatory diagnosis of impacts on health

The D_p variable took into account the data collected in studies by Bressane et al. [7] using interviews with residents of the central urban area of Rio Claro, with previously prepared forms consisting of multiple-choice questions. In that study [7], the sample needed for a ±0.05 margin of error was calculated with the statistical method proposed by Krejcie & Morgan [36], according to the following equation (6):

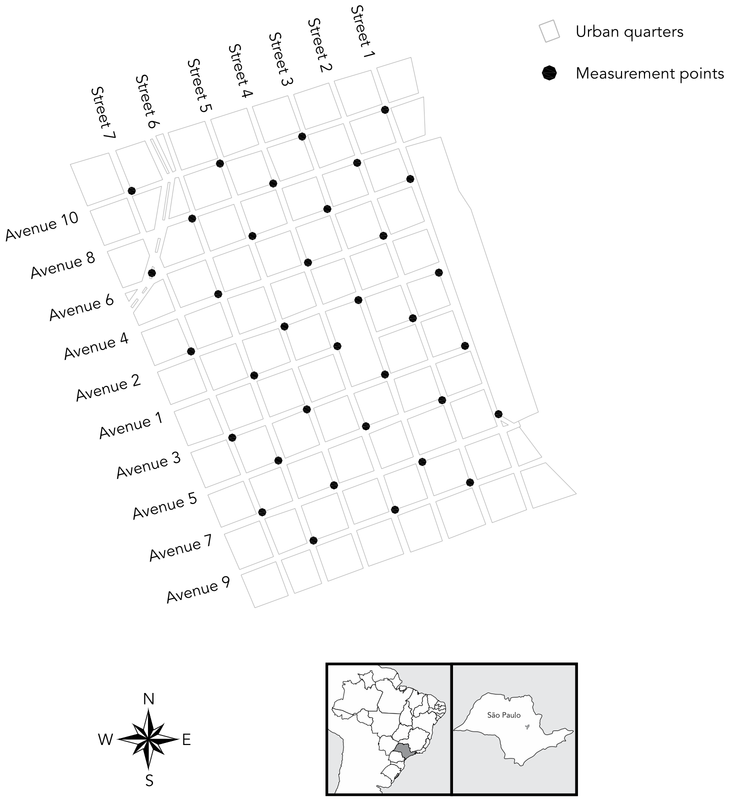
$$s = X^2NP(1-P)/(d^2(N-1) + X^2P(1-P)) \qquad (6)$$

Where: *s*, sample size; X^2, table value of the chi-square for 1 degree of freedom, assumed as 3.841; *N*, size of the study population; *P*, proportion of the population (equal to 0.50 for greatest variance); *d*, tolerated margin of error.

However, since the area in which the interviews were conducted is larger than that in which the noise measurements were taken, for the study's purposes only a proportion of the sample

Figure 1

Location of the study area and distribution of noise level measurement points. Rio Claro, São Paulo State,Brazil, 2007.



Source: Modified from Mochizuki [5].

from the area common to both analyses (interviews and noise measurements) was considered, totaling 109 interviewees. Considering an estimated resident population of 1,800 in the area, the resulting margin of error was ±0.09.

To reach the number of interviewees, sampling was conducted such that residents from one out of five households were approached on one side of the street or avenue in the preselected blocks. When nobody answered the door, the adjacent households were selected, and when necessary the procedure was repeated on the opposite side of the street or avenue.

The questionnaire consisted of two questions on the participant's profile (age and gender) and a question with 5 items on noise perception, as follows: "Do you feel that the noise pollution has hurt your: (1) nighttime sleep or rest periods; (2) disposition or physical performance; (3) emotional condition or well-being; (4) concentration or mental performance; and/or (5) hearing or communication?".

Results

The expert consultation produced a base with 36 rules, shown in Table 1.

The support system for the evaluation of the impacts of noise pollution on health resulted in the architecture shown in Figure 2.

The modeling of variables with fuzzy sets aimed to establish a gradual transition between noise sets or conditions. For example, in the variable L_{eq}(A), the NCR (60 dB) was defined as the upper limit for the "slightly noisy" state. From this level upward, the noise was classified as belonging to the "noisy" state, defined around 70 dB in the]60-80 dB[range. Next, the "very noisy" state began at the upper limit of the previous class (70 dB) and became certain for noise levels of 80dB or higher. Thus, the fact that sampling points belong to more than one class is the consequence of the gradual transition, evaluated in the fuzzy inference process.

Table 1

Rules set in the fuzzy inference system (FIS).

Input variables			**Output variable**
L_{eq}(A)	L_{TNI}(A)	D_p	I_{PS}
Slightly noisy	Low annoyance	Low perception	Insignificant (I)
		Medium perception	Scarcely significant (SS)
		High perception	Scarcely significant (SS)
	Medium annoyance	Low perception	Scarcely significant (SS)
		Medium perception	Scarcely significant (SS)
		High perception	Significant (S)
	High annoyance	Low perception	Scarcely significant (SS)
		Medium perception	Significant (S)
		High perception	Significant (S)
	Very high annoyance	Low perception	Significant (S)
		Medium perception	Significant (S)
		High perception	Very significant (VS)
Noisy	Low annoyance	Low perception	Scarcely significant (SS)
		Medium perception	Scarcely significant (SS)
		High perception	Significant (S)
	Medium annoyance	Low perception	Scarcely significant (SS)
		Medium perception	Significant (S)
		High perception	Significant (S)
	High annoyance	Low perception	Significant (S)
		Medium perception	Significant (S)
		High perception	Very significant (VS)
	Annoyance muito alto	Low perception	Significant (S)
		Medium perception	Very significant (VS)
		High perception	Very significant (VS)
Very noisy	Low annoyance	Low perception	Scarcely significant (SS)
		Medium perception	Significant (S)
		High perception	Significant (S)
	Medium annoyance	Low perception	Significant (S)
		Medium perception	Significant (S)
		High perception	Very significant (VS)
	High annoyance	Low perception	Significant (S)
		Medium perception	Very significant (VS)
		High perception	Very significant (VS)
	Very high annoyance	Low perception	Very significant (VS)
		Medium perception	Very significant (VS)
		High perception	Extremely significant (ES)

Meanwhile, Table 2 shows the results of the interviews with the resident population in the study area, with the proportion of answers for each of the five target items: 66.4% of the interviewees felt that noise pollution had some impact on their health.

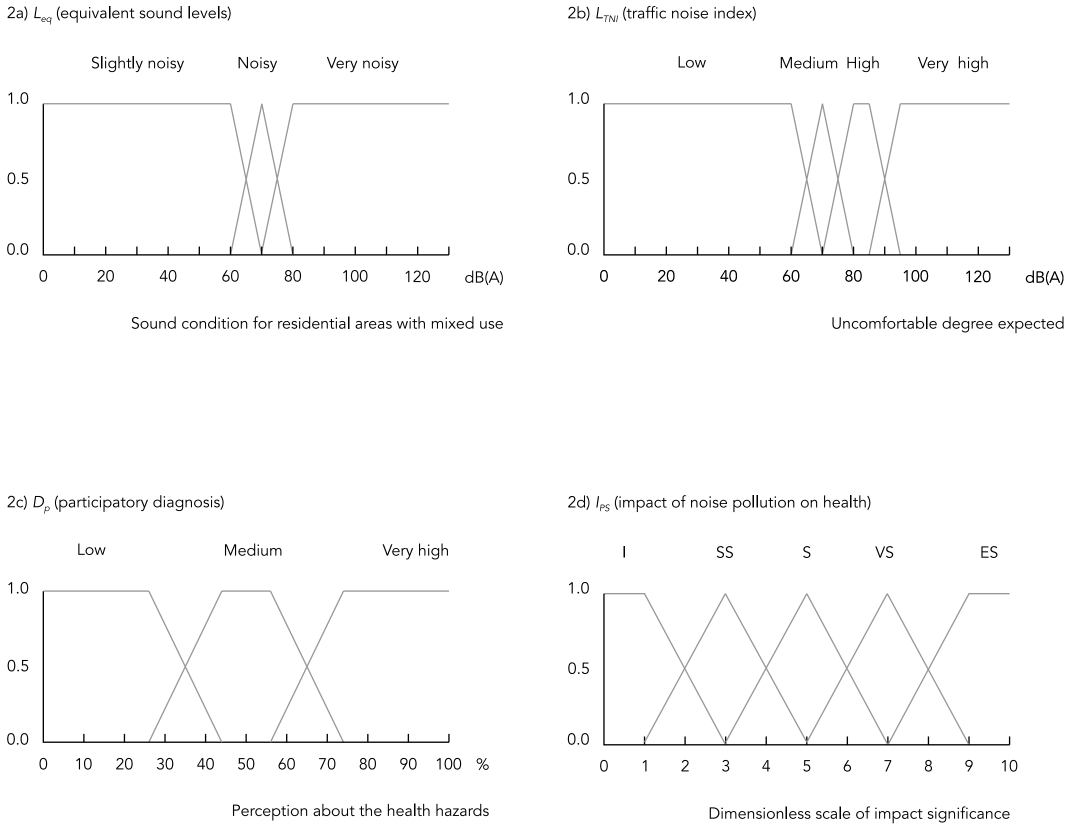
Noise measurements at the 35 sampling points totaled 5 hours and 50 minutes of environmental noise evaluation. Figure 3 shows the values and spatial distribution of L_{eq}, L_{TNI} and the result of the integrated analysis with D_p by means of the FIS, as a map of the impact of noise pollution on health in that area.

Discussion

Based on L_{eq}, all the measurement points exceeded the limit of 60 dB(A) established by Brazil's prevailing legislation for areas with mixed

Figure 2

Modeling of input data: equivalent sound level (L_{eq}), traffic noise index (L_{TNI}) and participatory diagnosis (D_p) – and; output data: impact of noise pollution on health (I_{PS}) using fuzzy sets.



ES: extremely significant; I: insignificant; S: significant; SS: scarcely significant; VS: very significant.

Table 2

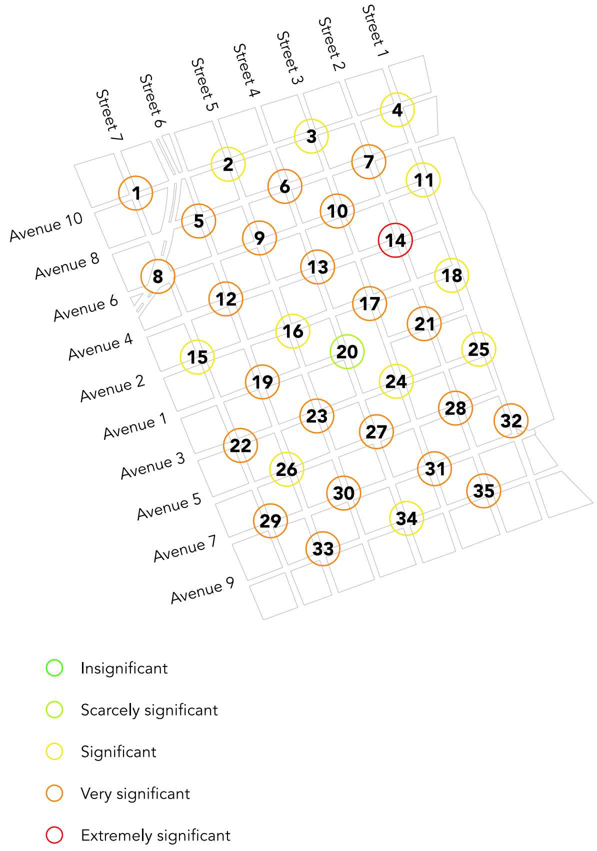
Distribution of answers from the participatory diagnosis on the impacts of noise pollution on the population's health. Rio Claro, São Paulo State, Brazil, 2007.

Noise pollution hurt the following	**Yes**		**No**		**DK/NA**	
	n	**% (±d)**	**n**	**% (±d)**	**n**	**% (±d)**
(1) Nighttime sleep or rest periods	77	70.6	30	27.5	2	1.9
(2) Disposition or physical performance	43	39.4	57	52.3	9	8.3
(3) Emotional condition or well-being	80	73.4	26	23.8	3	2.8
(4) Concentration or mental performance	78	71.5	27	24.8	4	3.7
(5) Hearing or communication	84	77.0	23	21.1	2	1.9
Medium perception of impacts on health	-	66.4	-	29.9	-	3.7

DK/NA: doesn't know/didn't answer.

Figure 3

Distribution of equivalent sound levels (L_{eq}), traffic noise index (L_{TNI}), and mapping of the impact of noise pollution on health (I_{PS}). Rio Claro, São Paulo State, Brazil, 2007.



	L_{eq}	L_{TNI}	D_p	I_{PS}
1	69.8	80.0	66.4	6.4:VS
2	66.5	75.4	66.4	5.3:S
3	67.7	77.3	66.4	5.7:S
4	69,6	69.8	66.4	4.8:S
5	73.4	89.9	66.4	7.1:VS
6	74.1	90.5	66.4	7.2:VS
7	74.2	78.1	66.4	6.4:VS
8	69.8	75.9	66.4	6.3:VS
9	70.6	83.2	66.4	6.4:VS
10	73.2	86.4	66.4	6.7:VS
11	69.4	67.4	66.4	4.2:S
12	69.9	81.9	66.4	6.4:VS
13	69.0	84.3	66.4	6.4:VS
14	77.2	100.4	66.4	8.7:ES
15	63.5	74.3	66.4	4.9:S
16	67.8	74.1	66.4	5.4:S
17	71.8	74.7	66.4	6.2:VS
18	71.1	66.3	66.4	4.4:S
19	68.3	81.8	66.4	6.4:VS
20	65.5	65.6	66.4	3.8:SS
21	72.7	89.6	66.4	6.9:VS
22	66.7	82.3	66.4	6.4:VS
23	70.7	78.0	66.4	6.4:VS
24	68.9	73.9	66.4	5.7:S
25	70.1	67.7	66.4	4.3:S
26	67.2	76.9	66.4	5.5:S
27	67.8	80.6	66.4	6.4:VS
28	72.1	88.1	66.4	6.8:VS
29	69.9	100.2	66.4	7.5:VS
30	68.6	100.6	66.4	7.0:VS
31	70.5	79.3	66.4	6.4:VS
32	73.2	75.8	66.4	6.4:VS
33	66.8	97.7	66.4	6.6:VS
34	62.9	88.0	66.4	5.9:S
35	62.6	96.8	66.4	6.4:VS

ES: extremely significant; I: insignificant; S: significant; SS: scarcely significant; VS: very significant.

commercial and administrative use. Still, the community's response can vary according to the amount exceeded.

According to Gerges [40], limits exceeded by about 10 dB(A) commonly lead to complaints in the community, and differences greater than 15 dB(A) can spark more energetic responses such as class action. In the area evaluated here, 52.8% of the measurement points exceeded the noise limit by 5 to 10 dB(A) and 36.1% exceeded the limit by 10 to 15 dB(A).

Considering L_{eq}(A), 21 points (60%) had noise levels in the [60-70 dB[range, which defines partial membership of the slightly noisy state, although lower than presence of the noisy state, starting at 65 dB, which occurred in 18 of the measurement points in this range. In the [70-80 dB[range, the remaining 14 points (40%) also showed partial membership in the "noisy" state, but among these, 1 showed mainly the very noisy state.

Although L_{eq} is the standard applied to noise evaluation aimed at community comfort [35], in areas with lower average noise, the annoyance can be even greater due to wider sound range, which occurs when the difference between L_{10} and L_{90} (levels exceeded 10% and 90% of the time) is more significant [41]. An important source of such variation is traffic noise, which was evaluated as L_{TNI}.

Based on L_{TNI}, 7 of the points (20%) belong totally to the definition for high annoyance and another 5 (14%) for very high annoyance, while the rest fell into ranges defined as transitional. In this sense, 10 measurement points had greater membership for medium annoyance (29%), 12 points for high annoyance (34%), and 1 point for very high annoyance (3%).

Thus, a large proportion of the points met the definition for high annoyance (54%) or very high annoyance (17%), and L_{TNI} values greater than 100 dB(A) were observed at three intersections (avenue 4 x street 2, avenue 7 x street 5, and avenue 7 x street 7). The points with the lowest degrees of annoyance were mainly located along avenue 2 and street 1. At certain intersections evaluated as slightly or moderately noisy, the expected degree of annoyance was evaluated as high, or even very high, since in these cases the wide variation in noise levels and very high instantaneous peaks had a heavy impact on the population.

As observed during the measurements, the concentration of commercial and service establishments produced intense circulation, making vehicle traffic the main source of noise in the study area.

When asked about noise pollution and the effect on their sleep and rest, 70.6% of the interviewees reported a negative impact. Environmental sound is one of the most important synchronizers of sleep, which can become shallow or even interrupted, causing the loss of restorative sleep stages, with psychological and intellectual harm and negative impact on mood and creativity [42,43,44,45].

Although at a lower proportion, 39.4% of subjects reported negative effects on their disposition or physical performance. Noise pollution can alter rhythmic breathing movements, heart rate, and blood flow and viscosity and lead to hypertension and decreased tissue oxygenation [3,46,47,48].

In relation to emotional well-being, 73.4% of subjects reported excessive noise as a stress factor. Studies indicate that high noise levels can induce emotional instability and a tendency to hostility, intolerance, and aggressiveness [3,49,50,51,52].

Some 71.5% of the research subjects reported negative effects of noise pollution on their concentration or mental performance. Studies have shown that excessive environmental noise alters the brain's electric conductivity, leading to more rapid physical and intellectual fatigue and compromising motor activity, concentration, and task performance [53,54,55,56].

Negative effects on hearing and communication were the most widely perceived, reported by 77% of subjects. Environmental noise can comprise communication, increasing the likelihood of mistakes and accidents [57,58]. Higher noise levels can cause auditory stress and temporary changes or even permanent loss of the auditory threshold [59,60,61].

According to the integrated analysis using the system proposed here, the impact of noise pollution on the exposed population's health could only be considered slightly significant at a single measurement point (intersection of street 4 and avenue 1), while it was significant at 11 points (31.4%), very significant at 22 points (62.9%), and extremely significant at 1 point, located at the intersection of avenue 4 and street 2.

Thus, the SIPS using fuzzy inference to allow classifying the points according to the degree of impact and thus prioritize locations for urgent identification of noise sources and implementation of appropriate control measures.

The possibility of adjusting the fuzzy sets to the local conditions (NCA) according to the land use and occupation, as well as the margin of error in the D_p, allows generalization of the system to evaluate other geographic areas.

Based on the above, the support system for evaluation of the impact of noise pollution on health proved to be an appropriate tool for environmental noise evaluation and its respective management in order to prevent and control the impacts of noise pollution on the population's health.

Contributors

A. Bressane participated in the collection, treatment, and analysis of data from interviews with the population, writing, revision, approval of the final version, and responsibility for the article accepted for publication. P. S. Mochizuki collaborated in the collection, treatment, and analysis of data from the acoustic survey, writing, revision, approval of the final version, and responsibility for the article accepted for publication. R. M. Caram contributed in the project conception for the data collection, analysis, and interpretation, critical revision of the manuscript, approval of the final version, and responsibility for the article accepted for publication. J. A. F. Roveda collaborated in the conception of the fuzzy inference model for integrated evaluation, critical revision of the manuscript, approval of the final version, and responsibility for the article accepted for publication.

References

1. Portela BS, Queiroga MR, Constantini A, Zannin PHT. Annoyance evaluation and the effect of noise on the health of bus drivers. Noise Health 2013; 15:301-6.
2. Firdaus G, Ahmad A. Noise pollution and human health: a case study of municipal corporation of Delhi. Indoor Built Environ 2010; 19:648-56.
3. Niemann H, Bonnefoy X, Braubach M, Hecht K, Maschke C, Rodrigues C, et al. Noise-induced annoyance and morbidity results from the pan-European LARES study. Noise Health 2006; 8:63-79.
4. Berglund B, Lindvall T, Schwela DH. Guidelines for community noise. http://www.who.int/docstore/peh/noise/guidelines2.html (accessed on 16/Jan/2015).
5. Mochizuki PS. Zoneamento acústico urbano e mapeamento de níveis sonoros na zona central de Rio Claro (SP): diretrizes para o gerenciamento do ruído integrado ao planejamento ambiental urbano [Monografia de Graduação]. Rio Claro: Universidade Estadual Paulista; 2007.
6. Gerges SNY. Noise in large cities in Brazil. J Acoust Soc Am 2004; 115:2592.
7. Bressane A, Mochizuki PS, Salvador NNB, Caram RM. Diagnóstico qualitativo do ruído ambiental em cidades médias. Parte 3: análise comparativa da percepção aos impactos da poluição sonora no centro de Rio Claro (SP). In: Anais do VI Congresso de Meio Ambiente da AUGM. São Carlos: Universidade Federal de São Carlos; 2009. p. 1-15.
8. Belojević G, Jakovljević B, Aleksić O. Subjective reactions for traffic noise with regard to some personality traits. Environ Int 1997; 23:221-6.
9. Aparicio-Ramón DV, Suárez-Varela MMM, Garcia GA, González AL, Ruano L, Sánchez AM, et al. Subjective annoyance caused by environmental noise. J Environ Pathol Toxicol Oncol 1993; 12:237-43.
10. Zannin PHT, Engel MS, Fiedler PEK, Bunn F. Characterization of environmental noise based on noise measurements, noise mapping and interviews: a case study at a university campus in Brazil. Cities 2013; 31:317-27.
11. Lacerda ABM, Magni C, Morata TC, Marques JM, Zanin PHT, Calizto A. Ambiente urbano e percepção da poluição sonora. Ambiente & Sociedade 2005; 8:85-98.
12. Zannin PHT, Calixto A, Diniz FB, Ferreira JA. A survey of urban noise annoyance in a large Brazilian city: the importance of a subjective analysis in conjunction with an objective analysis. Environ Impact Assess Rev 2003; 23:245-55.
13. Zannin PHT, Szeremetta B. Avaliação da poluição sonora no parque Jardim Botânico de Curitiba, Paraná, Brasil. Cad Saúde Pública 2003; 19:683-6.
14. Fiedler PEK, Zannin PHT. Evaluation of noise pollution in urban traffic hubs: noise maps and measurements. Environ Impact Assess Rev 2015; 51:1-9.
15. Casas WP, Cordeiro EP, Mello TC, Zannin PHT. Noise mapping as a tool for controlling industrial noise pollution. J Sci Ind Res (India) 2014; 73:262-6.
16. Zannin PHT, Gama VL, Cunha ML, Damiani EF, Benetti M, Bianchi H, et al. Noise mapping of an educational environment. Can Acoust 2013; 40:27-35.
17. Saboya RT. Fundamentos conceituais para uma teoria do planejamento urbano baseada em decisões. Urbe. Revista Brasileira de Gestão Urbana 2013; 5:81-95.
18. Goldstein RA, Barcellos C, Magalhães MAFM, Gracie R, Viacava F. A experiência de mapeamento participativo para a construção de uma alternativa cartográfica para a ESF. Ciênc Saúde Coletiva 2013; 18:45-56.
19. Argento RG, Barcellos C. Geoprocessamento e participação social: ferramentas para vigilância ambiental em saúde. In: Miranda AC, Barcellos C, Moreira JC, Monken M, organizadores. Território, ambiente e saúde. Rio de Janeiro: Editora Fiocruz; 2008. p. 205-15.
20. Becker D, Edmundo K, Nunes NR, Bonatto D, Souza R. Empowerment e avaliação participativa em um programa de desenvolvimento local e promoção da saúde. Ciênc Saúde Coletiva 2004; 9:655-67.
21. Rifkin SB. A framework linking community empowerment and health equity: it is a matter of CHOICE. J Health Popul Nutr 2003; 21:168-80.
22. Zancan L, Bodstein R, Marcondes WB. Promoção da saúde como caminho para o desenvolvimento local: a experiência em Manguinhos-RJ. Rio de Janeiro: ABRASCO; 2002.
23. Janssen JAEB, Krol MS, Schielen RMJ, Hoekstra AY, Kok JL. Assessment of uncertainties in expert knowledge, illustrated in fuzzy rule-based models. Ecol Modell 2010; 221:1245-51.
24. Zadeh L. Is there a need for fuzzy logic? Inf Sci (Ny) 2008; 178:2751-79.
25. Sánchez-Lezama AP, Cavazos-Arroyo J, Albavera-Hernández C. Applying the Fuzzy Delphi Method for determining socio-ecological factors that influence adherence to mammography screening in rural areas of Mexico. Cad Saúde Pública 2014; 30:245-58.
26. Ruggeri BFF, Voci SM, Borges CA, Slater B. Assessment of the usability of a nutritional epidemiology computerized system. Rev Bras Epidemiol 2013; 16:966-75.
27. Canavese D, Ortega NRS, Giatti LL. Ecosystem approach and the Fuzzy logic: a dialectical proposal for information on environmental health. Eng Sanit Ambient 2012; 17:363-8.
28. Copetti A, Leite JCB, Loques O. Um mecanismo de decisão para inferência de contexto em ambientes pervasivos de tratamento de saúde. Sba Controle & Automação 2011; 22:363-78.
29. Drumond EF, Machado CJ, França E. Óbitos neonatais precoces: análise de causas múltiplas de morte pelo método *Grade of Membership*. Cad Saúde Pública 2007; 23:157-66.
30. Reis MAM, Ortega NRS, Silveira PSP. Fuzzy expert system in the prediction of neonatal resuscitation. Braz J Med Biol Res 2004; 37:755-64.
31. Nascimento LFC, Ortega NRS. Fuzzy linguistic model for evaluating the risk of neonatal death. Rev Saúde Pública 2002; 36:686-92.
32. Pedrycz W, Gomide F. Fuzzy systems engineering: toward human-centric computing. New York: Wiley/IEEE Press; 2007.

33. Guedes M, Valadas B, Coelho JLB. Exposição ao ruído da população em Portugal. Amadora: Instituto do Ambiente; 1997.
34. Associação Brasileira de Normas Técnicas. Norma Técnica NBR 10.151. Avaliação do ruído em áreas habitadas visando ao conforto da comunidade: procedimento. Rio de Janeiro: Associação Brasileira de Normas Técnicas; 2000.
35. Langdon FJ, Scholes WE. The traffic noise index: a method of controlling noise nuisance. Architects Journal 1968; 147:38-57.
36. Krejcie RV, Morgan DW. Determining sample size for research activities. Educ Psychol Meas 1970; 30:607-10.
37. Nagem MP. Mapeamento e análise do ruído ambiental: diretrizes e metodologia [Dissertação de Mestrado]. Campinas: Universidade Estadual de Campinas; 2004.
38. Companhia Ambiental do Estado de São Paulo. Norma Técnica L11.032. Determinação do nível de ruído em ambientes internos e externos de áreas habitadas: método de ensaio. São Paulo: Companhia Ambiental do Estado de São Paulo; 1992.
39. Companhia Ambiental do Estado de São Paulo. Norma Técnica L11.033. Processo prático para calcular o nível de ruído equivalente contínuo: procedimento. São Paulo: Companhia Ambiental do Estado de São Paulo; 1992.
40. Gerges SNY. Ruído: fundamentos e controle. 2ª Ed. Florianópolis: NR Editora; 2000.
41. Alvares PAS, Pimentel-Souza F. A poluição sonora em Belo Horizonte. Revista Acústica e Vibrações 1992; 10:23-42.
42. Kawada T, Shimizu T, Kuratomi Y, Suto S, Kanai T, Nishime A, et al. Monitoring of the sleep patterns of shift workers in the automotive industry. Work 2011; 38:163-9.
43. Cappuccio FP, D'Elia L, Strazzullo P, Miller MA. Sleep duration and all-cause mortality: a systematic review and meta-analysis of prospective studies. Sleep 2010; 33:585-92.
44. Miedema HM, Vos H. Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behav Sleep Med 2007; 5:1-20.
45. Jakovljević B, Belojević G, Paunović K, Stojanov V. Road traffic noise and sleep disturbances in an urban population: cross-sectional study. Croat Med J 2006; 47:125-33.
46. Penney PJ, Earl CE. Occupational noise and effects on blood pressure: exploring the relationship of hypertension and noise exposure in workers. AAOHN J 2004; 52:476-80.
47. Babisch W, Ising H, Gallacher JEJ. Health status as a potential effect modifier of the relation between noise annoyance and incidence of ischaemic heart disease. Occup Environ Med 2003; 60:739-45.
48. Babisch W. Traffic noise and cardiovascular risk. Noise Health 2008; 10:27-33.
49. Schmidt FP, Basner M, Kröger G, Weck S, Schnorbus B, Muttray A, et al. Effect of nighttime aircraft noise exposure on endothelial function and stress hormone release in healthy adults. Eur Heart J 2013; 34:3508-14.
50. Franssen EA, Wiechen CM, Nagelkerke NJ, Lebret E. Aircraft noise around a large international airport and its impact on general health and medication use. Occup Environ Med 2004; 61:405-13.
51. Maschke C. Stress hormone changes in persons exposed to simulated night noise. Noise Health 2003; 5:35-45.
52. Lercher P, Hörtnagl J, Kofler WW. Work noise annoyance and blood pressure: combined effects with stressful working conditions. Int Arch Occup Environ Health 1993; 65:23-8.
53. Folscher LL, Goldstein LN, Wells M, Rees D. Emergency department noise: mental activation or mental stress? Emerg Med J 2014; 32:468-73.
54. Banbury SP, Berry DC. Office noise and employee concentration: identifying causes of disruption and potential improvements. Ergonomics 2005; 48:25-37.
55. Hygge S, Evans GW, Bullinger M. A prospective study of some effects of aircraft noise on cognitive performance in school children. Psychol Sci 2002; 13:469-74.
56. Evans GW, Johnson D. Stress and open office noise. J Appl Psychol 2000; 85:779-83.
57. Girard SA, Leroux T, Courteau M, Picard M, Turcotte F, Richer O. Occupational noise exposure and noise-induced hearing loss are associated with work-related injuries leading to admission to hospital. Inj Prev 2015; 21:e88-92.
58. Anjelo KLH, Queiroz DS, Zannin PHT. Noise in leisure activities. Occup Med Health Aff 2014; 2:181.
59. Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, et al. Auditory and non-auditory effects of noise on health. Lancet 2014; 383:1325-32.
60. Henderson D, Bielefeld EC, Harris KC, Hu BH. The role of oxidative stress in noise-induced hearing loss. Ear Hear 2006; 27:1-19.
61. Morata TC, Fernandes M. Estudo dos efeitos auditivos e extra-auditivos da exposição ocupacional a ruído e vibração. Rev Bras Otorrinolaringol 2002; 68:705-13.

Resumo

O objetivo do trabalho foi desenvolver um sistema de apoio à avaliação da poluição sonora, aplicado na zona central de Rio Claro, São Paulo, Brasil. Para isso, dados foram obtidos por meio de medições sonoras e entrevistas com a população, gerando como indicadores o nível sonoro equivalente (L_{eq}), o índice de ruído de tráfego (L_{TNI}) e um diagnóstico participativo (D_p), integrados por intermédio de um sistema de inferência fuzzy *(SIF). Como resultado, o sistema proposto permitiu classificar os pontos avaliados quanto ao grau de impacto da poluição sonora sobre a saúde da população (I_{PS}) na área de estudo, que pode ser considerado significativo em 31,4% dos pontos e muito significativo em 62,9%. A possibilidade de adequar o SIF de acordo com as condições de estudo viabiliza a sua generalização e, desta forma, apoia a avaliação e respectiva gestão do ruído ambiental em outras regiões.*

Lógica Fuzzy*; Poluição Sonora; Efeitos do Ruído*

Resumen

El objetivo del trabajo fue desarrollar un sistema de apoyo a la evaluación de la contaminación acústica, aplicado en la zona central de Río Claro, São Paulo, Brasil. Con este fin, se obtuvieron datos mediante mediciones sonoras y entrevistas a la población, generando como indicadores el nivel sonoro equivalente (L_{eq}), el índice de ruido de tráfico (L_{TNI}) y un diagnóstico participativo (D_p), integrados a través de un sistema de inferencia fuzzy *(SIF). Como resultado, el sistema propuesto permitió clasificar los puntos evaluados, en cuanto al grado de impacto de la contaminación sonora sobre la salud de la población (I_{PS}) en el área de estudio, que puede ser considerado significativo en un 31,4% de los puntos y muy significativo en un 62,9%. La posibilidad de adecuar el SIF, de acuerdo a las condiciones de estudio, viabiliza su generalización y, de esta forma, puede apoyar la evaluación y consiguiente gestión del ruido ambiental en otras regiones.*

Lógica Difusa; Contaminación Sonora; Efectos del Ruido

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