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Noise contamination and automobile traffic along the Mexican frontier

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Abstract: Objective: The aim was to establish a correlation between the noise levels at major road intersections and the volume of vehicles passing through these areas. **Method:** A non-invasive electronic vehicle sound level meter was used for one-week periods; noise levels were assessed on a daily basis throughout the week, utilizing type I integrating sound level meters. **Results:** An annual average daily traffic volume of 2739 vehicles was recorded; an estimated noise level of 77.6 decibels for 12-hour spans was observed; peak noise levels reached 98.5 decibels, with the lowest recorded level at 58.3 decibels. Constraints: The fieldwork was conducted over a period shorter than one year, which may limit the comprehensiveness of the findings. **Main findings:** The city's noise levels surpass the World Health Organization's recommended threshold of 65 decibels, indicating that the city is experiencing noise pollution as a result of vehicular traffic.

Keywords: pollution; noise; traffic; sound

1. Introduction

The quality of the environment can be altered by different risk factors; for example, biological, chemical and/or physical. Noise is an agent that ranks among the physical risk factors, along with vibrations and temperature. Noise pollution is one of the least valued, however, it generates a negative impact on the quality of life of exposed people [1]. According to reports from the World Health Organization (WHO), this phenomenon should be considered a public health problem in the modern world, particularly in cities with large populations and limited or confined spaces [2–4]. The noise produced by traffic is an aggressor agent of human health, it is considered that internationally about 40% of the population is exposed to levels above 55 dB and this percentage increases in underdeveloped countries [5,6].

The production of noise can be attributed to the rapid increase in industry, infrastructure of transportation systems whether railroads, airports and roads [7–9]. In addition, it should not be overlooked that noise is easily produced, which potentiates its penetration capacity, this means that it can be detected in different areas, such as residential, recreational and leisure areas, commercial and industrial areas, i.e., as the population concentrates in a certain area, depending on the type of activities performed, the presence of noise also increases [10].

The degradation of the environment in urban environments due to noise can have different sources, but most of the time vehicular traffic is considered as the main cause [3,11]. The findings of some authors such as Gündođdu et al. [12], as well as Li et al. [13] have pointed out that it is not a phenomenon exclusive to developed countries, but also to developing countries, it is a danger to environmental health and should be addressed in the cities that suffer from it. Especially in those

countries and cities where urban spaces are concentrated and the authorities lack management systems that facilitate the implementation of planning processes in the face of development. Such statements make it possible to define that the situation of noise pollution caused by vehicular traffic represents a complexity for the authorities responsible for environmental and urban management [13].

There is some research that associates the presence of noise produced by vehicular traffic and the damage it causes to health, mainly in urban areas, showing that the effects can be grouped into four categories: auditory, physiological, psychological and finally, those that affect people's performance [7]. In particular, the most frequent symptoms include: alterations in people's behavior such as nervousness, irritability, lack of concentration, interruption of sleep, and even the appearance of high blood pressure [5]. It is important to emphasize that exposure to noise does not only imply hearing loss, but also other pathologies of which individuals are not aware of their cause, which implies the need to explore new lines of study around noise exposure.

The way to address the issue of noise exposure involves a very particular approach and analysis, for example, in a punctual way in the generating sources, through the use of predictive simulators which take into account the shape of the street, green areas, density of constructions, position and shape of buildings; and by means of surveys that evaluate human response [14–16]. To obtain an assessment of noise pollution in cities, it is necessary to perform a measurement of the noise generated by vehicle traffic, this includes engine noise and the friction generated by tires on the surface [17]. The measurement can also include some additional characteristics such as the number of vehicles and their type, as well as the average speed at which they circulate [18]. The determination of the noise level can have different scenarios and it will depend on the researcher the choice of the evaluation method to be used.

While it is true that the noise levels generated by a vehicle have not presented great changes since a few decades ago, it is preponderant to point out that, what has changed is the amount of vehicles that are circulating in the city [19].

To take into consideration vehicular traffic as a determinant in the presence of noise, it is important to know the level of vehicular traffic in an area. This activity implies making a decision regarding the type of observation to be carried out. The first option is permanent gauging, i.e., when the measurement is carried out every day of the year. In the second type, the measurement is carried out only during some days of the year, usually during one week; this methodology is known as weekly base weekly gauging. The result of the observations, in either case, is used to make estimates: annual average daily traffic, maximum or minimum, passing through a given point on a highway [20]. Based on the traffic estimates and according to the classification of roads established by the Mexican Secretariat of Communications and Transportation [21], the type of roadway can be determined. **Table 1** describes the six categories classified according to speed and Annual Average Daily Traffic (TPDA).

Table 1. Classification of roads.

Type of kettle	Speed km/h	TPDA
Highways	80 to 110	>5000
Fast lanes	80 to 110	3000–5000
Secondary	70 to 110	1500–3000
Collector	60 to 100	500–1500
Premises	50 to 80	100–500
Gaps	30 to 70	<100

Source: Recommendations for updating some elements of the geometric design of roads [21].

In Mexico, environmental authorities at different levels of government have proposed and established laws to curb noise pollution. However, the effort has not been sufficient, since the regulatory framework lacks methodological and technical aspects that involve the community in general and not only institutions or businesses. The particular case of the Mexican Official Norm 081, which establishes the maximum permissible limits of noise emission from fixed sources and its measurement method, published in 1995, which presents a modification in the maximum permissible limits [20], but still considers only noise emitted by fixed sources leaving aside other activities that take place in public places, open spaces or roads. Likewise, such regulations are used by state and local authorities to address citizen complaints and grievances, due to the absence of other types of regulations with greater specificity. This forces governmental and private environmental managers to be subject to a method and values that probably do not correspond to their activity.

Another aspect to take into account are the regulations that address the noise produced by the exhaust ducts of means of transportation: motorcycles, motorized tricycles and automobiles; which describe certain procedures for their evaluation, but present a methodological weakness, since the measurement is carried out in specialized verification centers, in situations and conditions different from the daily use of the vehicles or the conditions of the roads.

This study has its origin in the research project: “Urban noise and its effects on the population of Matamoros, Tamaulipas”. The objective is to establish a relationship between the noise level generated in the main road corridors and the number of vehicles traveling in the city of Matamoros, Tamaulipas, Mexico.

2. Methodology

The study was developed in the city of Matamoros, Tamaulipas, in the Northeast region of Mexico. The city has a geographical extension of 4632 km² and the population is made up of a total of 520,367 people, according to the report presented in 2015 by the National Institute of Statistics and Geography. While it is true that the figure barely exceeds half a million inhabitants, it is necessary to emphasize that such information reflects only and exclusively people who have a fixed address, and, therefore, live permanently in the city. This figure does not include all those people who arrive for migratory reasons and who represent a floating population of around one million people, of whom there is no precise census.

The vehicle fleet is in a similar situation, since records indicate a total of 144,113 motor vehicles; however, the number may at least double due to the large number of vehicles coming from the United States. These vehicles have U.S. owners who constantly cross the border for leisure, work and/or business. Another large number of foreign vehicles are part of the informal economy in the city and the number may far exceed official records due to the lack of controls over these.

Data collection, as part of the field work, was carried out in the period from April to September 2016. For the selection of the evaluation zones, the inclusion of those places with houses within a diameter of one kilometer was considered. Data collection required two activities: the first consisted of a vehicular gauging, and the second, in the evaluation of daytime noise levels.

2.1. Vehicular traffic

In order to understand the way in which a particular phenomenon is presented and developed, it is necessary to describe it from its universe as a whole. Based on this premise, the behavior of vehicular traffic requires obtaining information with the instrumentation of continuous gauging throughout the year, however, this represents a difficulty in the development of urban studies due to the high cost involved in the installation of monitoring points for prolonged periods. One way of resolving this type of conflict is to obtain traffic samples that allow the elaboration of calculations to generalize the behavior of the population [22].

In order to determine the existing traffic on each of the roads, a vehicle gauging was performed by installing a non-invasive Traffic Logix gauging device. With the information obtained, we proceeded to estimate the Average Daily Weekly Traffic (TPDS), which represents the average daily traffic value and is obtained based on a week's traffic. The calculation is based on that established by the Ministry of Communications and Transportation and the mathematical expression is defined by Equation (1).

$$TPDS = \frac{TS}{7} \quad (1)$$

where:

TPDS = Weekly Average Daily Traffic.

TS = Sumulative weekly traffic [20].

Subsequently, TPDA was estimated using the procedure proposed by Reyes and Cárdenas [22], using Equation (2).

$$TPDA = TPDS \pm KE \quad (2)$$

where:

TPDS = Average daily weekly traffic.

K = Product of the number of standard deviations (s) by the confidence level (1.96).

E = Standard error of the mean.

The standard deviation was determined by Equation (3).

$$S = \sqrt{\frac{\sum_1^n (TD_{ip} - TPDS)^2}{n - 1}} \quad (3)$$

where:

TD_i = Transit volume of the day.

The standard error of the mean was obtained using Equation (4).

$$E = \frac{S}{\sqrt{n}} \left(\sqrt{\frac{N-n}{N-1}} \right) \quad (4)$$

where:

S = Standard deviation of traffic volume distribution.

n = Sample size in number of days of the gauging.

N = Population size in number of days of the year [22].

2.2. Daytime noise

The evaluation of the noise level was carried out during the seven days of the week, the data collection considered three different periods throughout the day, with a duration of one hour. The noise recording was carried out during four intervals of 15 min each, which allowed the equipment to be located at the four cardinal points of the intersection, thus completing each one-hour period. Class I integrating sound level meters were used in this process, with their respective field calibrators; both the sound level meters and the acoustic calibrators were verified by an environmental testing laboratory.

During the location of the measuring equipment, it was ensured that they were placed at a minimum distance of at least two meters from any facade or surface that could reflect sound. In addition, the installation height of the tripods supporting the sound level meters was four meters. The evaluation parameters obtained by programming the sound level meters were: daytime equivalent continuous sound pressure level in the 12-hour time interval (L_{day12}), the maximum sound level (L_{max}), as well as the minimum sound level (L_{min}) [23]; the retrieval of the measurements stored in the instruments was by connecting to a computer, through the Quest Suit Pro II software.

Additionally, field personnel ensured compliance with ISO Standard 1996-1 2016, description, measurement and evaluation of environmental noise, where the weather conditions at the time of measurement are established: absence of rain and thunder; as well as anemometers were used to determine that the wind speed was less than three meters per second [23], in cases where different situations were present, the measurement was omitted.

3. Results

Table 2 shows the results of the vehicle counts performed, the weekly traffic volume and the TPDA estimators; it is worth mentioning that, during the field work, three road intersections (15%) were discarded because maintenance work was being carried out on the storm drainage system, as well as road reconstruction activities. Through this activity it was possible to identify that, at least among the selected areas, 11 intersections were found (55%) with a TPDS higher than 1500 vehicles.

Table 2. Description of traffic in circulation.

Location	TPDS	±K9	TPDA _{max}	TPDA _{min}
Ave. Cavazos Lerma and Calixto Ayala	1733		1848	1617
Ave. Cavazos Lerma and Virgilio Garza	2091		2247	1935
Virgilio Garzay Mexicali	1170	99	1269	1071
Ave. Constituyentes and 12 de marzo	1652		1737	1568
Ave. Constituyentes and Sendero Nacional	1830		1956	1704
March 12 and Sendero Nacional	1723		1832	1614
Rigo Tovary Ave Rigo Tovary National Trail	ND	ND	ND	ND
Ave. Cavazos Lerma and Cuauhtémoc			2112	1805
Sixth and Cuauhtémoc	2484		2739	2228
Sixth and Gonzalez	1288		1401	1175
Ave. Avaro Obregón and Sexta	ND	ND	ND	ND
Ave. Cavazos Lerma and Sexta	2422	212	2634	2210
Ave. Cavazos Lermay Ave. Del Nino	ND	ND	ND	ND
Ave. Cavazos Lerma and Roberto Guerra	1455		1565	1344
Ave. Lauro Villar and Acción civica.	2318	292	2610	2025
Ave. Lauro Villar and Francisco Villa	1933		2073	1793
Ave. Lauro Villary Roberto F. Garcia	1486	92	1577	1394
Ave. Lauro Villar and Primera	1344	132	1477	1212
Marte R Gomez Ave. and 12 de marzo	933		1062	805
Marte R Gómez Ave. and Pedro Cárdenas Ave.	2193		2326	2059

Source: vehicle gauges, own elaboration.

Table 3. Daytime noise level.

Location	TPDA _{min}	dB _L _{day}	dB _L _{min}	dB _L _{max}
Ave. Cavazos Lerma and Calixto Ayala	1617	77.4	72.3	87.34
Ave. Cavazos Lerma and Virgilio Garza	1683	74.5	58.7	98.5
Ave. Constituyentes and 12 de marzo	1568	73.5	65.5	84.1
Ave. Constituyentes and Sendero Nacional	1502	72.3	59.1	97.8
12 de marzo and Sendero Nacional	1614	71.5	62.3	89.3
Ave. Cavazos Lerma and Cuauhtémoc	1558	77.6	58.9	95.8
Sexta and Cuauhtémoc	1813	75.6	61.3	96.8
Ave. Cavazos Lerma and Sexta	1866	75.6	58.3	97.9
Ave. Lauro Villar and Acción Civica.	1550	72.1	59.7	-
Ave. Lauro Villar and Francisco Villa	1568	71.7	58.6	86.7
Marte R Gómez Ave. and Pedro Cárdenas Ave.	1845	74.8	60.4	95.2

Source: Type I integrating sound level meter, own elaboration.

As part of the field work activities, those streets and avenues were selected with TPDA min estimates of between 1500 to 3000 vehicles, considered as arteries or secondary roads, with a small route and although the Secretary of Communications and Transportation mentions that they could have a speed limit in a range of 60 to 110 km/h, the speeds ranged between 20 to 60 km/h as maximum. Noise

measurements were obtained at each of the selected locations. **Table 3** shows the results.

The results generally show that in all zones the L_{day12} parameter exceeds 65 dB. The minimum value reaches 58.3 dB and the maximum value 98.5 dB. It is important to note that, according to WHO recommendations, environmental noise during the day should not exceed 65 dB, to avoid damage or disorders that people could suffer, especially those who are constantly exposed [4]. In Mexico, the agreement to modify the Mexican Official Standard 081, published in 2013 establishes that, for spaces dedicated to the residential sector, there will be a maximum permissible limit of 55 dB, while industrial and commercial areas, may reach 68 dB, and finally, in school areas may reach 55 dB, during recreational activities. The results of the field work for the assessment of noise levels in the previously selected areas show that in all cases the recommended values are exceeded.

4. Discussion

The existing studies that address the problem of noise present the perspective of interest of those who develop them, in some cases, address the problem in the workplace; others are oriented to the design and formulation of environmental policies on noise pollution; some, through the design of urban maps and others, seek to confirm and discover the effects that noise produces on the exposed population.

The review of different authors allows the development of a frame of reference in relation to the strategies for measuring noise, some use methodologies established by law, but many others propose a method that helps to redefine the established levels. Such is the case of the study carried out in the city of Medellin, Colombia, where they identified that in 15 of the 16 points evaluated (94%) 65 dB are exceeded [24]. In a similar way, it was observed in the present study that in all the measurement points this value is exceeded. This means that at least in the aforementioned areas there is an environmental health problem, but other roads with traffic of close to 1500 vehicles per day cannot be ignored. A similar situation occurs in Cochabamba, Bolivia, where they recorded, evaluated and presented the noise levels to which the population is exposed, prepared noise maps and defined that at least 75% of the city has noise pollution levels [25]. In this type of case, it is important to consider the characteristics of invasion and depth of the noise.

In Cuba, a simulation model was developed in the city of Havana, which made it possible to determine the noise level of vehicular traffic. Based on this model, values higher than 68 dB were determined during the day, which reflects an alteration of environmental quality due to noise pollution [26]. A similar study was conducted in the city of Bogota, Colombia, in which it was concluded that environmental noise is mainly caused by road corridors, where it can be observed that they exceed 70 dB, also determining that it is not only produced by the number of vehicles but also by the type and characteristics of the vehicles that travel there [27].

In the city of Chihuahua, Mexico during 2013, a study was conducted in road accesses finding that in 100% of the 64 measurement points 65 decibels were

exceeded [28], results almost identical to those found in the present study. This shows that the noise level is related to the vehicles traveling on a given road, and that the noise levels exceed the parameters established by the World Health Organization.

The work presented mainly presents the limitations of the assessment of vehicular traffic in a partial manner, subject to a period of five months, as well as the noise was evaluated only during the daytime period. Other variables that could influence the results and that were not considered are: soil characteristics and vehicle speed. However, the results do not contradict the existing evidence which demonstrates that the evaluations in short periods allow associating the noise level with the amount of vehicular traffic circulating on a given road without finding differences in the results of long-term evaluations [29].

5. Conclusions

It cannot be ignored that means of transportation are of great utility, even becoming a reference of the modernity of today's societies, what is transcendental implies that these means of transportation have the best scenarios to achieve their best performance.

The noise levels reached are directly related to vehicular traffic, so it is necessary to promote and inform the exposed population about this risk factor. In this sense, the intervention of health and environmental authorities becomes necessary, since the establishment of actions that favor the reduction of noise levels depends on them. One of these actions could be the establishment of regulations, accompanied by mechanisms to monitor compliance, mainly because in Mexico there is a lack of laws regulating the noise generated in cities.

Developing and implementing appropriate policies would allow the city to improve its urban growth strategies. Of great help in reducing noise would be the development of new road corridors to free certain areas from traffic, reorient traffic, improve the structure of street surfaces, verify vehicle conditions to ensure optimal operation, promote with experts the development of studies, as well as methodologies that allow establishing the actual noise conditions in certain spaces.

The population also plays an important role, as they need to be aware of this risk factor and the consequences of exposure to noise, how to protect themselves, but mainly, how to avoid generating loud noises, which is why information and awareness programs are required.

Finally, the results only present the pollution generated by vehicular traffic noise; therefore, the studies should be expanded to other parameters, such as community noise, noise in plazas and shopping centers; noise maps should be drawn up and the nuisance caused by noise on the population in general should be assessed. This will provide a more in-depth understanding of noise pollution and its effects.

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Notes

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