DOI: 10.61782/fa.2025.0186

FORUM ACUSTICUM EURONOISE 2025

CAN ROAD TRAFFIC NOISE ANNOYANCE MAPS DESCRIBE THE LACK OF MENTAL WELL-BEING IN AN URBAN AREA?

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ABSTRACT

The urban acoustic environment is often affected by road traffic noise, which has a negative impact on health and mental well-being by causing annoyance and discomfort to residents and visitors. Nevertheless, urban areas also have sounds that are pleasant to people. In this study, a mixed methodology was designed and applied in neighbourhoods in southern Chile. Urban road traffic noise and annoyance were quantified using noise maps estimated with open-source software and validated with measurements. In addition, walking interviews were conducted to assess self-reported mental well-being of residents. In parallel, the soundscape perceived by visitors was evaluated through guided soundwalks and surveys. Preliminary results suggest that in places where the population was highly annoyed, there was a lack of mental well-being. However, where the soundscape was dominated by natural sounds, mental well-being improved despite high estimated percentage of road traffic noise annoyance. Future studies aim to generalise our results and to investigate the observed positive influence of specific groups of sound sources on mental well-being in urban areas with high levels of road traffic noise.

Keywords: *road traffic noise, annoyance, well-being, soundscape, neighbourhoods*

1. INTRODUCTION

Road traffic noise damages physical and mental health [1]. Annoyance is one of the psychological adverse effects most studied, which has led to the definition of dose-effect relationships, allowing the estimation of the percentage of highly annoyed population (HA%) at specific levels of road traffic noise (Lden) [2]. Recently, it has been hypothesised that annoyance could be a mediator between noise and well-being. Relationships have been investigated linking noise exposure levels outside dwellings, neighbourhood urban characteristics and questionnaires associated with diagnoses of mental disorders such as anxiety and depression, both of which decrease well-being [3]. Nevertheless, clear connections are not yet established, especially considering that in public spaces many other elements of the built environment influence directly and indirectly mental well-being [4], which interact with the urban acoustic environment [5], affecting the short-term perceptions of visitors and residents. The aim of this study is to examine if annoyance (HA%) estimated based on a long-term health effects-related noise indicator (Lden) can be useful to describe and identify locations in public spaces of urban neighbourhoods where the acoustic environment affects mental well-being of residents and visitors.

2. METHODOLOGY

2.1 Study area: neighbourhoods

The study was carried out in two neighbourhoods in Valdivia, a city from southern Chile. Neighbourhood population differs according to their total area, as well as the availability of public space and green areas.

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Figure 1 shows the difference between the scales of the studied neighbourhoods.

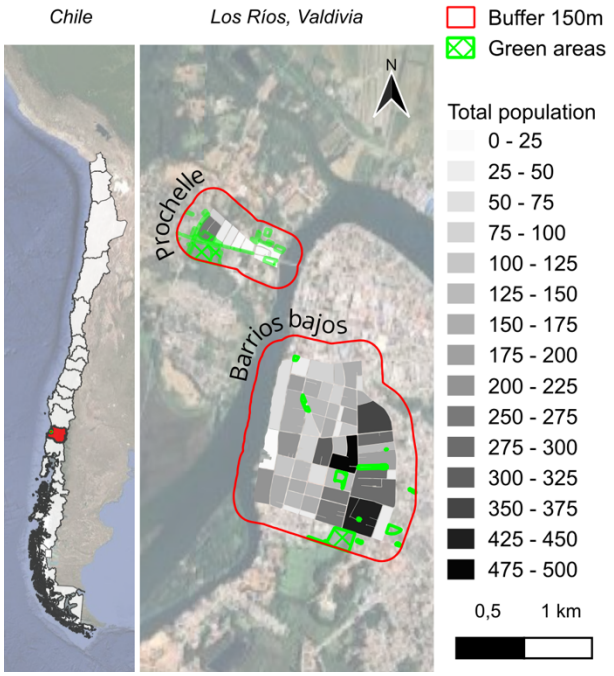

Figure 1. Barrios Bajos and Prochelle, Valdivia [6].

2.2 Noise measurements for noise mapping validation

Road traffic noise measurements were conducted on different streets in each neighbourhood to calibrate the noise maps. First, a street categorisation method was used to distinguish noise levels according to their functionality in an urban environment [7]. A simplified version was applied which requires data on transport infrastructure, road length, median width, sidewalk width, number of traffic lights at intersections and public transport bus routes [8]. Figure 2 identifies the three street groups and the measurement points. Category C1 groups the main streets of each neighbourhood, category C2 are the streets that connect C1 to residential streets C3.

All measurements lasted 15 min., under the supervision of an expert, and were carried out during the daytime, between 07.00–19.00 hrs on weekdays, avoiding periods of traffic congestion. A type 1 sound level meter was placed at 1.2 m from the roadside, following ISO 1996-2 standard for equipment location and favourable meteorological conditions, and checking the calibration of the instrument before and after each measurement campaign.

Additionally, speed and traffic flow were measured for the day, evening (19.00–23.00 hrs) and night (23.00–07.00 hrs), considering CNOSSOS categories [9], and segregating light and heavy public transport.

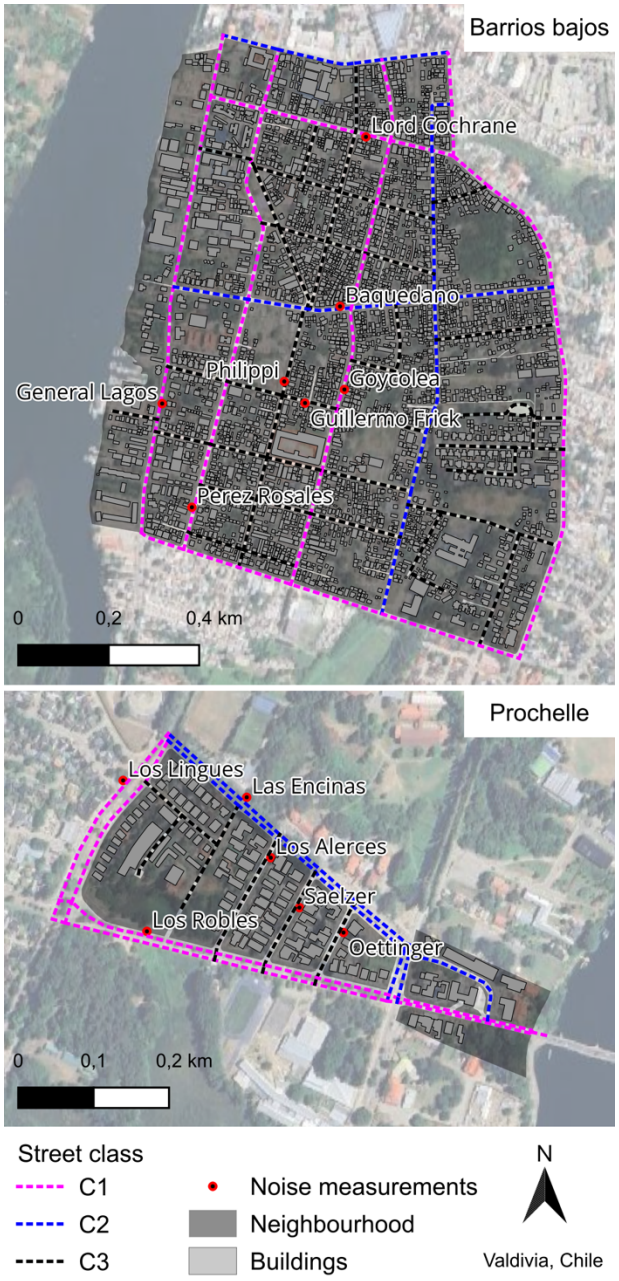

Figure 2. Street categorisation and noise measurement points in the studied neighbourhoods.

2.3 Road traffic noise annoyance maps

Noise maps and exposure were calculated using NoiseModelling [10]. Given the lack of reliable public databases in Chile, the buildings of each neighbourhood were mapped in-situ, their height was estimated through the number of floors of each site, assuming each floor height of 3 metres. The elevation of the terrain was generated from contour lines provided by the Municipality of Valdivia. The ground type and the acoustic absorption of the neighbourhood was obtained with the methodology described in other studies [11]. Weather conditions, traffic light intersections and street pavement type were determined in situ for each neighbourhood during the noise measurements.

Subsequently, the estimation of people highly annoyed by road traffic noise in public space was estimated using the equation described by *Guski et al. (2017)* [2], using isolines at a height of 1.5 metres from the ground. This represents the locations in the neighbourhood where a certain percentage of residents and visitors will potentially experience annoyance from road traffic noise.

2.4 Walking interviews to assess self-reported mental well-being of residents

For the assessment of mental well-being of neighbourhood residents, 76 volunteers from Barrios Bajos, and 56 from Prochelle participated. All of them recruited with the support of local associations.

A qualitative Walking Interview method was used with each resident, using the Natural Go–Along technique [12], to obtain recordings of residents' self-reported perceptions of their built environment. The interviews were conducted on weekdays between January 2023 and January 2024. The dialogue was 1:1 between the researcher and residents, capturing the usual hidden or unnoticed relationships with the places, highlighting environmental perception, spatial practices and social context, among other aspects. Each resident was asked to freely narrate their walking experience, and to stop at those places capable of evoking emotions or behaviours associated with greater affective impact.

General and then increasingly specific questions were asked to the residents, such as: *How do you feel while walking in this place?. What noises and sounds in this street provoke emotional reactions in you?*. The route of each interview was chosen voluntarily by the residents and recorded with the Strava app. Each conversation audio was recorded, coded and analysed by using Atlas.ti software. Photographs of aspects highlighted by the interviewers were also collected.

2.5 Guided soundwalks and surveys to assess soundscape perceived by visitors

The soundscape assessment involved 21 visitors in Barrios Bajos, and 16 in Prochelle. All volunteers had previously visited each neighbourhood, but no one was resident.

Their soundscape perception was assessed through Google form questionnaires using Method A of Part 2 of ISO/TS 12913 in Spanish [13, 14]. Complementarily, the taxonomy of sound sources was extended from traffic noise (e.g. cars, buses, trains, airplanes), other noise (e.g. sirens, construction, industry, loading of goods), sounds from human beings (e.g. conversation, laughter, children at play, footsteps), and natural sounds (e.g. birds call, flowing water, wind in vegetation), to a disaggregated version which includes sounds present in Latin American soundscapes (see Table 1). Also, at the start of each soundwalk, visitors were introduced to breathing and deep listening techniques, discussed in previous publications by the authors [15].

The soundwalks were organised in groups of no more than five volunteers, on different days of the week and at different times, between June 2023 and March 2024. Was required to not produce sounds that could interfere with the acoustic environment. Winter clothes like waterproof jackets and umbrellas sounds was not supposed to influence the responses of the participants. Eating and drinking were not allowed during the walks.

Every soundwalk route was designed by the researchers based on an ethnographic sound analysis of each neighbourhood, defining stop nodes that would represent each section of the route. The first questionnaire was applied at each node and was divided into three parts: identification of sound sources, soundscape quality and general evaluation. In this study, results are analysed with respect to the predominance of sound sources identified on each section between the stop nodes. Future publications by the authors will analyse all the findings.

Table 1. Sound taxonomy, adapted from [15].

Technophony
Transport
N1. Road traffic noise: car, bus, motorcycle, etc.
N2. Other transport noise: aircraft, vessels, etc.
N3. Non-motor traffic: bicycle, carriage, etc.
Urban noises
N4. Urban management: build-in, gardening, etc.
N5. Other noises: rumbles, gun shots, fans.
Music
AM. Amplified music: through loudspeakers.
NM. Non-amplified music: musical instruments.
Anthropophony
H. Human movement: footsteps, rubbing, etc.
S. Speech: conversations, whisper, voices, etc.
V. Vocal expressions: cry, laugh, cough, etc.
CT. Cultural or traditional: bell, siren, preach, etc.
Biophony
DA. Domestic animals: dog bark, cat meow.
FA. Farm animals: crow, bellow, neigh.
EA. Exotic animals: birds, amphibians, insects.
WA. Wild animals: hoot, roar, growl, howl, buzz.
Geophony
PN. Wind: Zum.
W. Water: rain, river, ocean waves, waterfall.

3. RESULTS

3.1 Noise mapping validation

Measurement points for noise, speed and traffic flow were included as receivers in each neighbourhood noise model to calculate differences between the measurements (see Table 2). Several iterations were performed by modifying the parameters of CNOSSOS model [9] to adapt them to the particularity of each neighbourhood in southern Chile.

Air temperature and relative humidity were set to 15°C and 70%. The most significant modification was the type of pavement in old streets. SMA surface with 8 mm stones (NL05) was assigned to consider the sound absorption due to the lack of maintenance of concrete pavements (NL06). An overall target accuracy of ±2 dB uncertainty in the emission level of the source is considered. For one point (see Table 2 (*)) the defined accuracy was not achieved, as the 15 min. measurement did not stabilise, because the flow was too low, and CNOSSOS overestimated in such situations. However, for most of the points the target was reached, therefore, every setting applied in the noise model was replicated in all other streets of the same road category for each neighbourhood.

Table 2. Differences between noise modelling and measurements at the neighbourhoods.

	Street		LAeq (dB)		
	Class	Name	Mea.	Mod.	Diff.
Barrios bajos	C1	P. Rosales	68,2	70,03	-1,8
		G. Lagos	70,2	71,41	-1,2
		Goycolea	66,1	67,97	-1,9
		L. Cochrane	68,0	69,07	-1,1
	C2	Baquedano	70,2	69,39	0,8
	C3	Phillippi	63,8	65,17	-1,4
		G. Frick	58,9	60,93	-2,0
Prochelle	C1	Los Lingues	68,6	69,2	-0,6
		Los Robles	71,9	72,6	-0,7
	C2	Los Encinos	61,6	64,1	-1,8
	C3	Los Alerces	49,8*	56,4	-6,6
		Saelzer	60,6	61,3	-0,7
		Oettinger	56,4	58,8	-1,6
*15 min measurements non-stabilized due to low traffic flow.					

3.2 Noise annoyance maps and source sources affecting mental well-being

Locations where people were annoyed by noise and places where sounds generated positive emotions are identified on maps. During the walking interviews, the acoustic environment was mentioned 65 times in Barrios Bajos, and 28 in Prochelle, playing an important role in the perception of well-being.

3.2.1 Barrios Bajos

Road traffic noise (N1) is predominant for visitors on the path between the start and nodes A and B. As well as between nodes E and F (see Figure 3). On the other hand, on the path between nodes B, C and D, visitors can distinguish an important presence of the sounds of domestic animals (DA) and exotic animals (EA). The proximity of the river at node E makes visitors perceive the sound of water. Along the whole route urban noises and music were present.

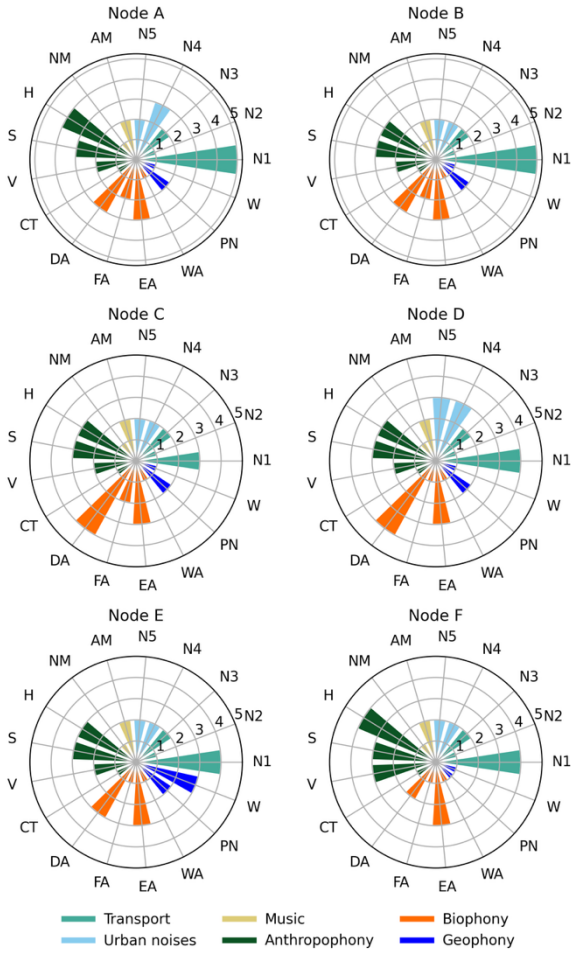

Figure 3. Sound source dominance at Barrios Bajos. 1) Not al all; 2) A little; 3) Moderately; 4) A lot; 5) Dominates completely.

Complementarily, Figure 4 shows the map of road traffic noise annoyance estimated for Barrios Bajos. Likewise, nodes A, B, C, D, E and F of the soundwalks were overlapped, together with the identification of public spaces where residents mentioned technophonic and anthropophonic noise sources that generated negative emotions, and biophonic and geophonic noise sources that generated positive feelings.

Two places were defined as quiet and positively valued. Quietness was a concept incorporated by the residents which was not defined in the taxonomy.

Among interviewed residents, high volume of traffic and vehicles parked on streets with multiple points of interest are associated with emotions of discomfort, insecurity, fear and stress. Likewise, heavy public transport operating at high speeds generates anger, rage, fear and insecurity. Moreover, streets with limited traffic led to emotions of insecurity and fear (women), especially when they walk late in the evening and at night.

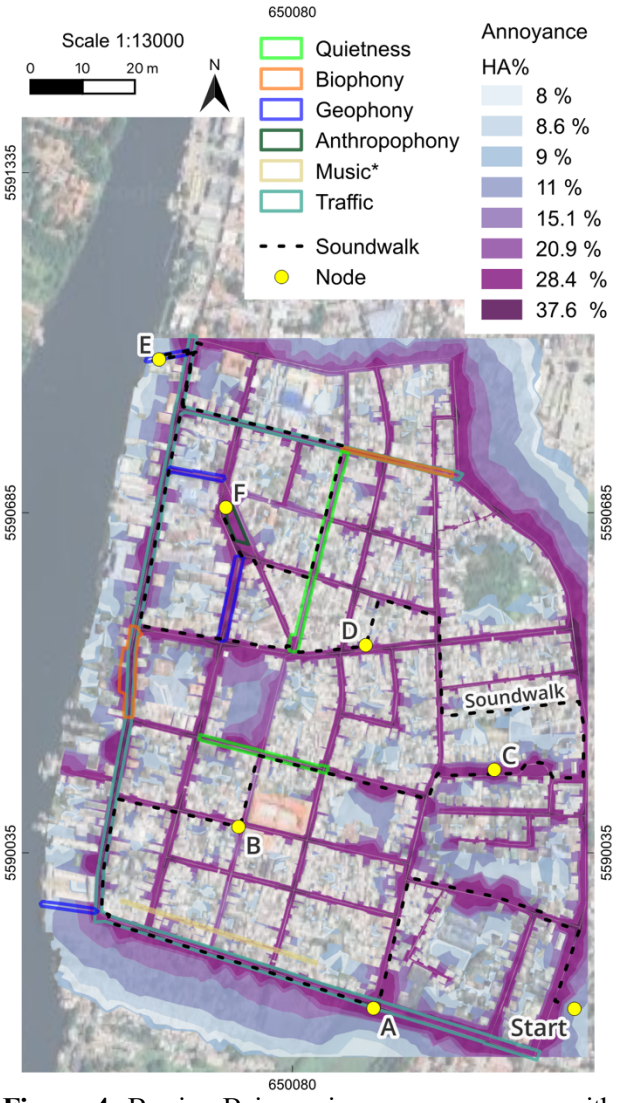

Figure 4. Barrios Bajos noise annoyance map with sound sources impacting mental well-being.

A negative externality of traffic is noise. Residents indicated that road traffic noise triggers annoyance and unpleasantness, especially the noise from heavy public transport in congested streets. Further sources of noise identified in the acoustic environment of the neighbourhood were the dogs' barking which created displeasure and

insecurity. As well as noise from neighbours and music in the street, which annoy residents and make them uncomfortable at night.

However, several sound sources generate positive emotions in residents. Children's voices in squares and playing in open spaces generate pleasure and joy. The sound of the wind produces tranquillity and calm in public spaces near or by the river. Similarly, when the wind interacts with trees, residents feel pleasure and joy. In addition, when birds are in the trees, the sound of their calls brings enjoyment and happiness, while in riverside locations it produces tranquillity, relaxation and joy. The absence of noise associated with urban life in wide and narrow streets are interpreted as quiet areas which give a sense of tranquillity among residents.

3.2.2 Prochelle

In this neighbourhood, road traffic noise (N1) and the sound of wind (PN) were predominant for visitors throughout the entire soundwalk. However, on the path between A and B, people perceived also exotic animals (EA) (see Figure 5).

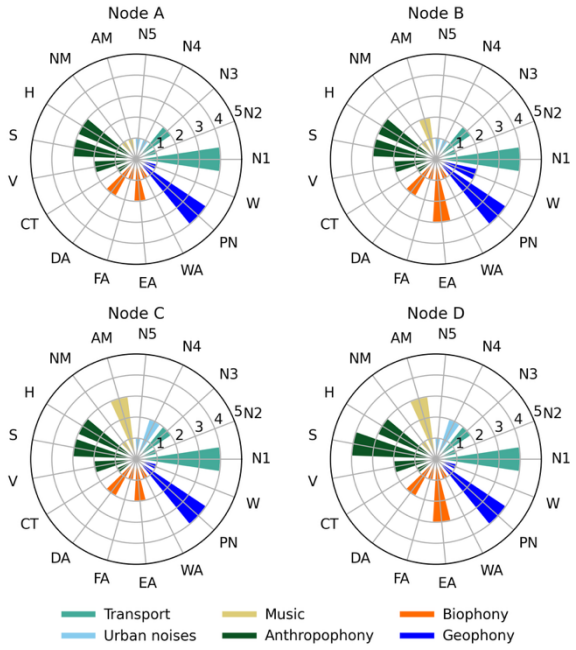

Figure 5. Sound source dominance at Prochelle.
1) Not al all; 2) A little; 3) Moderately; 4) A lot; 5) Dominates completely.

In addition, Figure 6 shows the road traffic noise annoyance map estimated for Prochelle, overlaying the soundwalk nodes, together with the identification of public spaces where residents recognised technophonic noise sources which generated negative emotions, and biophonic and geophonic sound sources which generated positive emotions.

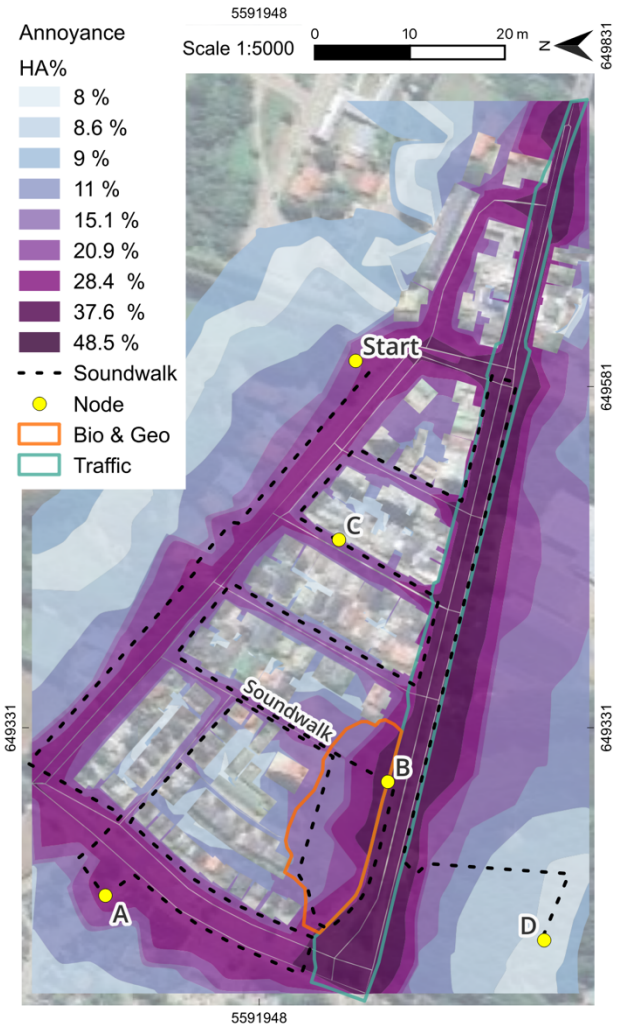

Figure 6. Prochelle noise annoyance map with sound sources impacting mental well-being.

Significant volumes of traffic flow at high speeds were associated with emotions of fear, stress, annoyance, discomfort, displeasure, and frustration among interviewees. Conversely, on narrow streets where vehicles drive at slow speeds, residents experienced peace, calm, security and tranquillity.

This result was directly related to places where sources of noise were explicitly identified (see Figure 6). Road traffic noise became associated with emotions of anger, anxiety, insecurity, unpleasantness and annoyance among respondents. In addition, at congested periods, the noise of horns generates mainly anxiety.

Meanwhile, the natural sounds of the acoustic environment were associated with emotions of pleasure, tranquillity, calm and enjoyment among residents. The sound of the wind interacting with the trees was associated with pleasure, enjoyment, calm, peace and satisfaction. Likewise, in some interviews it was mentioned that at a specific time of the year at Los Patos Lagoon (marked as Bio & Geo in Figure 6) the sound of frogs croaking was associated with feelings of calm, awe and satisfaction among residents. In the same area, several residents indicated that not hearing the typical noises associated with the city makes them feel quiet, calm, peaceful and safe.

4. DISCUSSION

Overall, when neither residents or visitors recognised a significant presence of sound sources different from traffic, annoyance maps were useful to locate places where road traffic noise negatively affects mental well-being. However, in Barrios Bajos, where HA% was between 20.9–28.4%, i.e. levels around 65–70 dBA, geophony (water flowering mostly produced by wind) enhanced well-being even though in the same area (path D–E) traffic noise was predominant. Likewise, in areas without heavy public transport routes but significant dominance of human movements sounds (path E–F), people perceived quietness. Furthermore, our findings suggest that even if there were high HA% levels (e.g. in the street parallel to the river) the sounds of exotic animals across the neighbourhood produce emotions associated with positive mental well-being. Similar patterns are observed in Prochelle, where despite HA% between 20.9–37.6% (levels around 65–75 dBA) with dominance of traffic noise (path A-B), in areas with wind sounds combined with trees and wild animals, people feel emotions that improve their mental well-being and make them perceive tranquillity regardless of the high noise levels. Consequently, noise annoyance maps can only describe a lack of mental well-being when there are no other biophonic and geophonic sound sources that potentially psychologically mask road traffic noise [5]. Such sounds are closely linked to other elements of the urban context which synergistically influence mental well-being [4].

5. CONCLUSIONS

- According to residents and visitors, road traffic noise was the most dominant source of noise in all the studied neighbourhoods, negatively affecting their mental well-being by generating emotions of annoyance and discomfort.
- In locations with elevated noise levels, annoyance due to road traffic noise, calculated through long-term indicators, identified areas that induce a lack of mental well-being.
- In places where geophonies and biophonies were present in combination with traffic, participants reported better mental well-being, as these sound sources induced positive emotional states such as quietness, calm, pleasantness, tranquillity, happiness, enjoyment and relaxation.
- It is not sufficient to generalise and use annoyance as an indicator of a lack of mental well-being, as in some urban environments there are also soundscapes that contribute to enhance the urban experience. These relationships need to be explored by considering all dimensions of the soundscape in future studies. As well as mapping other noise indicators which might be more related to short-term effects.
- Studying the acoustic environment from its noise and soundscape dimension is a good practice which helps to understand how people experience, listen and feel public spaces of the built environment.

6. ACKNOWLEDGMENTS

This research was funded by Chilean National Agency for Research and Development (ANID) through the project FONDECYT No. 1230027.

7. REFERENCES

[1] World Health Organization. Environmental Noise Guidelines for the European Region, 2018.

[2] R. Guski, D. Schreckenberg, R. Schuemer: "WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance", *Int. J. Environ. Res. Public Health.* 14, 1539, 2017.

[3] J. Shi, J. Huang, M. Guo, L. Tian, J. Wang, T.W. Wong, Ch. Webster, G.M. Leung, M.Y. Ni: "Contributions of residential traffic noise to depression and mental wellbeing in Hong Kong: A prospective cohort study", *Environ. Pollut.* 338, 122641, 2023.

[4] A. Zumelzu, C. Heskia, M.G. Herrmann-Lunecke, G. Vergara, M. Estrada, C. Jara: "Street Design Elements That Influence Mental Well-Being: Evidence from Southern Chile", *Land*. 13, 1398, 2024.

[5] J. Kang. "Soundscape in city and built environment: current developments and design potentials", *City Built. Environ.* 1, 1, 2023.

[6] Instituto Nacional de Estadísticas de Chile. Geodatos abiertos, Microdatos Censo 2017 [database], 2018.

[7] G. Rey Gozalo, J.M. Barrigón Morillas, V. Gómez Escobar: "Urban streets functionality as a tool for urban pollution management", *Sci. Total Environ.* 461–462, 453–461, 2013.

[8] A.L. Montenegro, G. Rey Gozalo, J. Arenas, E. Suárez: "Streets classification models by urban features for road traffic noise estimation", *Sci. Total Environ.* 932, 173005, 2024.

[9] Directive 2015/996/EU of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council, 2015.

[10] E. Bocher, G. Guillaume, J. Picaut, G. Petit, N. Fortin: "NoiseModelling: An Open Source GIS Based Tool to Produce Environmental Noise Maps", *ISPRS Int. J. Geo-Inf.* 8, 130, 2019.

[11] A.L. Montenegro, A. Panci, M. Bolognese, D. Palazzuoli, M. Cerchiai, D. Melluso, G. Stasi, G. Licitra, "An open-source pipeline in noise modelling and noise exposure reduction in a port city", in *Proc. of the 30th International Congress on Sound and Vibration,* (Amsterdam), 2024.

[12] B. Piga, D. Siret, and J.P. Thibaud: *Experiential Walks for Urban Design: Revealing, Representing, and Activating the Sensory Environment*. Cham, Switzerland: Springer, 2021.

[13] J. Vida, J.A. Almagro, R. García–Quesada, F. Aletta, T. Oberman, A. Mitchell, J. Kang: "Soundscape attributes in Spanish: A comparison with the English version of the protocol proposed in Method A of the ISO/TS 12913–2", *Appl. Acoust.* 211, 109516, 2023.

[14] E. Suárez and M. Gueregat. Soundscape Evaluator [software]. Web, Android and iOS, 2021.

[15] G. Leal, A.L. Montenegro, A. Zumelzu, "Estimación del paisaje sonoro utilizando una escucha activa e integral en entornos urbanos del sur de Chile", in *Proc. of the XIII Congresso/Congreso Iberoamericano de Acústica FIA*, (Santiago), 2024.