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Interference of vehicle frequency sound pressure levels on the density of green areas: a case study in Irati, Paraná

Interferência da densidade de áreas verdes e da frequência de veículos nos níveis de pressão sonora: estudo de caso em Irati, Paraná

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Abstract

Noise is a problem of modern society and is an environmental pollutant caused by industrial activities, traffic, among others which can cause health problems. As such, this work aims to evaluate the potential for urban green areas to be used as a noise attenuating barriers. For this purpose, a proximity analysis was performed between noise samples measured in 10 locations in urban areas, considering the density of green areas and the density of vehicle traffic. Mapping by class of urban noise traffic levels, of green areas, was carried out around 10 sample points and the respective rates of green areas were calculated using orbital images of high spatial resolution. For the same areas, urban traffic densities were calculated. The attenuating influence of noise due to the presence of higher or lower rates of urban green areas was evaluated. They were characterized as arboreal green areas that can serve as vertical green noise-attenuating barriers, along with providing interference due to the frequency and density of vehicular traffic. Thus, statistical relationships were sought between the noise levels found within their different degrees of urbanization. The results showed that the high frequency of vehicles, both at 100 and 250 meters away from the sampling points, influenced the noise with greater intensity and that the green arboreal areas reduced noise marginally. Although this reduction was not significant.

Keywords: noise monitoring; urban forest; high resolution orbital imaging; proximity analysis.

Resumo

O ruído é um problema da sociedade moderna e um poluente ambiental causado por atividades industriais, de tráfego, entre outras, podendo gerar problemas à saúde. Neste contexto, esse trabalho tem por finalidade avaliar o potencial de áreas verdes urbanas como barreira atenuadora de ruídos. Para isto, foi realizada uma análise de proximidade entre amostras de ruído mensurados em 10 locais da área urbana considerando a densidade de áreas verdes e a densidade de tráfego de veículos. Foi realizado o mapeamento por classe de níveis de tráfego urbano, das áreas verdes, no entorno de 10 pontos amostrais e calculadas as respectivas taxas de áreas verdes com uso de imagens orbitais de alta resolução espacial. Para as mesmas áreas foram calculadas densidades de tráfego urbano. Foi avaliada a influência atenuadora de ruídos devido a presença de maiores ou menores taxas de áreas verdes urbanas, caracterizadas como áreas verdes arbóreas e que possam funcionar como barreiras verticais verdes atenuadoras de ruídos, como também a interferência da frequência de veículos em função da densidade de tráfego veicular. Desta forma, buscou-se relações estatísticas entre os níveis de ruído encontrados e seus diferentes graus de urbanização. Os resultados demonstraram que as altas frequências de veículos, tanto a 100 como a 250 metros de proximidade dos pontos amostrais, influenciaram com maior intensidade de ruído e que as áreas verdes arbóreas reduziram marginalmente, porém tal redução não foi significativa.

Palavras-chave: monitoramento do ruído; floresta urbana; imagens orbitais de alta resolução; análise de proximidade.

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Introduction

Environmental noise is one of the main contaminants of modern society and directly affects the well-being of the population (CHÁVEZ; YOZA; ARELLANO, 2009). This author and some peers also claim that noise is mainly caused by vehicular traffic, industrial activities, construction and recreational.

In large urban centers, noise is a common fact mainly generated by means of transport. Studies show that traffic noise of 66dB(A) is considered as the threshold of damage to health. Consequently, preventive medicine establishes 65dB(A) as the maximum level to which a citizen can be exposed in an urban environment without hazardous risk (BELOJEVIĆ; JAKOVLJEVIĆ; ALEKSIĆ, 1997; MASCHKE, 1999).

Nunes (1999) considers vehicular traffic as the greatest contributor to urban environmental noise, depicting it as pulsating, due to the fact that vehicles move with a series of accelerations and decelerations, developing low and medium speeds and resulting in high sound levels on their itineraries. At intersections with traffic lights, vehicle stops and consequent accelerations are responsible for increases in noise emissions. Furthermore, it is assumed that the nuisance generated is much greater compared to similar situations of traffic in continuous flow. In this way, noise pollution has become one of the ramifications of development, causing problems in the quality of life and health of the population, especially in large and medium-sized cities.

The direct effects of noise on human health are: hearing loss, stress, hypertension, sleep disorders, mental health disorders, cardiovascular risks, interference with oral communication and low productivity at work (LOUPA *et al.*, 2019).

The rapid increase in the number of motor vehicles has caused a significant uptick in the number of complaints from the population in relation to the noise generated in cities, both in Brazil and for the rest of the world. Studies carried out in several cities have revealed that traffic noise is the greatest contributor to measured sound levels and the greatest cause of annoyance in urban areas (GERGES, 2004).

In recent decades, scientific research has alerted to the fact that humankind seems to be increasingly accustomed to noise. In research carried out by Yorg and Zannin (2003) individuals clearly demonstrated that continuous and repeated exposure to noise is no longer perceived in a conscious or uncomfortable way. Nevertheless, the authors emphasize that the effects of exposure continue to act harmfully against health. In this way, the amount of noise produced by vehicles and the equipment installed in them can reach the point of being considered as polluting the environment, since it causes discomfort, possibly resulting in diseases, in addition to other damage to the environment.

According to Silva *et al.* (2017) it is scientific knowledge that high levels of noise are harmful to human health, causing permanent damage to the receiver. The mapping of noise from traffic and other emission sources can serve as conceptual and definitive tools for improvements in the study of environmental management and urban planning of a city.

According to the Organization Mondiale de la Santé (OMS, 1980), measuring the consequences of noise on people's quality of life is difficult because there are several factors. Albeit, the Non-governmental organization (NGO) stresses the necessity to study noise since this situation involves the world's population on a large scale. In Brazil, like other countries in the world, research is carried out to qualify and quantify urban noise.

Considering that the presence of noise in cities is directly proportional to population growth, in which exposure is caused by diverse types of sound sources, this is one of the main factors responsible for physical and mental health problems (OMS, 1980). In this regard, the study of acoustics is very broad as it covers several areas of knowledge, in which it aims to benefit society (MAGALHÃES; BARBOSA, 2017).

Bistafa (2011) describes that any sound source emits a given power, which generates sound levels, which exhibits noise attenuation mechanisms, which depends on the path of wave propagation towards the receiver.

The first reflections that come to mind when we talk about green areas refer to their usefulness and how far the scope of the term goes (LONDE; MENDES, 2014). Frequently used by municipal planning bodies and in academia to classify the vegetation present in cities, the terms green areas, open spaces/areas, urban trees, urban green and vegetation cover have been used for the same meaning. However, most of these terms are not synonymous, and do not refer to the same elements, nor do they refer to the same elements (LIMA *et al.*, 1994).

Vegetation has direct effects on the mental and physical health of the population. Oliveira (1996) also points out that these effects contribute to the enhancement of areas for social interaction, economic enhancement of properties and to the formation of a memory and cultural heritage.

According to Sancho and Senchermes (1982), the most common urban acoustic barriers are the walls or facades of buildings. The noise source, vehicles, is located between two parallel barriers. As they noticeably reduce sound levels at the back, they reflect the noise to the sidewalk, creating a semi-reverberant space between buildings, especially when the distance between the facades, or barriers, is small. Therefore, the sound reflections with the walls lead to an increase in noise levels, and in narrow streets, noise levels are higher than in wide streets, even if the hourly flow of vehicles is lower in narrow streets.

Several authors cite the benefits that green areas can bring to humankind in cities, such as: control of air and acoustic pollution, increased environmental comfort, stabilization of surfaces by fixing the soil with plant roots, shelter for fauna, balancing the humidity index in the air, protection of springs and springs, organization and composition of spaces in the development of human activities, visual and ornamental enhancement of other environments, recreation, and diversification of the built landscape (TOLEDO; SANTOS, 2008).

There are several types of acoustic barriers. However, for this research, emphasis will be given to the vegetal barrier. Botari *et al.* (2013) state that, generally, plant barriers do not guarantee efficient sound reduction, such as concrete barriers and other acoustic materials. However, the vegetation barrier provides visual comfort by hiding the source of noise, thus acting as psychoacoustics, which provides the sensation of attenuation of environmental noise. The same authors argue that the behavior of the vegetation present in the barrier is capable of reducing noise by absorbing sound (eliminating sound), by deviation (altering the direction of sound), by reflection (sound waves change direction around an object), or by concealment (the unwanted sound is covered with a more pleasant one).

The study of vegetation or green areas as a barrier to the effects of noise pollution is related to their functional advantages as an acoustic barrier. It is known that vegetation has good absorption capacity and good landscape integration, i.e., it has little visual impact compared to other types of barriers such as concrete, metal, or glass (MAGALHÃES; BARBOSA, 2017).

Among the methods used to analyze and map noise in the urban environment, several parameters and criteria are taken into account, which vary in terms of the number of samples to be collected, location, time and duration of measurements (MENDONÇA *et al.*, 2012). Noise control at the source involves introducing modifications to the sound source itself in order to reduce the noise generated by it. It ranges from design changes (such as the development of quieter engines) to simple modifications such as reducing (or dampening) vibrations, impacts, or turbulence. The selection of equipment, aiming to choose the quietest, can also be considered an important way to exercise control at the source (MUSAFIR, 2014).

Trajectory control normally involves the use of insulating and/or absorbing materials, either to hinder the transmission of noise and vibrations (isolation) or to reduce the importance of reflections (through absorption). The more rigid or heavy a material is, the more insulating it is, as it offers greater resistance to vibration caused by sound waves. The absorbing material, in turn, must be porous to allow a significant portion of the incident sound energy to be dissipated in the form of heat while the wave propagates inside it. The use of barriers to protect dwellings from traffic noise is a typical example of path control for outdoor noise (MUSAFIR, 2014).

Satellite image mapping is an important source for obtaining data on the type and dynamics of land occupation. Land use information is essential for territorial and environmental planning, as it is extremely important for the knowledge process of space organization (TENEDÓRIO, 1989). With information on land use and occupation that can be obtained through the interpretation of images in pre-delimited areas through geoprocessing tools and proximity analysis, it is possible to combine this information later with acoustic data measured in the field.

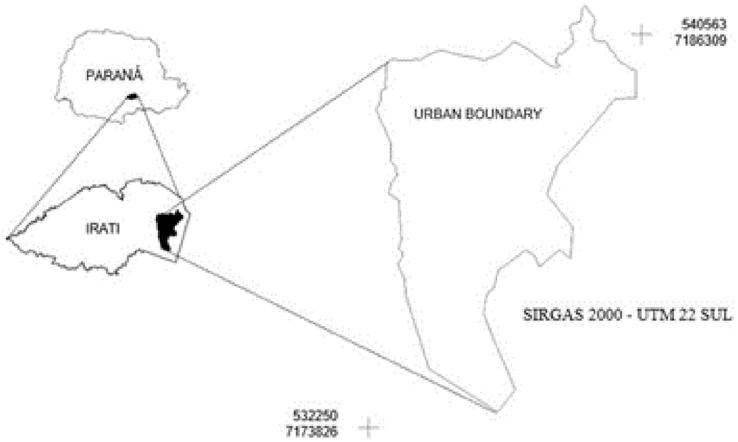
Thus, this work presents a study in which it intends to relate the levels of sound pressure with the density of urban traffic.

Materials e methods

Study area

The study was carried out in Brazil in the urban area of the municipality of Irati, Paraná (PR), Figure 1, located 150.34 km from the capital Curitiba. The municipality was founded in 1907, and since then, it has experienced population, economic, and industrial growth.

Figure 1 – City limits of Irati, Paraná.



Source: The authors.

A geographic information system was implemented for the spatialization of the cartographic base of the study area, including the urban perimeter, orbital images of special high resolution, and the road network. The sampling points used for measuring the sound pressure level (SPL) were defined and georeferenced.

Ten points distributed in the urban perimeter of the city of Irati were georeferenced, five of them in more central (urban) neighborhoods and another five in more peri-urban places, where the population density is lower and consequently the rate of green areas is higher. With the support of orbital images of high spatial resolution, 50 cm, the green arboreal areas were mapped within the surroundings of the SPL measurement sampling points, in the urban and peri-urban limits of the city of Irati, PR. The surroundings or buffers were defined from distances of 100 and 250 meters in radius from each sampling point.

Proximity analyses were carried out between multidirectional noise monitoring samples and different quantities and distinct spatial distributions of surrounding green areas, using central and peripheral, or periurban, sampling points. SPL measurements were obtained using a decibel meter, and the reading was performed 10 times, every 10 seconds, at each sampled point, and the average value was considered. An SPL analyzer meter with a range of 30 to 130 dBA was used in this study. Measurements were carried out in accordance with ABNT NBR 10151: 2019 (ABNT, 2019).

For georeferencing the points, a Trimble Spectra Precision DGNSS receiver was used.

The measurement of sound pressure levels in the field was carried out simultaneously with the georeferencing of urban and peri-urban sampling points. All measurements were performed between 3:00 p.m. and 5:00 p.m. during 5 weekdays (Monday to Friday).

From the same cartographic base as the arrangement of the proximity analysis buffers used to map the green areas, mapping by class of urban traffic levels within the surroundings of the sampling points was also carried out. This mapping considered the importance of public areas based on road structure and vehicle frequency.

Next, statistical relationships were sought between the noise levels found and their different degrees of urbanization, which were implicitly related to the densities of green areas.

After the proximity analysis for the calculation of the rate of green arboreal areas, an analysis of the density rate of the mesh network of public spaces within the radius of 100 and 250 m was also carried out. For this, the vectorization of public roads or streets located around each georeferenced sampling point was carried out for both 100 and 250 meters. After the vectorization of the road network, the street layout was quantified. The aim was to establish different levels of vehicle flow density, which is normally directly proportional to sound pressure levels.

After obtaining the SPL field data as well as the results of rates of green tree areas and surrounding street density (traffic), statistical analyses were carried out to seek relationships between the results obtained between the measured SPL values and the different rates of green area obtained as well as the street layout density.

Unlike traffic on roads and highways, in urban areas, vehicles hardly move smoothly. The greatest intensity of traffic occurs at signposted or traffic-lighted intersections, whose variety of destinations and the characteristics of the roads on which they circulate make a vehicle on a given route move with a series of accelerations and decelerations, with short periods of movement (flow), and at other times completely stopped. This type of traffic is called heartbeat. Speeds are low to medium, with idling vehicles and high-revving engines clearly dominating the noise produced by the engine and exhaust. Automobiles and heavy vehicles, in general, travel close to their maximum power and, as a result, at a high noise level. The variables that influence sound propagation in urban areas are many and the study of their relationships is very complex (NUNES, 1999).

Statistical analysis

To test the hypothesis that the frequency of vehicles and the presence of a tree component, up to 250 meters away, influence the sound pressure (average SPL), the data were evaluated in a multivariate way using cluster analysis.

The clustering was built from Euclidean distance and simple linkage. To ratify the groupings found in the cluster, the means of the average SPL variable for the "urban" and "peri-urban" groups were contrasted by the "t-student" test, and Pearson's correlation analysis calculated a relationship between the SPL and the percentage of area green. Trees and vehicle frequencies (high, medium, and low), at distances of 100 and 250 meters. The significance level for all analyses was 5%. To verify the assumptions of normality, the Anderson-Darling test was used, and for the homogeneity of variances, the Fligner-Killeen test was applied. The result is expressed by the p value ($p < 0.05$ indicates that there is a statistical difference).

Analyses were performed using RStudio software, version 4.0.2, MASS packages, cluster and ggplot2 (RSTUDIO, 2020).

Results and discussion

Initially, based on the urban map of the city of Irati, PR, Figure 1, the locations of the sampling points for the measurement of sound pressure levels (SPL) were determined.

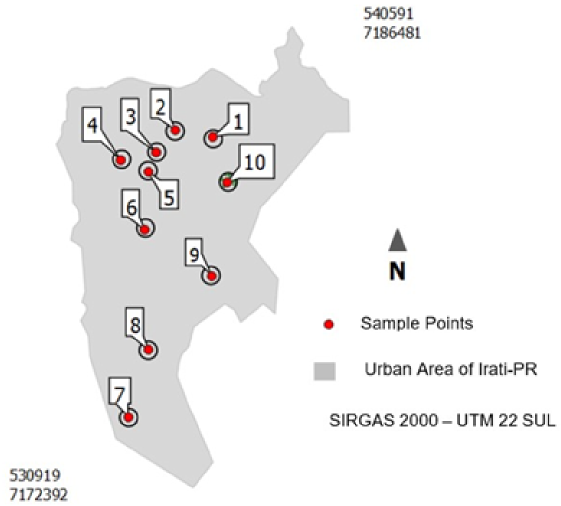
We opted for 10 points involving the "urban" groups, located in the most central part and "peri-urban" where the population area was smaller, as follows:

i) Points in the urban area: Point 1 in the Alto da Glória, Points 2 and 3 in the center, Points 4 and 5 in the neighborhoods of Rio Bonito and Fósforo, respectively;

ii) Points in the peri-urban area: Points 6-10 in the Lagoa, Riozinho , Engenheiro Gutierrez, Vila São João and Nhapindazal, respectively.

Figure 2 shows the location of the sampling points for measuring the sound pressure level (SPL).

Figure 2 – Location of sampling points for measuring the sound pressure level (SPL).



Source: The authors.

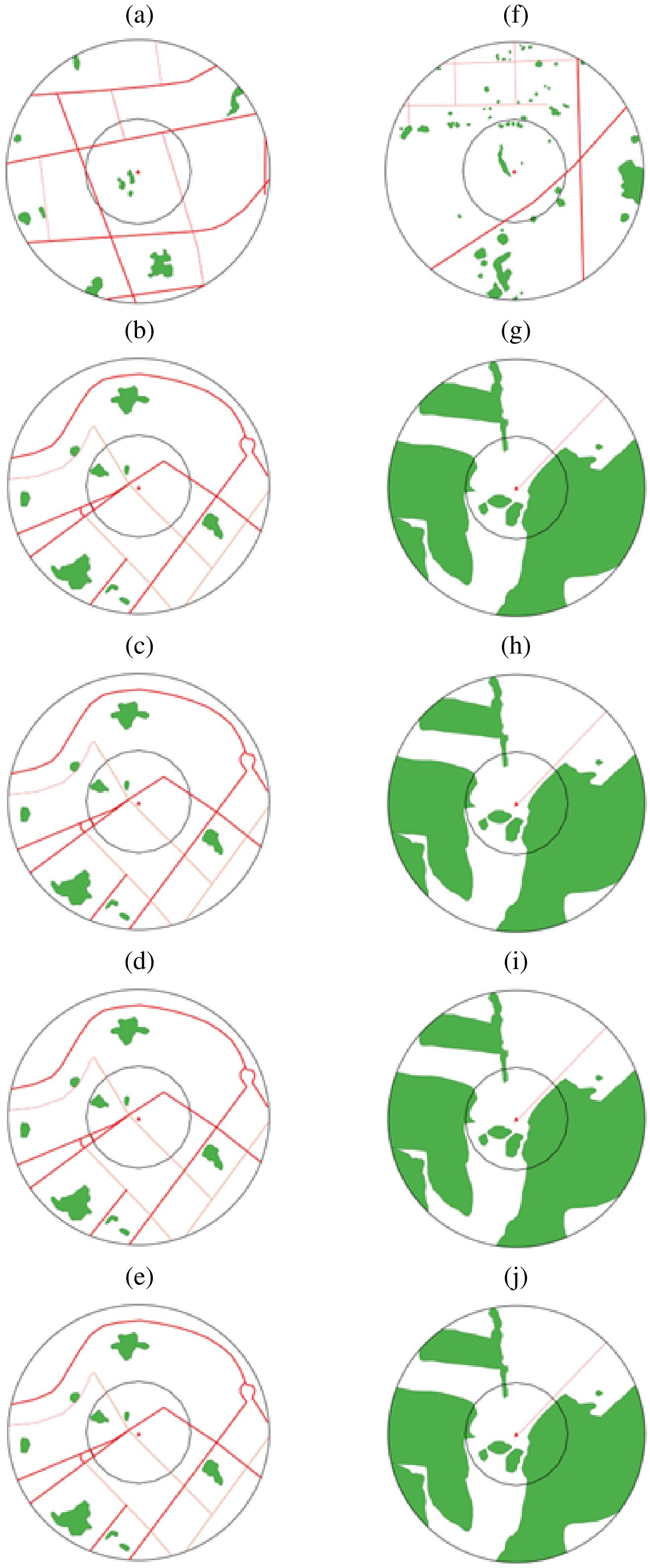
Based on the sample points, buffers of 100 and 250 meters were prepared for the execution of proximity analyses involving the mapping and calculation of tree green area rates, as well as the mapping and density of the motor vehicle flow network. For each sampling point, two buffers (100 and 250 m) were then defined for carrying out the analysis of proximity to the surroundings.

Table 1 presents the spatial distribution of both the green arboreal areas and the vehicle flow density in the two proximity areas tested, that is, 100 meters and 250 meters from the surroundings of each SPL sampling point.

With the mapping of all the green arboreal areas surrounding the 10 sampling points, as described in Table 1, the respective coverage rates were obtained for both proximity areas, as shown in Figure 3.

After measuring the road networks of the two surroundings, 100 and 250 meters, for the 10 points, the lengths of the arcs (lines) were measured, and the arcs were classified according to the frequency of vehicles, considering the public roads, preferred or not, in the city.

Figure 3 – Sample areas containing, in the center, the SPL measurement point; the circumferences with radii of 100 and 250 meters showing the proximity regions; the green arboreal areas (colored green); and the lines (thick, thin, and dotted) showing the high, medium, and low frequency of vehicles, respectively. For i =1..5, we have in (a)-(e) the urban group (Urb_i) and (f)-(j) the peri-urban group (Per_i).



Source: The authors.

Table 1 – Results of average SPL per sampling point and the respective rates of green tree areas at different proximity distances.

			Green areas (%)	
Points	**Group**	**SPL average**	**100 m**	**250 m**
1	Urb_1	53.1	1.27	2.02
2	Urb_2	65.6	1.94	0.94
3	Urb_3	67.3	4.16	4.23
4	Urb_4	55.9	5.18	6.54
5	Urb_5	65.4	0.93	11.38
6	Per_1	51.9	2.48	4.27
7	Per_2	47.2	37.02	52.79
8	Per_3	57.6	20.85	17.87
9	Per_4	54.1	34.78	34.80
10	Per_4	46.5	0.00	21.63

Source: The authors.

The analyses of the proximity of 100 and 250 meters, the average SPL results per sampling point, and the measurements of the road network are presented in Table 2.

Considering the data obtained in Table 2, the hierarchical grouping analysis yields the results described in Figure 4, which indicate 8 distinct clusters, 5 on the horizontal axis and 3 on the vertical axis, where the sample units of the experiment are found.

On the vertical axis, Figure 4, it is observed that the first cluster, denoted by Group 1, is formed by a sampling unit located in the urban region (road), the other points of study in the urban region form Group 2, and Group 3 is exclusively formed by points in the peri-urban region. This grouping was confirmed by the contrast between the averages of the areas: urban with an average of 61.46 and peri-urban with an average of 51.46, using the t-student test ($p \leq 0.01$).

On the horizontal axis, the variables sampled in each of the sampling units are grouped into 5 distinct classes, denoted, respectively, by high, medium and low frequency, 100 meters from the sampling points, as being AF_100, MF_100 and BF_100. Similarly, there are the notations for 200 meters of the sample points. Thus, it is observed in Figure 4 that the high frequencies of vehicles, both at 100, AF_100, and at 250 meters, AF_250, influenced the average SPL more intensely than land use and occupation, since the aforementioned variables are, statistically, in the same group as the SPL, Group 4. This fact is corroborated by Pearson's correlation analysis, as it demonstrated that there are significant correlations between the SPL and the high frequencies of vehicles within 100 meters ($r = 0.69$; $p = 0.03$) and 250 meters ($r = 0.65$; $p = 0.04$), while the green tree component only showed a marginal effect (significance for 10%) for 250 meters ($r = 0.58$; $p = 0.06$).

Pinto *et al.* (2013), in a study of the impact of vehicle traffic noise in Natal, RN, found a strong positive correlation between traffic volume and measured sound pressure levels (dBA). Nunes (1999), at traffic light intersections, the stops and consequent accelerations of vehicles are responsible for increases in noise emission, and it is assumed that the nuisance generated is much greater compared to similar situations with traffic in continuous flow. This explains why the sound pressure levels are higher in more central streets. Thus, in more central areas, although the amount of green areas is smaller than in peri-urban areas, there are also other types of important barriers for the absorption of noise pollution. In this way, in other studies, the methodology can be based on a spatial distribution of samples for the SPL measurement that is more directly related to a gradient of green arboreal areas and perhaps a constant in the aspect of motor vehicle flow.

According to Gozalo, Morillas and González (2019), in another body of research, measurements were performed simultaneously at different locations in the city of Cáceres, Spain. The results of this inquiry showed less noise and 71.4% of population satisfaction in areas with a greater amount of green spaces, where people go for walks and relaxation activities.

In the present study, measurements could not be performed at the same time due to the number of devices that would be needed. Gozalo, Morillas and González (2019) reported evidence of acoustic environmental comfort proportional to the size of green spaces, in addition to the importance of small green spaces between streets in order to reduce noise in cities.. Research carried out by Renterghem (2019) demonstrated how visible vegetation can mitigate the negative perception of noise. This fact is directly related to the visual comfort that vegetation causes humans. In this context, the city of Irati still has green spaces, both in more central urban areas and in more peri-urban areas. As in any city, the greenest regions of Irati are in its surroundings, but it is necessary to value the green areas that are present between highly anthropic regions, mitigating noise and the negative perception of noise, as stated by Renterghem (2019).

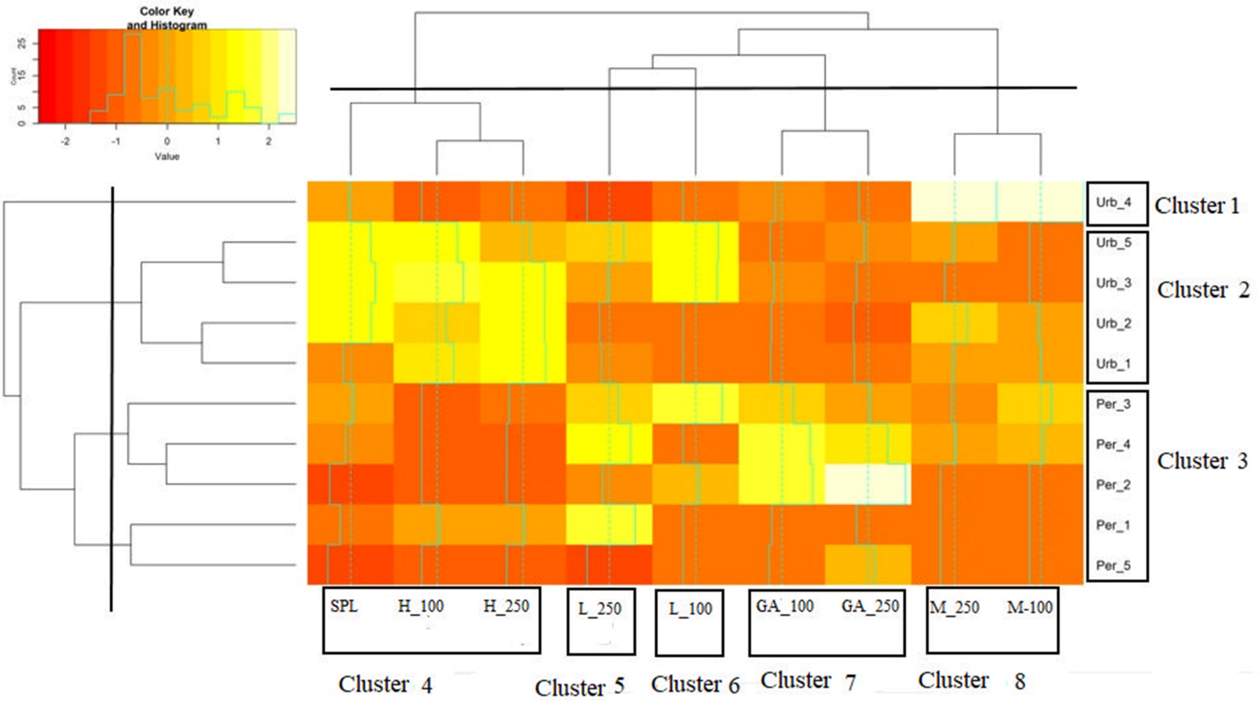
Table 2 – Results of mean SPL per sampling point and street length by vehicle flow frequency for the 100 and 250 meters areas.

	100 m				250 m			
		Frequency				Frequency		
Points	SPL average	High	Middle	Low	SPL average	High	Middle	Low
1	53.1	907.7	398.1	0.0	53.1	2055.3	398.1	242.4
2	65.6	684.3	283.2	0.0	65.6	2020.3	877.9	205.9
3	67.3	1163.3	0.0	217.8	67.3	2038.2	134.2	351.4
4	55.9	0.00	1841.4	0.0	55.9	264.6	1841.4	0.0
5	65.4	997.3	0.0	229.1	65.4	1237.7	420.9	609.3
6	51.9	494.8	0.0	0.0	51.9	925.0	0.0	810.2
7	47.2	0.0	0.0	107.5	47.2	0.0	0.0	259.2
8	57.6	0.0	748.5	251.4	57.6	118.6	356.0	521.2
9	54.1	0.0	499.2	0.0	54.1	0.0	499.2	733.2
10	46.5	0.0	0.0	0.0*	10	46.5	0.0	0.0*

* At point 10, approximately 100 meters, a new allotment has 1617.85 meters of road network and approximately 250 meters, 2126.51 meters of road network, both with very low frequencies. That's because, despite being a large allotment, there was still little occupation by residents and practically no vehicle flow, which is why the value was zeroed for the effect of footage.

Source: The authors.

Figure 4 – Hierarchical clustering analysis as a function of average SPL, tree component and vehicle frequency in 10 sampling points (urban and peri-urban), vehicle frequencies: high (H), medium (M), low (L) and green areas (G), in the region of Irati, Paraná.



Source: The authors.

Conclusions

Urban points produced significantly higher noise intensity than peri-urban points. This fact is due to the higher frequency of vehicles in urban stretches.

No significant differences in noise intensity were found between 100 and 250 meters.

The use and occupation of urban land, especially with regards to the presence of green arboreal areas, at least in the present study, was not able to significantly reduce the noise intensity since the correlations between the average SPL for the surroundings of 100 and 250 meters were not significant.

Acknowledgments

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