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Evaluation and analysis of road traffic noise for acoustic comfort in urban public spaces: case study of the Boussouf district, Algeria

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Abstract:
In the present work, the sound environment of road traffic was evaluated. The study and analysis of traffic noise were carried out in a part of the Boussouf residential district in Constantine, Algeria. This part contains the main street crossing the heart of the district, through which vehicles pass to enter or leave. The study area was divided into five zones, with 15 measurement points distributed across them. Acoustic indicators such as minimum of sound level $L_{eq,1s}$ (L_{min}), maximum of sound level $L_{eq,1s}$ (L_{max}), A-weighted sound level exceeded 10% of the time (L_{A10}), A-weighted sound level exceeded 50% of the time (L_{A50}), A-weighted sound level exceeded 90% of the time (L_{A90}), the equivalent sound level over the duration of the measurement, standard indicator in environmental acoustics (L_{Aeq}), Traffic Noise Index (TNI), Noise Pollution Level (NPL) and Noise Climate (NC), were recorded and analysed. The studied area exhibits high levels of road traffic noise, exceeding WHO (World Health Organisation) limits and, in some areas, Algerian standards. The NPL and TNI indices indicate a hazard to human health. Thus, acoustic comfort is significantly degraded in nearby recreational areas, and sidewalks as well as adjacent residential buildings are also adversely affected by this noise pollution. Users perceive the space positively if exposure to levels above 65 dB(A) remains brief. The study also shows a general trend in which perceived pleasantness decreases as exposure to higher noise levels increases. However, this relationship is not uniform: it varies significantly depending on the type of space and the associated patterns of use. The interaction between noise exposure and the context of use seems to play a decisive role in shaping perceptions. The findings of this research highlight the importance of considering not only average sound levels, but also their temporal dynamics, when assessing the sound environment.

Keywords:
sound environment, noise pollution, acoustic comfort, acoustic indicators

1. Introduction

Various problems, such as traffic congestion, air pollution, environmental pollution and noise pollution [1], are encountered in urban public spaces. As a result, the quality of these outdoor spaces has been gradually degraded by the persistent growth in vehicle numbers and the ongoing expansion of the road network.

Although users theoretically have priority in exercising their right to urban public spaces, in practice, due to population growth and technological developments, residents tend to spend much more time indoors, despite their need for outdoor spaces [2]. The user is uncomfortable in these spaces for the reasons mentioned above. Knowing that urban public spaces, and more particularly ordinary, everyday spaces, play an essential role in terms of keeping fit for city dwellers [3]; and knowing that walking is one of the practised physical activities in urban areas; they should therefore offer comfortable conditions and be an opportunity to encourage people to walk. At a time when lack of physical activity and obesity are emerging as major health issues, encouraging pedestrians to walk is essential. Thus, many benefits can be realised, including reduced motor-vehicle use. Various parameters are used to ensure pedestrian comfort in ordinary urban public spaces.

After air pollution and pedestrian safety (i.e., traffic accidents), noise is probably the most crucial comfort parameter [4,5]. For this reason, it is necessary to meet acoustic comfort criteria so that pedestrians can move around and use the space comfortably. Acoustic comfort conditions refer to creating a pleasant soundscape, as noise pollution is considered one of the most significant problems that disturbs people in densely populated urban areas.

Noise has various negative physical and psychological effects on human health (Table 1) [6-9]. It can damage hearing and have serious cardiovascular effects, and also affects speech intelligibility, mental health, performance, and social behaviour.

Noise pollution is reported as the third most important environmental pollution in metropolitan areas [10]. It has been indicated in various studies that a significant portion of noise-affected areas are along major transport links such as highways and railways [11-17] where noise levels alarmingly exceed prescribed levels.

In studies of environmental noise, it has been claimed that traffic noise is a major problem [18]. Other studies have concluded on the negative effects of traffic noise on human health as well as the relationship between environmental noise and health [19]; they have concluded that, in addition to air pollution, traffic noise is also an important environmental factor that has a significant impact on human health. Therefore, road traffic can be presented as the most important source of noise in cities, with the increase in the number of roads and boulevards crossing residential areas, creating traffic-induced noise that has negative effects on residents. Since correcting noise problems in existing situations is difficult and expensive, consideration of the noise environment should be given in the early phases of construction planning. Lessons must be drawn from studies conducted in areas where such difficulties have been encountered, and measures for future developments must be carefully evaluated. This research can serve as a reference for other studies and inform decision-making by stakeholders involved in the building process.

Table 1. The harmful health effects of different noise levels. Source: [6]

Noise level dB(A)	Health effect
140	Mechanical damage may occur to the ear for adults
120	Mechanical damage may occur to the ear for children
80	Increased risk of hearing impairment due to noise, increased aggressive behaviour
70	Minor hearing impairment with prolonged exposure to noise
65-70	Cardiovascular and physiological effects
60	Likely to bother most adults seriously
50	Likely to bother most adults moderately
45	Sleeping troubles

This work aims to characterise, quantify, and qualify the sound environment in urban areas in Algeria to better integrate noise-related issues into city planning and development. The traffic noise levels can then be analysed to identify the factors influencing them, thereby creating a resource for planning and/or designing future similar areas.

2. Materials and methods

2.1. Site selection

The present investigation was conducted between April and September 2021 and represents an evaluation and analysis of environmental noise pollution in Constantine. The city of Constantine, metropolis of the northeast of Algeria, is located at the eastern edge of the country with a population of about 938,475 [20,21] inhabitants and is situated between the two contour lines of 400 m and 800 m to the north and 800 m and 1200 m to the south. Constantine is an urban centre with a high population density, making it the third-largest city in the country.

The Boussouf district, the selected site for this study, is a contemporary urban area of the city of Constantine, built in the 1980s as part of the city's expansion. Boussouf is one of the outlying districts whose urban configuration follows the functional town-planning principles established by the Algerian planning authorities in 1970 (Fig. 1).

The site is predominantly residential. Its main boulevard, named Chahid Boussouf, is the district's heartbeat and the source of much of the noise, due to the numerous activities along it.

The noise observed at the site is primarily attributable to intense road traffic, which occurs predominantly during the day and persists almost continuously. This conclusion is based on a series of repeated observations and acoustic measurements conducted over several days at the same monitoring point, allowing for a reliable characterisation of the temporal dynamics of the ambient noise. These considerations underpin the selection of the study area. Namely, the site is situated on the main axis of the Boussouf district (Boulevard Chahid Boussouf), from which the majority of vehicles enter and leave, and where traffic, parking lots, and rest spots are mixed. This axis, a two-way road with sidewalks, is bordered by densely populated residential areas on both sides, with some facilities (e.g., a garden used as a playground and a parking space for nearby residents) (Figs 2-3).

The identification of the points P1, P2, P3, …, P15 of the measurement campaign is presented by the legend below:

- Pt.2 and Pt.3, measurement points taken Between Buildings (BeB).
- Pt.1, Pt.4 and Pt.5, measurement points taken on the Car Park (CP).
- Pt.6, Pt.7 and Pt.8, measurement points taken in the Garden (G).
- Pt.9, Pt.10 and Pt.11, measurement points taken on the Sidewalk Along the Boulevard (SAB).
- Pt.12, Pt.13, Pt.14, and Pt.15 measurement points taken at the Bottom of the Boulevard (BB).

Fig. 1. Location of the study area

Fig. 2. The studied area: general view. Source: own study

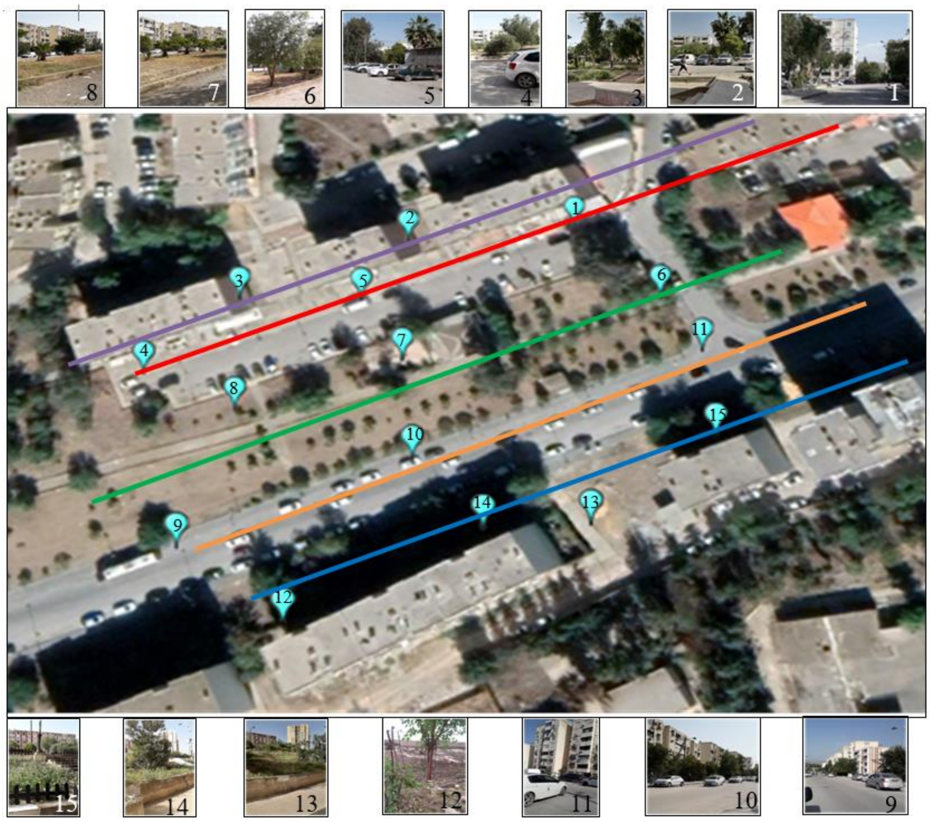

Fig. 3. Location of measurement points. Source: own study

2.2. Methodology

2.2.1. In situ measurements

In the study area, noise measurements were conducted across five zones: Between Buildings (BeB), Car Park (CP), Garden (G), Sidewalk Along Boulevard (SAB) and Bottom of the Boulevard (BB) in 15 different locations (Fig. 3). The noise level was measured not only at the edge of the sidewalk, but also in the relaxation area adjacent to the sidewalks, on the parking lot which the inhabitants also use as a gathering space because of the existence of commercial activities directly overlooking this space.

Noise measurements were also conducted below the roadway, in an adjacent area near residential buildings that is used as a playground by children and as a meeting place due to nearby commercial activities. Noise levels were then assessed to predict the extent of noise pollution and, consequently, the acoustic comfort around the boulevard of the Boussouf residential district.

The measurement points' locations, distributed evenly across the entire study area, were determined by pedestrian traffic density, and the area is residential. During the first phase of the study**,** we conducted acoustic measurements and sound recordings at the site. A limited set of acoustic indicators representative of the acoustic environments studied was subsequently derived from the collected data. In this study, the maximum and the minimum noise values (L_{max}) and (L_{min}), respectively, were recorded. The measurements were carried out keeping the sound source and the sound-measuring device at a height of 1.5 m ± 0.3 m above the ground, according to NF S 31-010 [22], and at a distance of at least 1 m from any reflective surface and 2 m from building facades. The measurement height was set to 1.5 m, corresponding to a pedestrian's ear level, with the phone placed at this height on an adjustable tripod. This height was verified with a standard measuring device before each recording to ensure consistent measurements across all locations.

The measurements were taken on seven favourable days (i.e., acceptable wind speed and absence of precipitation) for noise pollution using the open-source application "NoiseCapture". This application has, at best, a quality equivalent to that of a Class 2 device [23]. "NoiseCapture" is an Android application to assess the sound environment. Recent works have shown that the current characteristics of smartphones, which are close to class 2, could meet the requirements for assessing the sound environment [24-26].

It was created by researchers from the National Centre for Scientific Research (CNRS) and the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), which became Gustave Eiffel University on January 1st, 2020. "NoiseCapture" calculates acoustic indicators during the user's movements. It was developed within the framework of the European project ENERGIC-OD, a participatory initiative that brings together specialists in environmental acoustics and in geographic information sciences. The "NoiseCapture" application is, in fact, accompanied by a comprehensive information system that enables the storage, interrogation, analysis, and sharing of the collected data. It allows the collection of physical data (acoustic measurements, GPS positions, etc.) and perceptual data (a pleasant sound environment). Sound levels in octave bands from 100 Hz to 16,000 Hz, as well as the A-weighted equivalent sound level (L_{Aeq}), were recorded every second. The device was calibrated before each measurement.

Fifteen acoustic recordings of 5 minutes each were made with a Smartphone held in the hand at approximately 1.50 m above ground level. Simultaneously, acoustic measurements were conducted using the "NoiseCapture" application, complemented by observations of concurrent sound sources. Sound environment recordings were also made at all measurement points using a Sony ICD-PX333 recorder, with each recording lasting 30 seconds.

Noise measurements were made at the same height at three times during the day. The measurements were taken during rush hour, i.e., at 08:30 in the morning, at 12:00, and at 16:30 in the evening.

The physical data collected with "NoiseCapture" is listed below:

- The L_{Aeq}, is the equivalent sound level over the duration of the measurement, a standard indicator in environmental acoustics; this indicator is a temporal average of the sound energy.
- L_{A90}, A-weighted sound level exceeded 90% of the time. This indicator represents background noise.
- L_{A50}, A-weighted sound level exceeded 50% of the time. This indicator represents the average sound level.
- L_{A10}, A-weighted sound level exceeded 10%, characteristic of sound level peaks. This indicator is generally linked to road noise and is correlated with annoyance.
- Minimum (Min) and maximum (Max) of sound level $L_{eq,1s}$.
- RNE the distribution of noise exposure, which reflects the distribution of $L_{eq,1s}$ by sound level interval. As for its value, it is given by the "NoiseCapture" application.

All the data presented above were recorded simultaneously.

2.2.2. The types of acoustic indicators studied

The L_{eq} being an insufficient descriptor of annoyance caused by fluctuating noise [27], so more noise indices need to be calculated (i.e., NPL, NC, and TNI).

The Noise Pollution Level (NPL) is expressed in dB(A) using the following formula:

$$NPL = L_{eq} + a\left(L_{10} - L_{90}\right) \tag{1}$$

where: a = 1.0 (constant in the equation). The NPL accounts for variations in the sound signal and therefore serves as the best indicator of environmental pollution for physiological and psychological disturbances in the human system.

The Noise Climate (NC) is the range in which sound levels fluctuate over a time interval and is evaluated using the following formula [27]:

$$NC = \left(L_{10} - L_{90}\right) \tag{2}$$

Another important noise index to characterise noise pollution is the Traffic Noise Index (TNI), it is a parameter that determines the degree of variation in the flow of traffic in an area. It is also expressed in dB(A) and can be calculated using the following relationship [27]:

$$TNI = 4\left(L_{10} - L_{90}\right) + L_{90} - 30\ dB\left(A\right) \tag{3}$$

2.2.3. Statistical analysis

The analysis of measured noise levels generally shows that noise levels vary with factors such as time of day, the specificity of each area, road type, etc. Concerning the time of day, the measurements were conducted at various hours, leading to significant temporal variability in noise level. Regarding the measurement areas, we notice that they are of different shapes and serve different purposes, thus showing dissimilar "personalities". Finally, the roads varied in configuration, ranging from straight sections to intersections. To take into account the interaction of these variables in the analysis, the data obtained from the measurement campaign were submitted to a reliability analysis using the Modalisa 5.0 software [28]. Modalisa 5.0 is a data analysis software developed by the Kynos company. The software integrates a variety of functionalities within a single and coherent module. It allows the creation of questionnaires online or on paper, the dissemination and the collection of data, the transformation of variables, the codification of texts, and univariate and multivariate analyses. It also includes specific indicators, regressions, dynamic reports exportable to PowerPoint, maps, and the export and import of data in Excel and Text format [29,30].

The reliability analysis was unable to sort the data obtained during the campaign; unreliable data, as determined by standard significance thresholds, were rejected and not included in the calculations.

To determine the existence and statistical significance of these variations and tendencies, the data were analysed using a comparison of means and a *t*-test in the Modalisa 5.0 software.

2.2.4. Survey

This survey began in April 2021 and lasted 6 months. The interviews were conducted by asking a sample of 50 people present on site, passers-by, or residents, and focused on the socio-economic characteristics of the individuals and their perceptions of traffic noise. It is indeed a localised and static perception of urban sound phenomena. These people were asked about the sound environment in the study area. At the same time as the survey, sound levels in dB(A) are measured using the "NoiseCapture" application. The acoustic data thus collected will enable a quantified trace by comparing perceptual evaluations in the same space.

3. Results and discussion

Noise pollution was assessed and analysed at 15 locations in the study area. The noise data collected in these spaces shows a wide range of noise levels. The noise levels recorded during the day were compared with the Algerian regulatory noise level [31] and the WHO-stipulated level [32] (Table 2).

In Table 2, we summarise the limit values for environmental noise according to Algerian and WHO legislation. The environmental noise limit values adopted in this study correspond to the daytime period, as the measurement campaign was conducted during the day.

The sound level values collected during the measurement campaign are summarised in Table 3; the values presented correspond to the averages of the three periods of the day.

The L_{A10}, the L_{A50}, and L_{A90} values of the 15 points ranged from 60.3 to 96.3 dB(A), from 58.1 to 82.9 dB(A), and from 55.8 to 73.8 dB(A), respectively. Furthermore, the calculated values of L_{eq} (equivalent noise levels) ranged from 59.3 to 90.1 dB(A) (Table 3).

The NPL, NC and TNI were calculated using formulas (Eqs 1-3). Similarly, the NPL values of the different locations range from 62.9 to 112.6 dB(A). TNI values ranged from 41.1 to 133.8 dB(A), and NC values ranged from 2.2 to 22.5 (Table 4). All these values clearly show high noise levels, given that we are in a residential area and, furthermore, next to a relaxation facility, which in theory should be a quiet area.

The average noise levels are calculated from the fifteen points studied (Table 5). The observed mean value of 4.452 is lower than the theoretical absolute value and is not significant at the 5% and 1% significance levels. Thus, it is demonstrated that the noise levels of the different places do not differ significantly.

For the perceptual data collected with the "NoiseCapture" application, the scale of the level of pleasantness (L.P.) of the sound environment varies from 1 to 5 and reads as follows:

1 – Very unpleasant
2 – Unpleasant
3 – Moderately pleasant
4 – Pleasant
5 – Very pleasant

Table 2. Environmental noise limits values in Algeria, according to the WHO. Source: [31,32]

	Day time period (06h-22h) dB(A)	Night time period (22h-06h) dB(A)
Residential areas, in public or private roads and places (Algeria)	70	45
Hospital or educational establishments, and in rest areas (Algeria)	45	40
Road traffic noise (WHO)	L_{den} 53	L_{night} 45

Table 3. Noise level in dB (A) at different locations in the study area in Boussouf Constantine. Source: own study

Locations		$L_{eq,1s}$	L_{min}	L_{A90}	L_{A50}	L_{A10}	L_{max}	RNE/% in x-y interval			L.P
		dB(A)									
CP	Pt.1	67.9	63.2	63.3	66.7	71.2	71.8	27.3 in 55-65 [dB(A)]	72.7 in 65-75 [dB(A)]		3
	Pt.4	59.5	55.4	55.8	58.7	61.8	61.9	100 in 55-65 [dB(A)]			5
	Pt.5	64.9	58.8	58.8	61.2	66.8	73.2	93.8 in 55-65 [dB(A)]	62 in 65-75 [dB(A)]		4
	Avg.	64.1	59.1	59.3	62.2	66.6	69				
BeB	Pt.2	59.7	55.8	55.8	58.2	62.0	63.4	100 in 55-65 [dB(A)]			5
	Pt.3	71.5	56.4	56.6	65.8	77.3	77.5	40 in 55-65 [dB(A)]	13.3 in >75 [dB(A)]	46.7 in 65-75 [dB(A)]	5
	Avg.	65.6	56.1	56.2	62	69.6	70.4				
G	Pt.6	67.6	62.1	62.6	64.4	72.1	74	64.3 in 55-65 [dB(A)]	35.7 in 65-75 [dB(A)]		5
	Pt.7	73	64.4	64.6	66	78.8	81.1	64.7 in 65-75 [dB(A)]	23.5 in 55-65 [dB(A)]	11.8 in >75 [dB(A)]	4
	Pt.8	59.3	55.7	56.7	58.1	60.3	62.5	100 in 55-65 [dB(A)]			5
	Avg.	66.6	60.7	61.3	62.8	70.4	72.5				
SAB	Pt.9	73.7	65.3	65.6	70.3	77.1	81.6	89.5 in 65-75 [dB(A)]	10.5 in >75 [dB(A)]		2
	Pt.10	69.1	62.3	62.3	67.9	71.4	71.8	58.8 in 65-75 [dB(A)]	41.2 in 55-65 [dB(A)]		3
	Pt.11	90.1	73.7	73.8	82.9	96.3	97.4	88.2 in >75 [dB(A)]	11.8 in 65-75 [dB(A)]		1
	Avg.	77.6	67.1	67.2	73.7	81.6	83.6				
BB	Pt.12	61.9	59.8	59.9	60.6	62.1	65.4	94.7 in 55-65 [dB(A)]	5.3 in 65-75 [dB(A)]		5
	Pt.13	75.1	62.1	62.1	67.5	78.8	84.7	44.4 in 65-75 [dB(A)]	33.3 in 55-65 [dB(A)]	22.2 in >75 [dB(A)]	5
	Pt.14	64.2	60.3	60.3	62.1	66.2	66.2	76.5 in 55-65 [dB(A)]	23.5 in 65-75 [dB(A)]		5
	Pt.15	77.9	65.4	66.0	71.0	84.3	86.9	82.4 in 65-75 [dB(A)]	17.6 in>75 [dB(A)]		4
	Avg.	69.7	61.9	62.1	65.3	72.8	75.8				
Gen.Avg.		68.7	61	61.2	65.2	72.2	74.2				

Avg. – Mean value; Gen. Avg. – Overall mean value of all points; L.P. 1… 5 – Pleasantness level.

Table 4. Noise descriptors (TNI, NPL, NC) variations observed at different locations in the study area at Boussouf Constantine. Source: own study

Locations	Measuring points	NPL dB(A)	TNI dB(A)	NC dB(A)
CP	Pt. 1	75.8	64.9	7.9
	Pt. 4	65.5	49.8	6
	Pt. 5	72.9	60.8	8
	Avg.	71.4	58.5	7.3
BeB	Pt. 2	65.9	50.6	6.2
	Pt. 3	92.2	109.4	20.7
	Avg.	79	79.8	13.4
G	Pt. 6	67.6	70.6	9.5
	Pt. 7	87.2	91.4	14.2
	Pt. 8	62.9	41.1	3.6
	Avg.	75.7	67.7	9.1
SAB	Pt. 9	85.2	81.6	11.5
	Pt. 10	78.2	68.7	9.1
	Pt. 11	112.6	133.8	22.5
	Avg.	92	94.8	14.4
BB	Pt. 12	64.1	38.7	2.2
	Pt. 13	91.8	98.9	16.7
	Pt. 14	70.1	53.9	5.9
	Pt. 15	96.2	109.2	18.3
	Avg.	80.4	74.9	10.7
Gen.Avg.		79.7	75.1	11

Table 5. Comparison of noise level averages. Source: own study

Degree of freedom	Average observed	Population average	t-value	Probability
32	4.452	15	-58.253	0.001

4. Discussion

4.1. Average of the minimum sound levels L_{min}

The values of the noise levels obtained at the reference points after measurements are given in Table 3. From the analysis of this gathered data; we see that the lowest minimum noise level is 55.4 dB(A) at point 4 in the car park (CP), 55.8 dB(A) at point 2 (BeB), 55.7 dB(A) at point 8 (G), 62.3 dB(A) at point 10 (SAB) and 59.8 dB(A) at point 12 (BB). Considering the averages of the minimum sound levels of each group of points, it was found that the lowest average noise level was 56.1 dB(A) at BeB (Fig. 4). Furthermore, the overall average values of all minimum noise levels in the study area were 61 dB(A) (in dark green in Fig. 4).

The measured L_{min} values clearly exceed the World Health Organisation guidelines across all three measurement periods. Even for the garden, which is supposed to be a calm space, the L_{min} exceeds the limits set by both the World Health Organisation and the Algerian regulations for "recreational spaces".

In SAB, the highest hourly average L_{min} value 67.1 dB(A) was observed across all measurement periods. This elevated level can be attributed to the proximity of a dual carriageway. Traffic flow, including motorcycles, cars, and buses, generates intermittent noise, which is further amplified by activity in nearby densely populated residential areas.

When comparing the general average values of our study with the regulatory limits (i.e., Algerian regulations and WHO guidelines) for the daytime period, taking into account the different zone types (CP, BeB, G, SAB, BB), for the minimum levels, the general average value was 61 dB(A) (Fig. 4). This value is below the Algerian regulatory limit of 70 dB(A) for residential areas, roads, and public or private spaces.

In addition, the Algerian regulation stipulates that relaxation areas (Table 2) must have a value not exceeding 45 dB(A), and the general average value exceeds this level in zone G (Garden), which is a relaxation area. The WHO, for its part, stipulates a value of 53 dB(A) for road traffic noise; once again, the general average exceeds this requirement.

4.2. Average of the maximum sound levels L_{max}

The examination of the measurements for the fifteen points shows: the highest noise level is 97.4 dB(A) at point 11 on the sidewalk along the boulevard (SAB), 73.2 dB(A) at point 5 (CP), 77.5 dB(A) at point 3 (BeB), 81.1 dB(A) at point 7 (G), from 86.9 dB(A) at point 15 (BB). The highest average value of the noise level for each group of points is 83.6 dB(A) at SAB (Fig. 5). The general average values of all the maximum noise levels in the studied area are 74.2 dB(A) (in dark green in Fig. 5).

Figure 5 shows that the maximum general average sound level of 74.2 dB(A) exceeds all three reference limits. It is higher than the 70 dB(A) limit for residential areas and public or private roads, the 45 dB(A) limit for rest areas, particularly relevant to the garden area (G) and the 53 dB(A) guideline proposed by the World Health Organisation.

The value of the maximum average level should be assessed in relation to the negative effects of noise on human health.

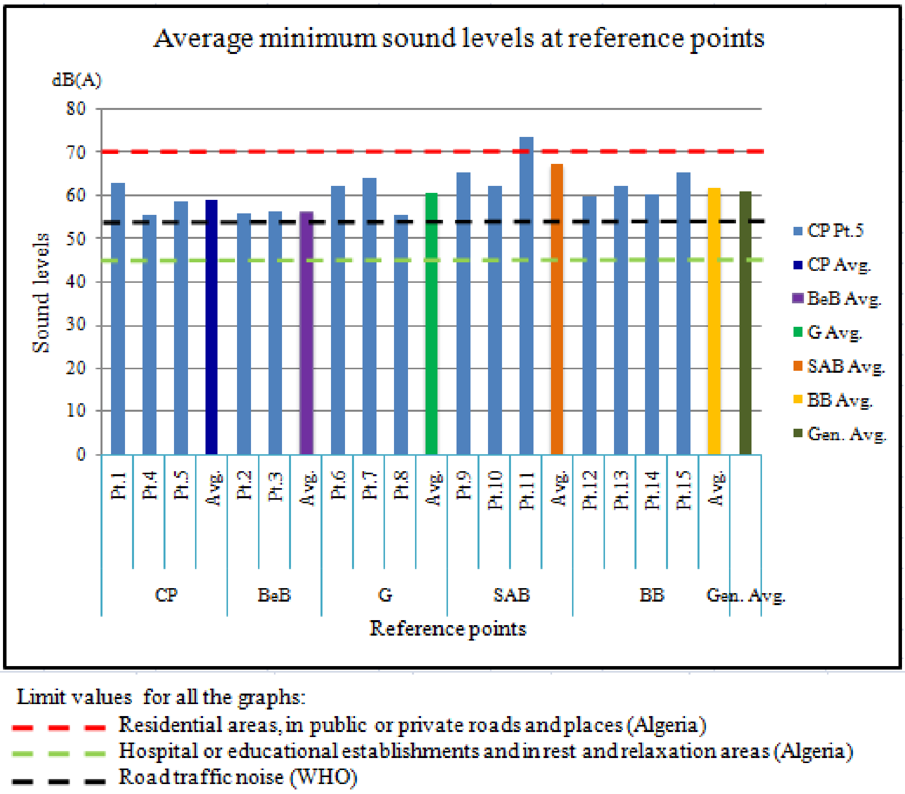

Fig. 4. Minimum Sound Pressure Levels. Source: own study

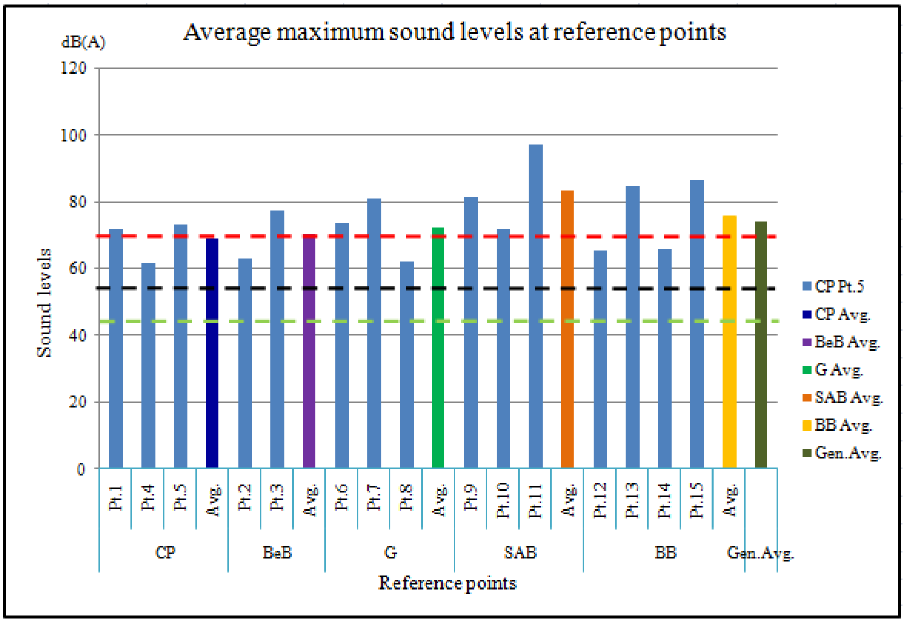

Fig. 5. Maximum Sound Levels. Source: own study

4.3. Average equivalent sound levels Leq

Among all the measurements for the fifteen points, the highest equivalent sound level is 77.9 dB(A) at point 15 at BB, except for the 90.1 dB(A) at point 11 at SAB, which is a road intersection always congested with traffic. The lowest equivalent sound level is 59.3 dB(A) recorded at point 8 at G. In contrast, the lowest average value, 64.1 dB(A), was observed at CP (Fig. 6). Overall, the mean equivalent sound level for the entire study area is 68.7 dB(A) (in dark green in Fig. 6).

As for the general average value of the equivalent level of 68.7 dB(A) (Fig. 6), the Algerian regulation is respected for residential areas, public or private roads, and places; on the other hand, it is exceeded for the relaxation area limit of 45 dB(A). For the WHO, the limit is exceeded.

From the calculations previously made, it can be seen that the average equivalent sound level of 68.7 dB(A) in the study area is very close to the limit value of 70 dB(A) set by Algerian regulations. But, although the calculated average equivalent noise level is below the limit of 70 dB(A), approximately 40% of the values recorded in the study area are above this level, as shown in the blue cells of Table 3, and approximately 7 % of these same values were above the average level of 68.7 dB(A). Therefore, over time, it is likely that the equivalent noise level will surpass the regulatory value.

According to Table 1, a noise level above 70 dB(A) can cause minor hearing damage with prolonged exposure. For our study, the brown cells of Table 3 (column L_{max}) show that about 67% of the values are above the value of 70 dB(A), and only 33% of the values recorded were below this level. Furthermore, it should be noted that between 65 dB(A) and 70 dB(A) cardiovascular effects can occur for prolonged exposure (Table 1). These health hazards, for instance, should be carefully considered, and measures should be taken to reduce the noise levels since human welfare is at stake. It would, for example, be necessary to re-examine the value of 70 dB(A) for the daytime period in the Algerian regulations.

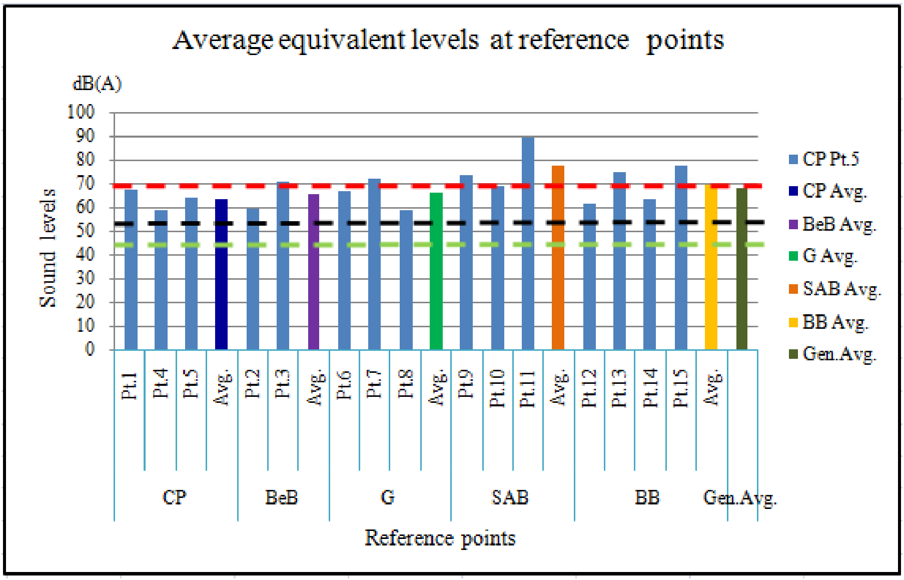

Fig. 6. Equivalent Sound Levels. Source: own study

4.4. Variation of percentile noise levels (L_{10}, L_{50} and L_{90}) at different locations in the study area

Table 3 shows the variation in the noise level indices L_{10}, L_{50}, and L_{90} across the different zones (BeB, CP, G, SAB, and BB) along the Boulevard Boussouf. The average noise level index L_{10} obtained in CP and BeB is lower than 70 dB(A), which is the recommended Algerian limit value, but remains higher than 53 dB(A), the limit recommended by the WHO.

For all the other zones, G, SAB, and BB, the average value of the L_{10} index is higher than the two recommendations (i.e., Algerian and WHO). However, the average Pleasantness level of the L50 and L90 noise level indices obtained across all zones was lower than the limit recommended by Algeria, except in the SAB zone, but remained higher than the WHO-recommended value. For zone G, a relaxation area, the average value of the L_{50} and L_{90} noise level indices also remains above the Algerian recommended limit (Table 2).

4.5. Variations in noise descriptors (NPL, TNI, NC) observed at different locations in the study area

For this study, the calculated values of Noise Climate (NC), the Traffic Noise Index (TNI), and the Noise Pollution Level (NPL) are shown in Figs 7, 8, and 9, respectively. The average variations of the Noise Climate (NC), the Traffic Noise Index (TNI), and the Noise Pollution Level (NPL) obtained at BeB, CP, G, SAB, and BB are also clearly shown on the same figures. Across all zones, we observe variations in the Noise Climate (NC), which are explained by differences in the activities that take place in each zone. We notice a surge in the mean NC in BeB, caused by the advent of children's voices in point 3, and in the BB zone, caused by a horn blow and human voices in points 13 and 15, respectively. The increase in the average NC value in SAB is mainly due to the incessant noise from vehicles.

Finally, the results show that both the minimum Noise Pollution Level (NPL) and the minimum Traffic Noise Index (TNI) values are below the Algerian standard limit of 70 dB(A). However, when compared with the World Health Organisation guideline of 53 dB(A), the minimum NPL value remains higher, whereas the minimum TNI value is lower (Figs 7-8).

However, the maximum values of both NPL and TNI exceed the applicable standard limits. Field observations during the measurement campaign indicate that noise generated by fast-moving traffic exhibits different characteristics from that produced under congested or slow traffic conditions.

Noise from congested traffic was found to contain occasional spikes and to vary in level. A systematic comparison between the average TNI and L_{eq} noise levels for all selected locations revealed that, in general, the TNI values were much higher than the L_{eq} levels (Fig. 10). Otherwise, all NPL values are greater than L_{eq} (Fig. 10). The cross-analysis of the indicators reveals strong internal consistency among the measured levels.

The general average L_{eq} of 68.7 dB(A) reflects a high sound level. On the other hand, the general average of Noise Climate (NC), at 11 dB(A), indicates that noise fluctuations are limited, suggesting that the acoustic environment is dominated by a relatively stable, continuous noise source. The general average of the TNI value of 75.1 dB(A) indicates regular, but not sharply pronounced, sound peaks. The NPL value of 79.7 dB(A), the highest among them, incorporates both the average level and the fluctuations, thereby characterising the overall perceived noise annoyance.

This configuration –Leq< TNI < NPL– is typical of an environment where road traffic is the dominant source, producing a constant energetically high and weakly fluctuating noise. Together, these indicators converge toward a diagnosis of a highly constrained sound environment, likely to generate significant noise annoyance due to its sustained intensity and persistent character.

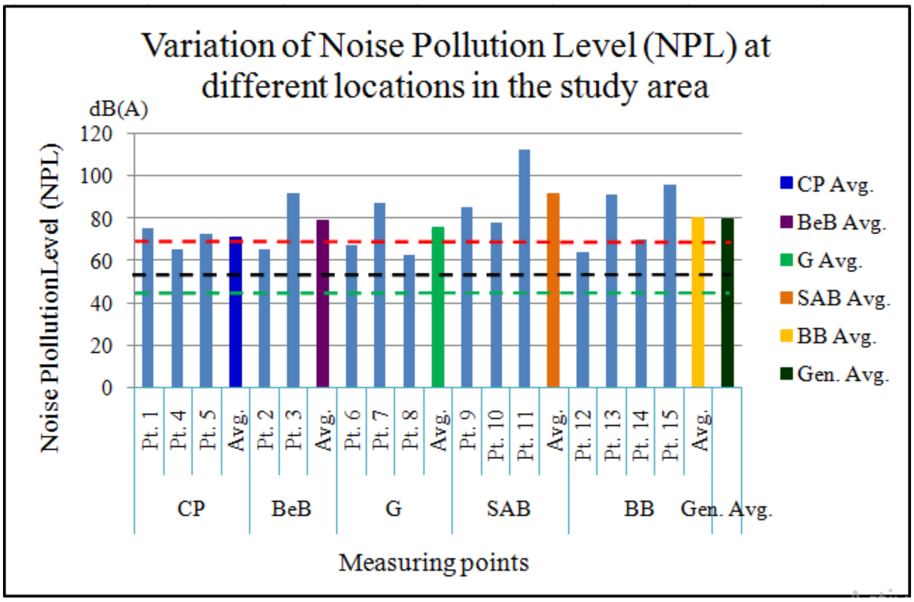

Fig. 7. Variation of noise pollution levels (NPL). Source: own study

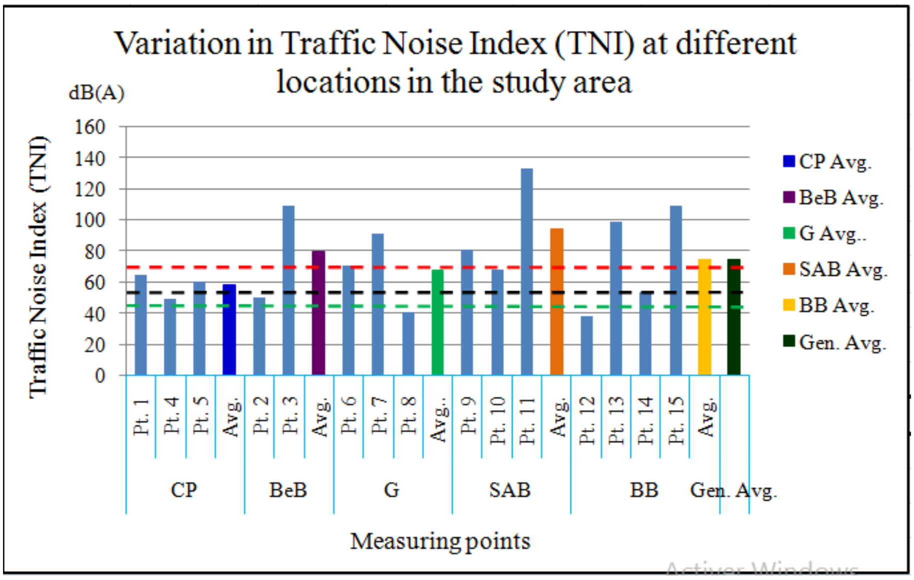

Fig. 8. Traffic Noise Index (TNI) variation. Source: own study

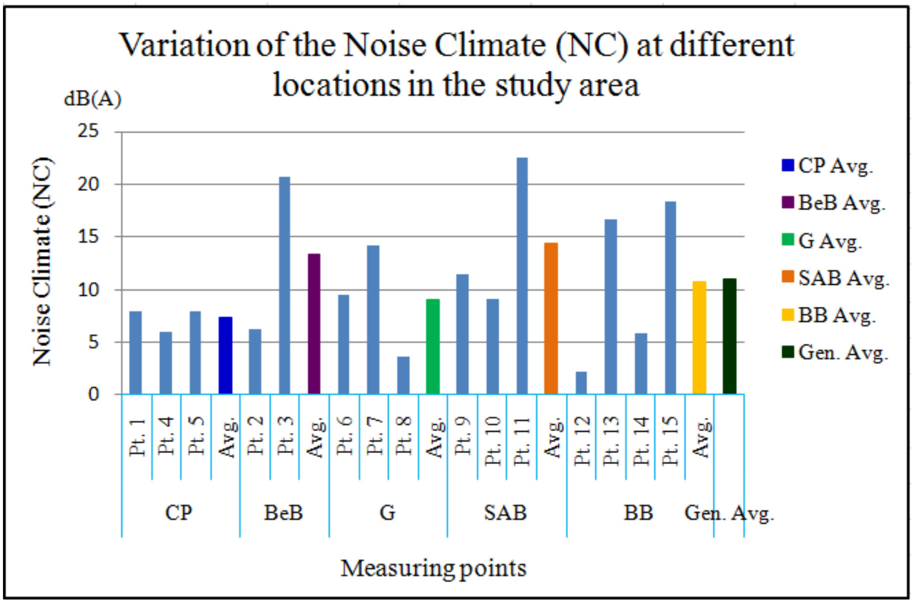

Fig. 9. Variation in Noise Climate (NC). Source: own study

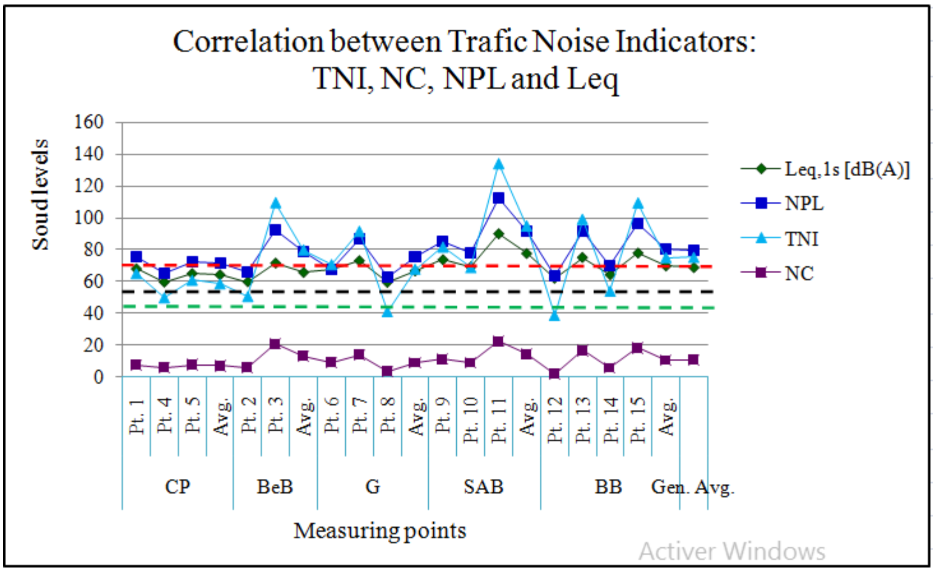

Fig. 10. Noise Correlation between Traffic Noise Indicators (TNI, NC, NPL, and L_{eq}). Source: own study

These results demonstrate that although noise levels at a given location are generally stable, a single noise event can influence the different noise percentile levels and, consequently, the TNI. This effect is largely associated with congested roads, limited traffic management, and inappropriate driver behaviour, particularly excessive horn use. In addition, human voices were observed to contribute to variations in the percentile noise levels.

5. Discussion on the survey

During the author's 2021 measurement campaign, a questionnaire survey was also conducted among local residents to gather information on their perceptions of the sound environment at the study site. The survey results show that 70% of the population tested feel bothered by the noise at home, and only 30% are not "at all" bothered; these are generally the inhabitants of accommodations on the top floors. Respondents who reported being disturbed by noise identified two main sources of nuisance: road traffic, cited as the primary source by 80% of participants, and neighbourhood-related noise, including daily activities, work-related sounds, and barking dogs.

To correlate the survey conclusions with the noise exposure level, it would be interesting to use the qualitative parameter 'the level of pleasantness' and cross-reference it with the distribution of noise exposure levels. As illustrated in the yellow cells of Table 3 (column: RNE/%), the sound level at most points is between 65 and 75 dB(A) and sometimes exceeds 75 dB(A).

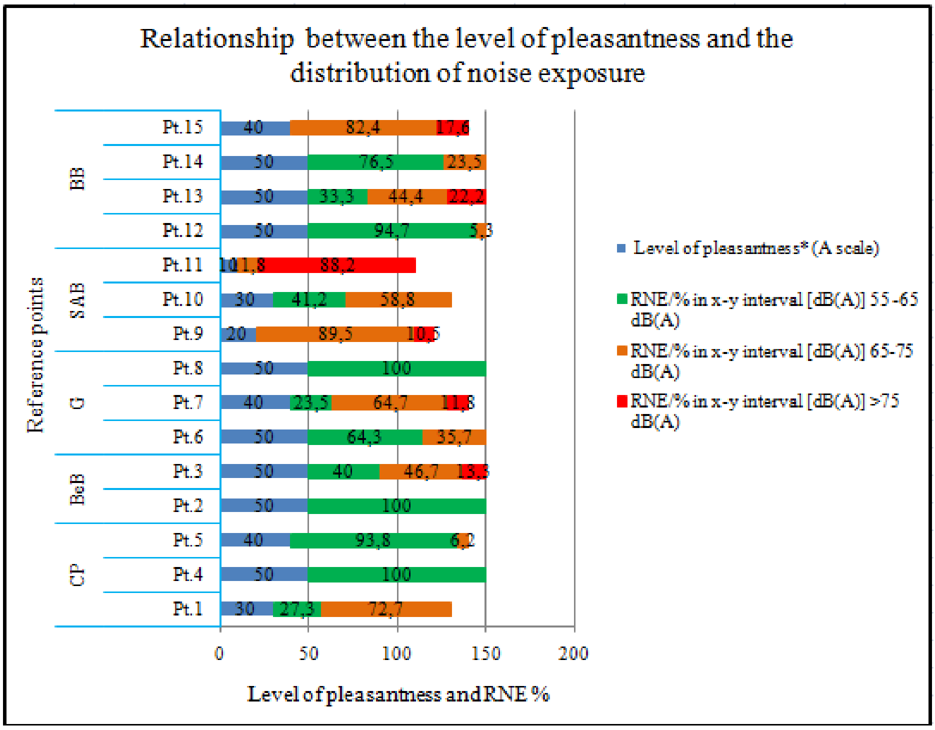

Fig. 11. Relationship between perceived pleasantness and noise exposure distribution. Source: own study.
(N.B. *for ease of interpretation, the pleasantness scale was multiplied by a factor of 10 to improve the readability of the graph

The time of exposure to noise influences the perception of space users from a sound comfort perspective [33,34]. However, the interaction between noise exposure and the context of use appears to be decisive in explaining the pleasantness levels observed in some typologies. In the Garden (G), the presence of natural elements and users' positive expectations requalify the sound environment, allowing for high pleasantness levels despite exposure sometimes falling within the 65–75 dB(A) range.

In the space between buildings (BeB), residential familiarity, the social nature of activities, and the diffusion of sound shaped by the built form all help to mitigate the perception of annoyance.

Finally, in (BB), everyday activities and local sociability make road traffic noise less salient, fostering greater tolerance.

These results show that pleasantness does not depend solely on measured sound intensity but arises from a contextualised perceptual process in which use, morphology, and the social valence of sounds play major roles (Fig. 11).

6. Conclusion

The study results indicate a traffic noise problem in the study area. If we consider, for example, the minimum general average value of 61 dB(A), the observed level is significantly above the limit of 53 dB(A) specified in the WHO regulations. However, under Algerian regulations, this value is within the standards. In addition, the minimum average noise level in the relaxation area is 60.7 dB(A), which exceeds the 45 dB(A) limit stipulated by Algerian regulations.

Our study shows that the general average equivalent noise level in the investigated area is lower than the limit values of Algerian regulations but higher than the WHO limit values. It should be noted that the general maximum average noise level of 74.2 dB(A) obtained is hazardous to human health. Therefore, measures should be taken to reduce the noise intensity in the study area. Based on this study, it is recommended that measures be taken to ensure acoustic comfort in areas affected by noise pollution. It also emerges from this study that the user perceives the space positively when exposure to levels above 65 dB(A) is brief. The above conclusions were drawn from results obtained without long-term and time-weighted measures, which require hours of noise measurements over weeks or months.

The equivalent A-weighted sound levels vary from 59.3 to 90.1 dB(A) while the L_{A50} percentile level varies from 58.1 to 82.9 dB(A); these values are relatively high, indicating a rather unfavourable sound environment in the studied area. The level of background noise, estimated by the fractile level L_{A90}, varies between 55.8 and 73.8 dB(A), and it appears that the noises of mechanical origins, in particular the engines, are present on the site, and this via the regular passage of vehicles (i.e., cars, motorised two-wheelers, buses). The continuous presence of mechanical noise introduces a background noise exceeding the WHO-recommended 53 dB(A), regardless of the area we are in.

The dynamic remains moderate on this site. Indeed, the Noise Climate (NC) is, on average, 10.98 dB(A), with a maximum of 22.5 dB(A) due to a road intersection. The measured average NPL values for our site are higher than both the Algerian and WHO standard values (Table 4 – Fig. 7). Generally, NPL values are good indicators of environmental pollution and indicate a risk of physiological and psychological disturbances for humans. For the TNI, the obtained average values are also higher than the Algerian standard except for CP and G, and are higher for all of them than the value recommended by the WHO (Table 4 – Fig. 8). The TNI indicates the degree of variation in the flow of traffic in the studied site. The high noise pollution level (NPL) and traffic noise index (TNI) clearly indicate high noise levels at the studied site throughout the day, posing a serious problem that must be taken into consideration.

Based on this research, measures should be taken to control noise in the study area and generalised to the whole neighbourhood to ensure a healthy environment for residents. We also recommend that Algerian regulations be revised to align with WHO regulations. The values for residential areas, public or private roads, and places should be amended for the day period.

As for the level of pleasantness, an inverse relationship is observed between its level and the exposure to the highest noise levels, but this relationship varies according to the type of space and its associated uses, as seen in graph 11. The findings helped clarify the understanding of the interaction between noise exposure and the context of use. These parameters appear crucial for understanding the levels of pleasantness observed across the studied typologies.

This research highlights the importance of an integrated approach combining acoustic measurements and perceptual indicators and highlights the need to control exposure levels to improve sound pleasantness in public spaces.

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