

PROXY-BASED ZONING

OF URBAN NOISE-EMITTER INTENSITY USING WEIGHTED GIS OVERLAY: A CASE STUDY OF TEPIC, MEXICO

ZONIFICACIÓN BASADA EN PROXIES DE LA INTENSIDAD DE EMISORES DE RUIDO URBANO MEDIANTE SUPERPOSICIÓN PONDERADA EN SIG: UN ESTUDIO DE CASO EN TEPIC, MÉXICO

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ABSTRACT

Assessing environmental noise in cities is an important challenge since it requires time, trained personnel, and specialized equipment. This paper proposes a pre-zoning proxy framework; acoustic levels are not measured in this version. It is based on the definition of five zones, maintaining the regional representativeness of the information, achieved through the overlay of six indicators of environmental noise sources. This procedure will allow for monitoring an area through field records and replicating this behavior in similar unmonitored areas. The study was conducted in Tepic, using $n=213$ Agebs (Basic Geostatistical Areas), 6 indicators, and the weighted overlay technique, generating 5 categories of noise intensity as a result.

Keywords:

City, indicators, environmental noise, zoning.

RESUMEN

La evaluación del ruido ambiental en las ciudades representa un desafío importante, ya que requiere tiempo, personal capacitado y equipo especializado. Este trabajo propone un marco de prezonificación basado en proxies; en esta versión no se realizan mediciones acústicas directas. El enfoque se fundamenta en la definición de cinco zonas, manteniendo la representatividad regional de la información, lo cual se logra mediante la superposición de seis indicadores de fuentes de ruido ambiental. Este procedimiento permite monitorear un área a través de registros de campo y replicar este comportamiento en zonas similares no monitoreadas. El estudio se llevó a cabo en Tepic, utilizando $n=213$ AGEB (Áreas Geoestadísticas Básicas), seis indicadores y la técnica de superposición ponderada, generando como resultado cinco categorías de intensidad de ruido.

Palabras clave:

Ciudad, indicadores, ruido ambiental, zonificación

INTRODUCTION

Environmental Noise (EN) is considered one of the main environmental risks to health and wellbeing (European Environment Agency, 2020), and that is not only environmental discomfort but also a public health problem for the modern world (European Environment Agency, 2025). Environmental noise can be defined as all unwanted and harmful outdoor sound from human activities, such as transportation (i.e., road, rail, and air traffic) and industry (Khomenko et al., 2022).

EN is an important problem with a growing presence in modern society, where the sources that generate noise are a part of everyday life in the city. Nevertheless, it has not received adequate attention since its effect is not immediate. Among the environmental pollutants, noise is the cheapest and it needs just a little energy to be emitted; it is hard to quantify and its measuring is complex. Noise is in specific places, it does not leave residues and, despite it does not have an accumulative effect on the environment, it does have it on humans.

Long-term exposure to traffic noise with 50-70 dBA (A-weighted decibels) values of A-weighted equivalent continuous noise pressure level (LAeq) could affect people's health (Hahad et al., 2025). For its part, the exposure to high-intensity noises (>80 dB) is considered a stressful event and it could cause auditory and extra auditory damage, including several injuries on the central nervous system (Molina & Guelman, 2022).

Exposure to noise could have negative effects on human health (Van et al., 2020). Noise from diverse sources has been shown to affect different organ systems (Cantuaria et al., 2021; Erdmann et al., 2022; Roswall et al., 2023) and promote a wide variety of diseases (Sørensen et al., 2023; Thacher et al., 2022; Thacher et al., 2023).

The most common effects include the lowering in reading comprehension (Thompson et al., 2022); heart diseases, increase in blood pressure and heart rate (Lizárraga-Mollinedo, 2006); physical and physiological problems, and nervous system disorders. The harmful effects of noise may also play a significant role in the onset and progression of aspects of mental health, such as anxiety and depression (Cantuaria et al., 2023; Hao et al., 2022). In addition to the impacts on physical and mental health, noise has social and coexistence implications.

The sources that generate noise pollution are as diverse as means of transport, construction works, industrial, commercial, and service activities, recreational activities, sirens, and alarms, as well as the concentration of people for community, work, and school activities.

The elevated levels of noise in cities, caused by human activities, have been related to high economic activity and high vehicular traffic. In urban areas, vehicular traffic is

one of the principal sources of noise pollution (Oliveira do Nascimento, 2021) in addition to carbon dioxide emissions (Rojas-Cuevas et al., 2022).

The EN assessment process for a city begins with selecting the number and location of measurement points. There are several criteria, one of which involves grouping similar points into clusters, reducing the measurements to just a few points that are representative of the total. From a regulatory perspective, neither the proposed European Parliament Directive nor the French standard NF S 31-085 specifies the number or distribution of measurement points needed to produce a noise map of a given area

According to Viro, it would be worth presenting a zone distribution depending on the noise pressure levels, including at least one measuring point in each zone. It would also be feasible, and maybe more efficient, to group some neighborhoods by Basic Geostatistic Area (Ageb) with a unique measuring point according to the surface or population density, or considering the similar characteristics of traffic noise, to reduce the total number of measuring points while maintaining the information representativeness in the neighborhoods.

This study details an alternative method that consists of dividing the study area into zones before deciding the number and location of noise pressure level monitoring points, to then construct the EN map. This zone will group together five categories, each of which groups together Agebs that share similar characteristics. With this, only five zones would be monitored, one from each category, reducing the measurements to only a few representative points of the total.

The international experience concerning the selection of sampling points is diverse. A specific number of points considered strategic have been selected more technical criteria have been included such as selection of points through the noise relevance of spaces through previous field tours or looking for heterogeneity on the variables.

Another point selection technique is the grid technique, with variable dimensions depending on the researcher's criteria, which selects certain points according to certain criteria. Another method of selecting sampling points is the roadway method; either by its road hierarchy, existing traffic density, or intersections with higher vehicular flow. The combination of methodologies to determine the measurement points is valid.

MATERIALS AND METHODS

The study was conducted in the city of Tepic, the capital of Nayarit, Mexico, which covers an area of 5,638.89 hectares and has a population of 371,387 inhabitants (México. Instituto Nacional de Estadística y Geografía, 2020). As the largest urban center in the state, Tepic serves as its

principal administrative, commercial, and industrial hub, concentrating economic activities and transportation infrastructure that represent the main anthropogenic sources of environmental noise (EN). The city comprises 213 Basic Geostatistical Areas (AGEBs), with an average urban density of 64 inhabitants per hectare and a heterogeneous urban structure characterized by residential, commercial, industrial, and mixed land-use areas.

To optimize the EN assessment, a 200 m × 200 m sampling grid was initially superimposed over the study area, generating 6,573 potential measurement points. Because monitoring every location would be impractical, a zoning strategy was implemented to reduce the number of sampling sites while preserving adequate spatial representation of the city's environmental and socioeconomic characteristics. This approach improved the efficiency of field measurements without compromising the representativeness of the sampling design.

The urban environment of Tepic includes an international highway, an interconnected network of primary and secondary roads, public transportation routes, railway infrastructure, commercial centers, public markets, and industrial facilities. These elements generate different levels of traffic intensity and human activity, making them relevant contributors to the spatial variability of environmental noise across the city.

Information on the principal EN sources was collected from official governmental databases and planning institutions and complemented with field observations. The compiled datasets included the geostatistical framework, urban land-use zoning, employment distribution, traffic congestion, light and heavy vehicle traffic, railway infrastructure, and public transportation routes. These variables provided the basis for constructing six standardized indicators representing vehicular congestion, heavy vehicle traffic, light vehicle traffic, public transport density, railway traffic, and the number of employed people. The indicators were selected because of their data availability, objectivity, comparability, and direct relationship with the main urban sources of environmental noise.

The resulting database was integrated into a Geographic Information System (GIS) to support subsequent spatial analyses. The standardized indicators constituted the input variables for identifying areas with different levels of potential environmental noise generation, providing a consistent framework for the zoning and prioritization of field measurements in the study area.

RESULTS AND DISCUSSION

The graphic representation of the Vehicular Congestion for each Ageb indicator is shown on Figure 1. The greatest saturation of vehicular flow occurs in the downtown area of the city. Also, it is noticeable that there is excessive demand for the roads in the Higher Institute of Technology area.

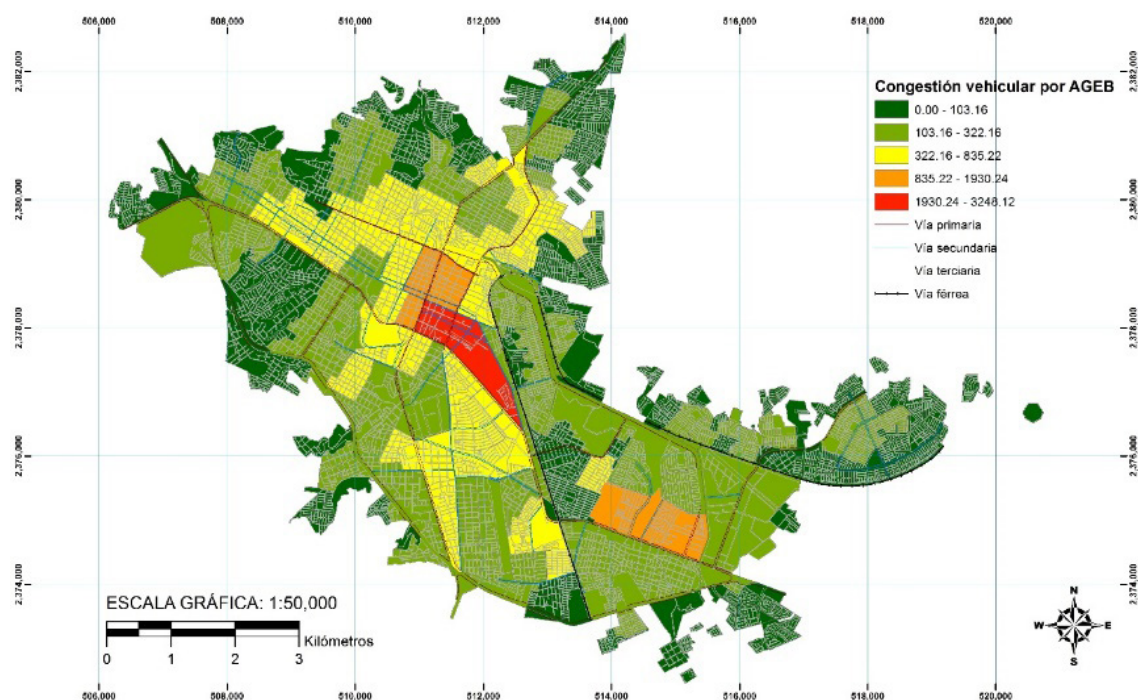


Figure 1. Vehicular Congestion for each Ageb of Tepic, Nayarit, Mexico.

Source: Prepared by the authors based on Google LLC (2019); Instituto Municipal de Planeación de Tepic (2019); Instituto Nacional de Estadística y Geografía de México (2018b).

The graphic representation of the indicators Light Vehicle Traffic and Heavy Vehicle Traffic for each Ageb is shown in Figures 2 and 3. It is observable that the intensity of vehicular flow, in both cases, happens in three areas. The first one corresponds to a fraction of the downtown. The second one is the Higher Institute of Technology area. The third area corresponds to the west exit of the city to Sinaloa. This exit from Tepic is adjacent to the municipal capital of Xalisco, Nayarit.

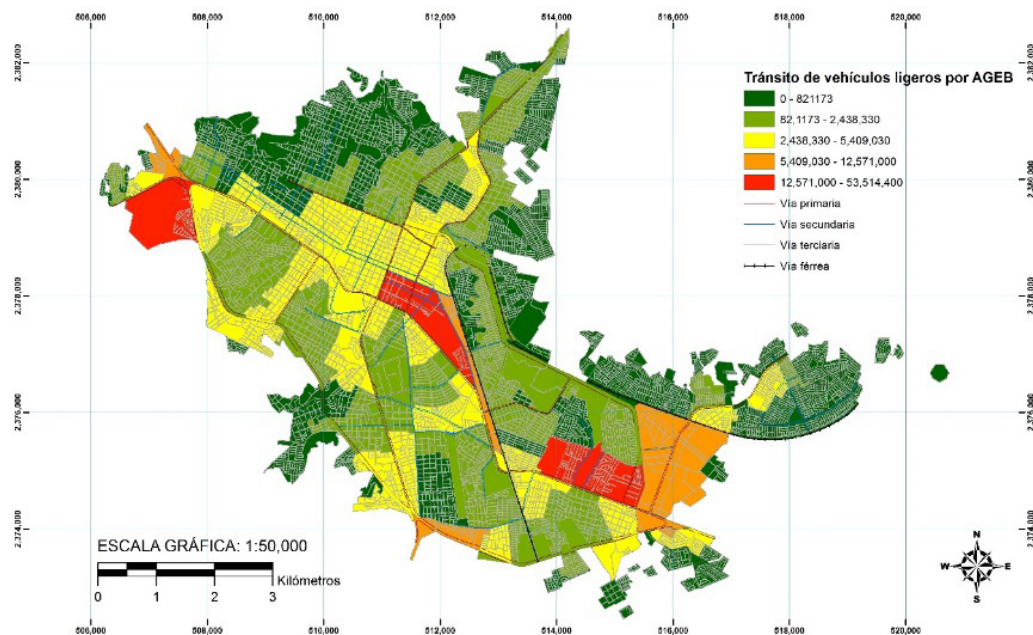


Figure 2. Light Vehicle Traffic for each Ageb in Tepic, Nayarit, Mexico.

Source: Prepared by the authors based on Instituto Municipal de Planeación de Tepic (2019); Instituto Nacional de Estadística y Geografía de México (2018b).

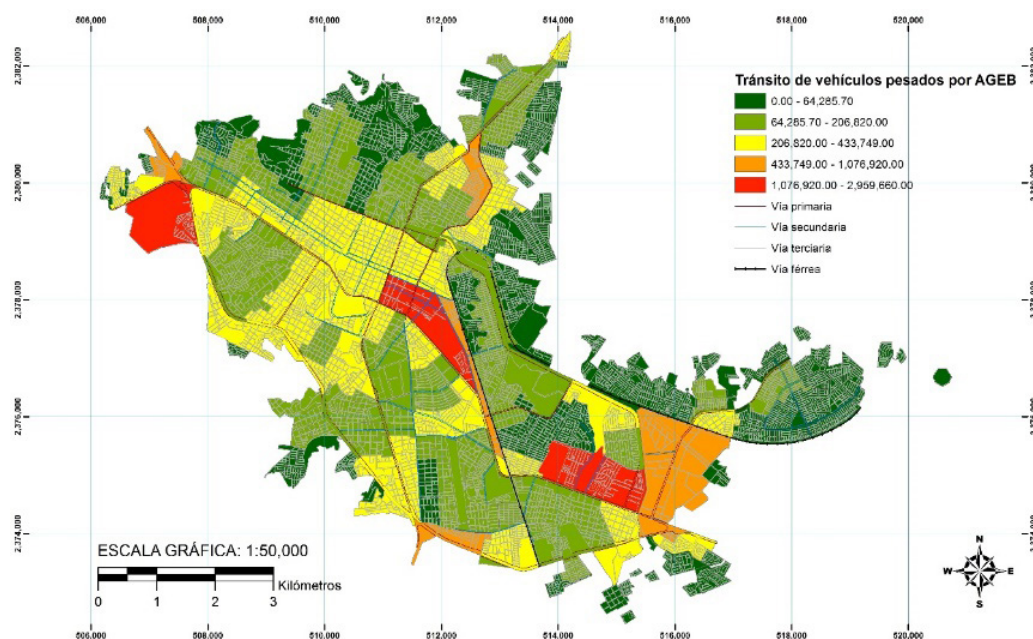


Figure 3. Heavy Vehicle Traffic for each Ageb in Tepic, Nayarit, Mexico.

Source: Prepared by the authors based on Instituto Municipal de Planeación de Tepic (2019); Instituto Nacional de Estadística y Geografía de México (2018b).

The graphic representation of the Public Transport Traffic for each Ageb indicator is shown in Figure 4. It shows that the highest traffic of collective passenger transport happens in the economically active areas in the city, corresponding to the downtown, Higher Institute of Technology and Industrial city areas. Other territories with a saturation of roads by public transport are the limits of Tepic, specifically in habitational areas in the north, west, and east of the city.

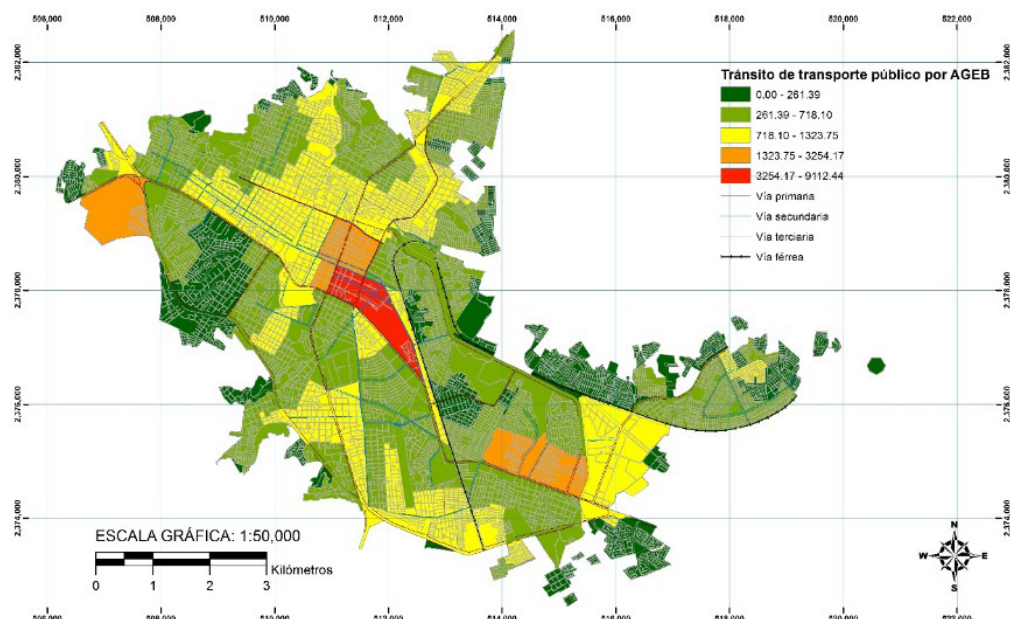


Figure 4. Public Transport Traffic for each Ageb in Tepic, Nayarit, Mexico.

Source: Prepared by the authors based on Instituto Municipal de Planeación de Tepic (2019); Instituto Nacional de Estadística y Geografía de México (2018b).

The graphic representation of the Railway Traffic for each Ageb indicator is shown in Figure 5. The areas with the highest density of railway are the Industrial city and the surrounding areas to the rail station together with its spaces for maneuvering.

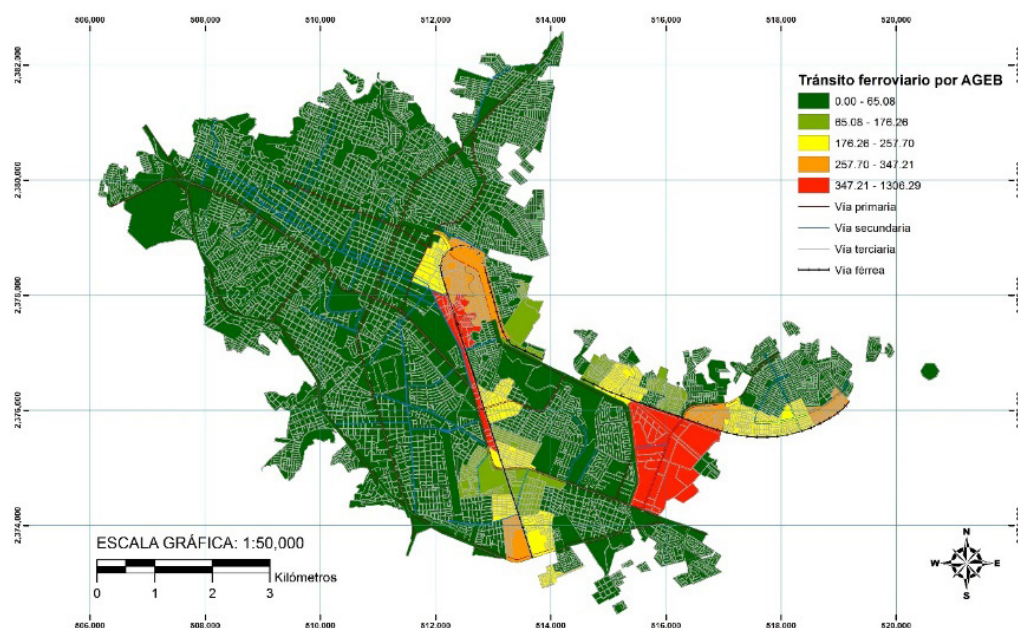


Figure 5. Railway Traffic for each Ageb in Tepic, Nayarit, Mexico.

Source: Prepared by the authors based on Instituto Municipal de Planeación de Tepic (2019); Instituto Nacional de Estadística y Geografía de México (2018b).

The graphic representation for the Number of Employed People indicator for each Ageb is shown in Figure 6. The highest number of employed people is concentrated in the first part of the downtown area and is gradually extending to other areas in and out of the downtown area, which have gradually turned space from residential use to commercial and service use. Other critical areas are Higher Institute of Technology and Industrial city.

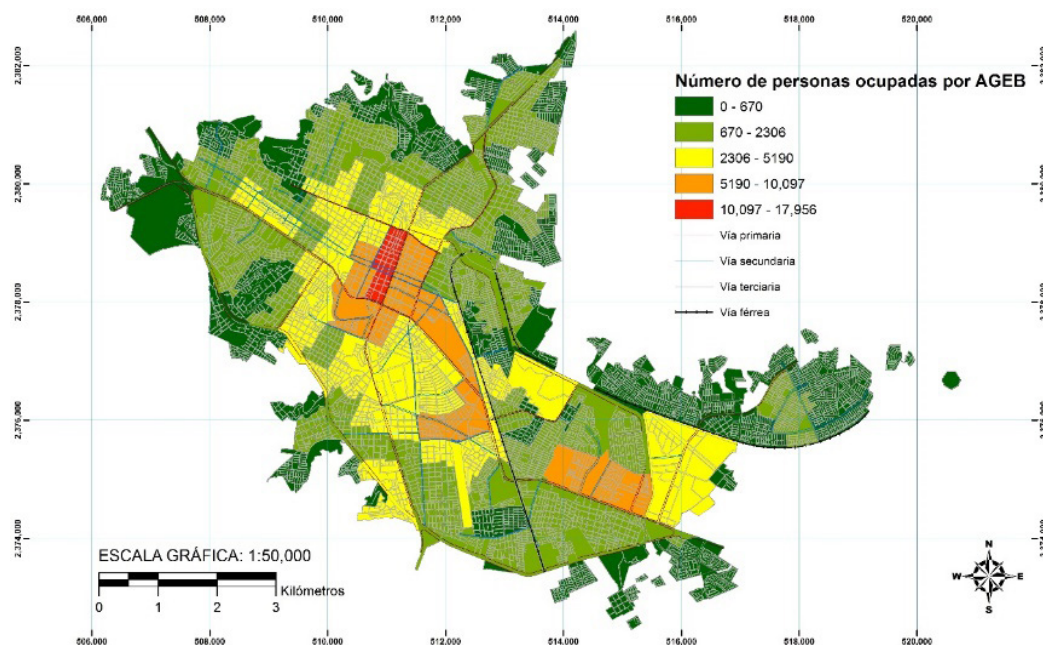


Figure 6. Number of Employed People for each Ageb in Tepic, Nayarit, Mexico.

Source: Prepared by the authors based on Instituto Nacional de Estadística y Geografía de México (2018ab).

Finally, the graphic representation for the Zoning of EN emitters for each Ageb is shown in Figure 7. This figure is the result of the weighted overlaying of the six figures described above. The 213 Agebs that form the city were classified into five categories of intensity, to focalize the efforts for the measuring in these zones.

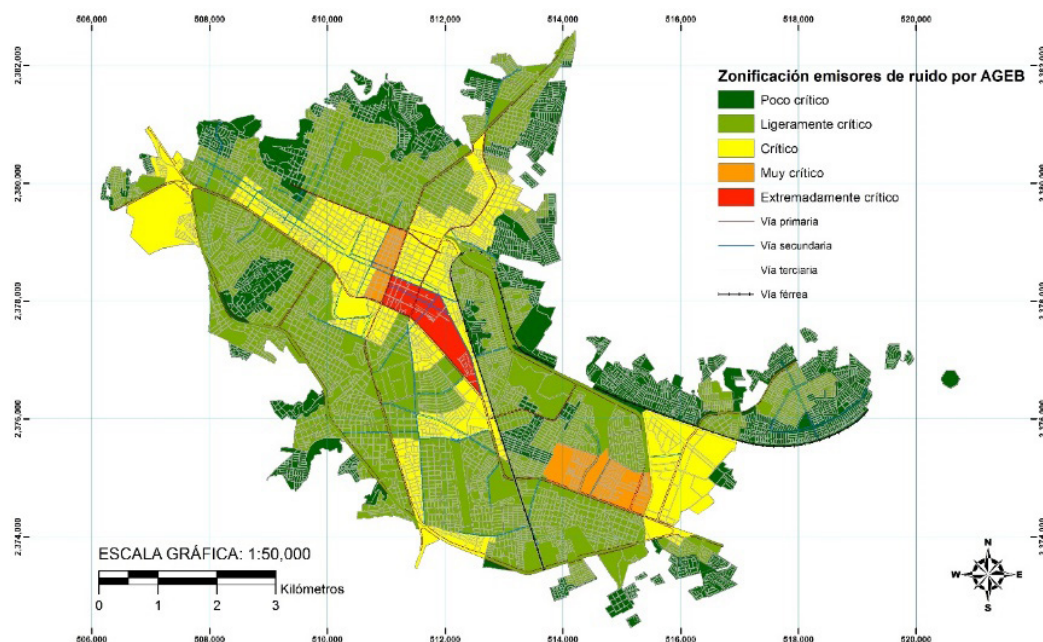


Figure 7. Zoning of EN emitters for each Ageb in Tepic, Nayarit, Mexico.

Source: Prepared by the authors based on Instituto Municipal de Planeación de Tepic (2019); Instituto Nacional de Estadística y Geografía de México (2018ab).

Table 1 shows the five zones into which the EN emitters were classified by Ageb in the city of Tepic, Nayarit.

Table 1. Number of EN emitters by specific zone of EN emitter.

Zoning	Number of Ageb	Percentage
Mildly critical	119	55,87
Slightly critical	71	33,33
Very critical	2	0,94
Extremely critical	1	0,47
Total	213	100,00

Tepic presents an extremely critical noise emitter zone. This zone corresponds to the eastern fraction of the city center, where there is a mix of industrial, commercial, and service establishments. It is also considered that this zone presents the highest density of primary and secondary road sections, with the resultant vehicular traffic.

Two very critical zones were identified. The first corresponds to the historic center, where various commerce and services are concentrated, including the headquarters of the three branches of government of the state and municipality.

The second zone corresponds to the Higher Institute of Technology area, where there are educational establishments, recreational establishments such as the natural protected area Ecologic Park of Tepic; institutional establishments; industrial establishments, and commercial establishments.

There exist 20 critical zones, which correspond to the historical and gradual expansion of the economic activity of the city, benefited by its closeness to the most prominent economic zones and its accessibility due to the continuity given by the urban pattern of principal and secondary roads; these zones belong to neighborhoods that have been progressively changing their use of residential land for commercial and service establishments. On the other hand, the Industrial city stands out for its considerable number of employed people on the diverse economic units and the high vehicular traffic. The 71 slightly critical zones correspond to traditional popular neighborhoods, where the use of land is preferably habitational. The 119 least critical zones are in the suburbs of the city, where the new housing developments, irregular human settlements, and urban vacant lots are observable.

Once the analysis has been conducted, the classification of the resulting zones corresponds to what was expected. The next step will be to estimate the number of sampling points considering only the points of one zone on each category: Extremely critical, very critical, critical, slightly critical, and mildly critical. This gives us 84 sampling points, reducing the sampling intensity by 98,7%.

There is a referent of acoustic zoning in the cities according to the uses of land, taking as a fundamental tool the Urban Development Plans. The Spanish government has been a pioneer in this matter with the Royal Decree 1367/2007, October 19th, from which the Law of Noise 37/2003, November 17, was developed, concerning the acoustic zoning, quality goals, and acoustic emissions. The cartographic delimitation of this acoustic zoning type is defined by the uses of land which could be existent or planned. Depending on the type of area (habitational, industrial, commercial, recreative, sanitary establishments, teaching, cultural, among others), the largest limits of noise are set up, to preserve the acoustic quality.

Nowadays, it has started the use of novel methods which consider the cluster analysis or the weight assignments to specific regions of the study areas to correlate the measuring points registered in the field with other zones of similar characteristics to model the EN.

In the city of Buenos Aires, Argentina, it was used the Saaty method, also known as the binary comparison matrix method. With the assessment matrix, a process of weight calculations for each criterium was conducted through approximations. Once these weights were obtained, each criterium was analyzed to obtain the weight for each noise source. Another case is that of the metropolis of Guangzhou, China, where the automatic query arithmetic method was used to obtain the geographic information, and after that, the regionalism was completed based on the road network. For each region, a cluster analysis was used, based on the points of interest's types and densities to infer the class of EN functional regions. Some points were monitored, and other points were simulated.

In the cases mentioned above, acoustic zoning has been used to project noise maps. The present methodological proposal replicates the EN regionalism based on the road network of the metropolitan area of Guangzhou, China, in the context of a Mexican city, taking as the spatial reference unit the Ageb by Instituto Nacional de Estadística y Geografía of Mexico, as an earlier step for the selection of sampling points. The zoning of EN emitters shows five zones similar to each other within the city, allowing the reduction of the total number of measuring points, and supporting the regional representativeness of the information. At present, this proposal, before the implementation of methodologies to figure out the number and location of the measuring points, does not have any referent with EN studies conducted in Mexico.

CONCLUSIONS

Before the zoning of EN emitters, diverse acoustic zoning works about different cities were analyzed. The case of the metropolis of Guangzhou was adjusted to the context of a Mexican city, replicating the EN regionalism based

on the road network, taking as a spatial reference unit the Ageb of Instituto Nacional de Estadística y Geografía of Mexico.

Six indicators were created that were meaningful in the context of EN emitters, rather than considering land use for zoning purposes. Later, the behavior of these indicators was seen through the weighted overlaying geospatial analysis in the program of geographic information system ArcMap version 10.5 by ESRI. This approach to noise monitoring allows for the selection of optimal areas to intensify noise recording efforts in the field and maximize equipment and trained personnel resources.

The application of the proposed zoning, before determining the number and location of the measuring points for EN in the cities, makes possible the grouping of points that show similitudes, decreasing the measuring to just a few representative points from the total, facilitating the study of the zones where the biggest efforts for measuring will be required.

With the earlier zoning of EN emitters, the evaluation of the phenomenon in the cities could be managed by zones, achieving the maximum homogeneity in each group and the highest difference to others. This will allow the simulation of the EN levels in other zones in the city that, for economic, time, personnel, and instrumentation reasons, would not be covered using field records.

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Conflicts of Interest:

The authors declare no conflicts of interest.

Author Contributions:

Daniel Isaí González-Gómez, Rebeca de Haro-Mota, Susana Marcelleño-Flores, Oyolsi Nájera-González, Josemanuel Luna-Nemecio: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, visualization, original draft writing, and writing, review, and editing.

Ethical statement:

The study was based on the analysis of documentary sources and publicly available data, and therefore did not involve the direct participation of human subjects. No personally identifiable information was handled.