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Study of Sound Pressure Levels through the Creation of Noise Maps in the Urban Area of Latacunga City using Plithogenic n-Superhypergraphs

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Abstract. Acoustic pollution has become an increasing problem in urban areas, and its monitoring is crucial for protecting public health. In Latacunga, the presence of noise sources has affected the quality of life of its inhabitants. Therefore, the study focused on monitoring sound pressure levels and identifying the areas most affected by acoustic pollution. The Plithogenic n-SuperHyperGraphs were used to analyze the interactions between noise sources, impacted areas, and regulatory frameworks. Among the results, it was observed that measurements were taken at 12 critical points, especially in high-traffic and commercial activity areas. It was also indicated that there is a priority for implementing public policies to manage noise, including the regulation of sources and promoting solutions such as acoustic barriers. Additionally, managing acoustic pollution using technological tools and advanced methodologies was recommended.

Keywords: Acoustic pollution, critical noise zones, stratified population groups, plithogenic n-SuperHyperGraphs.

1 Introduction

Acoustic pollution is an unpleasant and inarticulate sensation that generates negative and harmful effects on human health [1]. This phenomenon is generally considered unacceptable and represents one of the major environmental issues globally [2], as it directly affects public health. Prolonged exposure to elevated noise levels can trigger adverse effects such as increased stress levels, hypertension, hearing loss, concentration difficulties, and sleep disorders [3]. Additionally, acoustic pollution affects the nervous system, and the myocardium, and may even cause cerebrovascular alterations.

Therefore, it is essential to establish equivalent sound pressure levels at critical impact points to ensure the protection of public health and environmental well-being [4]. Acoustic impact assessment is fundamental for preventing and controlling the effects of noise on the population and the environment [5][6]. Urban planning and traffic management are key elements in mitigating the density and morphology of noise effects both on the population and the ecosystem [7][8]. As such, regulatory agencies at the global and national levels have established technical standards for maximum permissible noise levels to preserve environmental balance and public health.

In Ecuador, for instance, the Ministry of Environment, Water, and Ecological Transition, together with other competent entities, has defined acceptable noise ranges, which vary between 55 dB and 70 dB, depending on the type of area. These include residential areas, public service zones, industrial zones, and agricultural or commercial areas [9]. These regulations are based on the country's environmental classification and are governed by the Unified Text of Secondary Environmental Legislation (TULSMA) and its reforms.

In the city of Latacunga, various studies have highlighted the issue of noise and its impact on residents [10]. Previous research has revealed that noise generated by vehicular traffic on the city's main arteries exceeds the limits established by local and national legislation [11]. Recent studies have also shown that acoustic pollution negatively affects residents' quality of life, emphasizing the need for measures to mitigate its impact [12]. Thus, the objective of this study is to monitor the equivalent sound pressure levels in the urban area of Latacunga. To achieve this, it is proposed to use a Delta OHM brand sound level meter, which enables the creation of environmental noise maps to identify the areas most affected by acoustic pollution. Additionally, the study aims to identify and manage the structures of elements (vertices) and groups of elements (supervertex) that influence the reduction of decibel (dB) levels in the city using Plithogenic n-SuperHyperGraphs.

2 Materials and Methods

The study, conducted in Latacunga, Ecuador, analyzed acoustic pollution in critical areas such as commercial, educational, and high-traffic zones. Tools such as sound level meters, GPS, and specialized software were used to monitor and calculate specific noise levels, following normative methods and adjusting for impulsive noise and low frequencies. The results included acoustic maps that identified critical areas, providing key information for urban management.

The Plithogenic n-SuperHyperGraphs approach was used to model the relationships between noise sources, locations, and impacts, integrating elements of uncertainty into the study [13]. This method allowed for the identification of complex patterns, as well as optimization in decision-making. Despite limitations in selecting specific areas, the results provide a solid foundation for reducing noise and improving the quality of life in the city.

2.1 Plithogenic n-SuperHyperGraphs

Plithogenic n-SuperHyperGraphs were defined by Smarandache in the field of decision-making in [14] [15]

First, an n-SuperHyperGraph is defined as follows:

Given $V = \{V_1, V_2, \cdots, V_{\mathrm{m}}\}$, where $1 \leq \mathrm{m} \leq \infty$ is a set of vertices, containing *Single Vertices* which are classical, *Indeterminate Vertices* that are unclear, vague, or partially known, and the *Null Vertices* that are empty or completely unknown.

$P(V)$ is the power set of V including $\emptyset$. $P^n(V)$ is the n-power set of V, which is defined recursively as follows:

$P^1(V) = P(V)$, $P^2(V) = P\big(P(V)\big)$, $P^3(V) = P\big(P^2(V)\big)$, …, $P^n(V) = P\big(P^{n-1}(V)\big)$, for $1 \leq \mathrm{n} \leq \infty$.
Where it is also defined as $P^0(V) = V$.

An n-SuperHyperGraph (*n-SHG*) is an ordered pair $n - SHG = (G_n, E_n)$, where $G_n \subseteq P^n(V)$ and $E_n \subseteq P^n(V)$, for $1 \leq \mathrm{n} \leq \infty$. Such that, G_n is the set of vertices and E_n is the set of edges.

G_n contains all possible types of vertices in the real world:

- *Single Vertices* (the classics),
- *Indeterminate Vertices* (unclear, vague, partially known),
- *Null Vertices* (empty, totally unknown),
- *SuperVertex* (or *SubsetVertex*) contains two or more vertices of the above types put together as a group (organization).
- *n- SuperVertex* which is a collection of vertices, where at least one of them is a *(n-1)- SuperVertex,* and the others can be *r- SuperVertex* for $r \leq \mathrm{n} - 1$.

E_n contains the following types of edges:

- *Single Edges* (the classics),
- *Indeterminate Edges* (unclear, vague, partially known),
- *Null Edges* (totally unknown, empty),
- *HyperEdge* (connecting three or more single vertices),
- *SuperEdge* (connecting two vertices, at least one of them is a SuperVertex),
- *n- SuperEdge* (connecting two vertices, at least one of them is an n- SuperVertex and may contain another that is an r-SuperVertex with $r \leq \mathrm{n}$).
- *SuperHyperEdge* (connects three or more vertices, where at least one of them is a SuperVertex),

- *n-SuperHyperEdge* (contains three or more vertices, at least one of which is an n-SuperVertex and may contain an r-SuperVertex with $r \leq$ n),
- *MultiEdge* (two or more edges connecting the same two vertices),
- *Loop* (an edge that connects an element to itself),

Graphs are classified as follows:

- Directed Graph (the classic one),
- Undirected Graph (the classic one),
- Neutrosophic Directed Graph (partially directed, partially undirected, partially indeterminate directed).

Within the framework of the theory of Plithogenic n-SuperHyperGraphs, there are the following concepts:

Enveloping vertex: A vertex representing an object comprising attributes and sub-attributes in the graphical representation of a multi-attribute decision-making environment.

SuperEnveloping vertex: An enveloping vertex comprises of SuperHyperEdges.

Dominant Enveloping Vertex: An enveloping vertex that is with dominant attribute values.

Dominant Super Enveloping Vertex: A super enveloping vertex with dominant attribute values.

Dominant Enveloping Vertex is classified into *input*, *intervene,* and *output* based on the nature of the object's representation.

Plithogenic Connectors: The connectors associate the input enveloping vertex with the output enveloping vertex. These connectors associate the effects of input attributes with output attributes and these connectors are weighted by plithogenic weights [16].

3 Results

3.1 Structure of the Plithogenic n-SuperHyperGraph.

For the development, the Plithogenic n-SuperHyperGraph structure of the study was modeled, determining four priority vertices (see figures 1 to 4). Among the vertices, three are simple vertices (V_1, V_2, and V_3), and one is indeterminate (V_4), because the knowledge of regulations and environmental legislation is partially known by the study population.

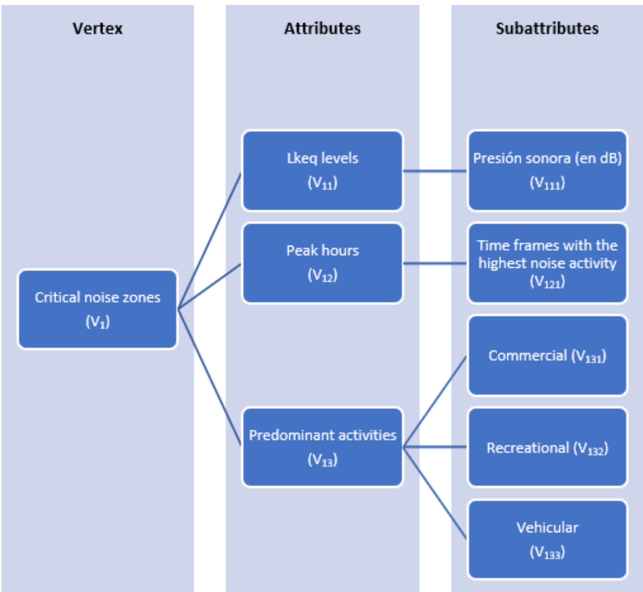

Figure 1: Critical noise zones (V_1).

In Figure 1, the areas affected by environmental pollution are represented as a vertex V_1. All its elements constitute intermediate-encompassing vertices. For this study, the predominant activities were limited to the scope of the study in the analyzed city of Latacunga.

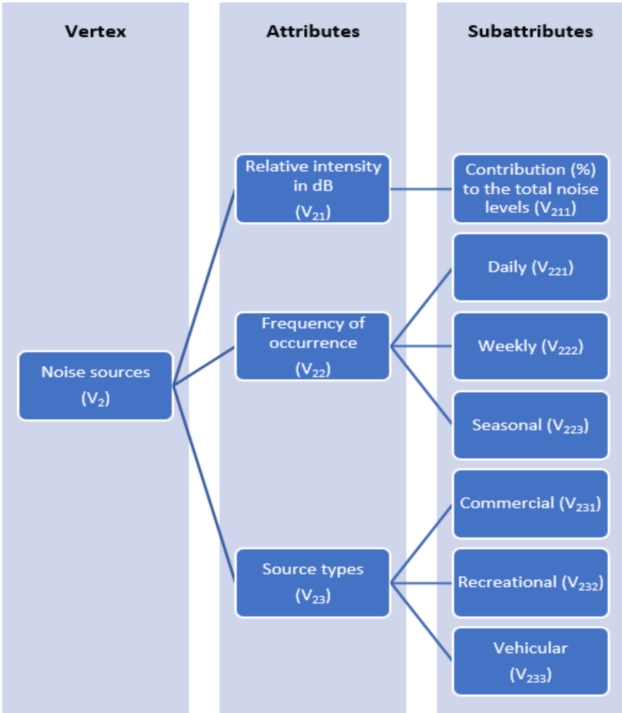

Figure 2: Noise sources (V_2).

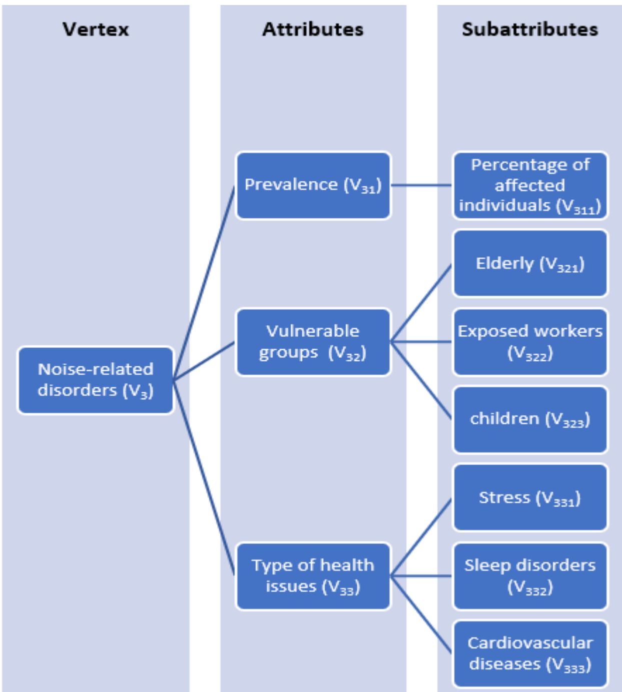

Figure 3: Noise-related disorders (V_3).

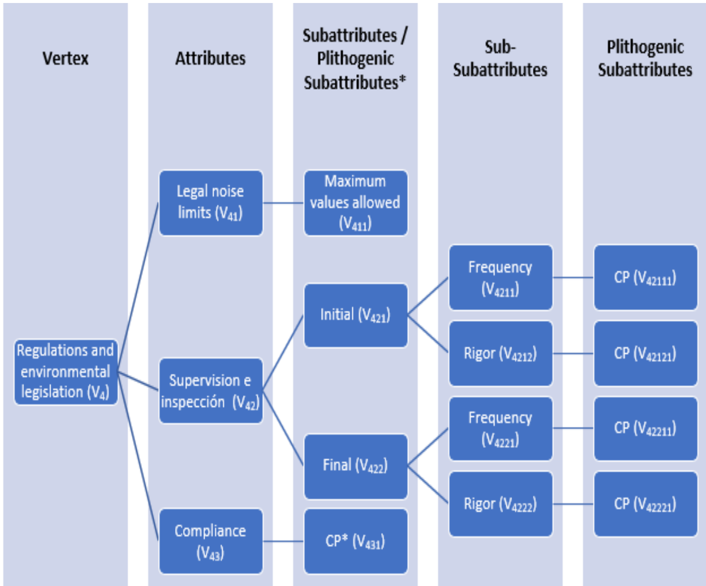

Figure 4: Regulations and environmental legislation (V_4).

In Figure 4, the vertices V_{431}, as well as V_{42111}, V_{42121}, V_{42211}, and V_{42221}, represent plithogenic sub-attributes used to determine or evaluate the vertex. For example, supervision encompasses elements such as inspections conducted (which may include ministerial visits, audits, controls, etc.). These inspections have a frequency and rigor (depending on the scope and depth of the inspection carried out). Therefore, both are characterized by plithogenic criteria, which in this study are defined by the labels CP (very high, high, medium, low, and very low). Similarly, compliance with these regulations does not occur immediately after a supervision visit. Hence, it is also defined by CP* (not fulfilled, partially fulfilled, and fulfilled, where the scale can be extended based on the stages of compliance or non-conformities to be addressed). Therefore, V_4 is considered an indeterminate or partially defined vertex. On the other hand, V_{421} and V_{422} are considered entry and exit encompassing vertices, respectively, while the others are considered intermediate encompassing vertices.

3.2 Geographic location of critical noise impact points (Vertex V_1).

Twelve critical impact points related to noise were identified, which were recognized as significant sources of acoustic pollution in productive activities (see Table 1). Among these sources, the constant flow of vehicles, traffic congestion, the use of sound amplification equipment for advertising, and the gathering of people near educational institutions stand out. Most of these points are concentrated in the historic center of the city.

For the monitoring process, four measurement points were selected and evaluated over three days, between November 2022 and January 2023, during a period of high commercial mobility. The noise measurements were organized according to the similar characteristics of the points, which facilitated the comparison of data between them (see Table 1).

Table 1: Measurement of timeline data. Source: Own elaboration.

Points	Reference location	Measurement day	Measurement schedule
P1	Traffic light at the terminal	Friday	19:00-20:00
P2	Vicente León Park	Friday	16:00-17:00
P3	General Hospital of Latacunga	Monday	16:00-17:00
P4	La Cocha	Friday	12:00-13:00

Points	Reference location	Measurement day	Measurement schedule
P5	Malteria	Monday	07:00-08:00
P6	San Felipe Park	Monday	19:00-20:00
P7	Canada Plaza	Thursday	07:00-08:00
P8	Simón Rodríguez Avenue	Thursday	19:00-20:00
P9	El Salto	Thursday	16:00-17:00
P10	U.E. Ramón Barba Naranjo	Thursday	12:00-13:00
P11	ESPE	Friday	07:00-08:00
P12	Traffic light at the intersection of Eugenio Espejo Avenue and Eloy Alfaro Avenue	Monday	12:00-13:00

3.3 Interactions of SuperVertex (V_1, V_2, V_3 and V_4) on research results.

3.3.1 Environmental diagnosis of the study area.

The identification of critical points was carried out through an evaluation of the measurement procedures, the equipment to be used, and the environment in which the measurements took place. A significant impact on health was evidenced, particularly in the more vulnerable population groups, such as the elderly, who experience high stress levels due to noise. It also revealed 43 areas of the city where elevated noise levels were perceived during daytime hours (7:00 to 21:00). These areas are primarily attributed to intense vehicular traffic during peak hours, with the "El Salto" Commercial Plaza being identified as having the highest noise levels. Of these 43 areas, 12 were selected for further study. Additionally, the results showed that the population was unfamiliar with noise isolation measures, although many suggested that green barriers could be an effective option to mitigate the noise (see Figure 5).

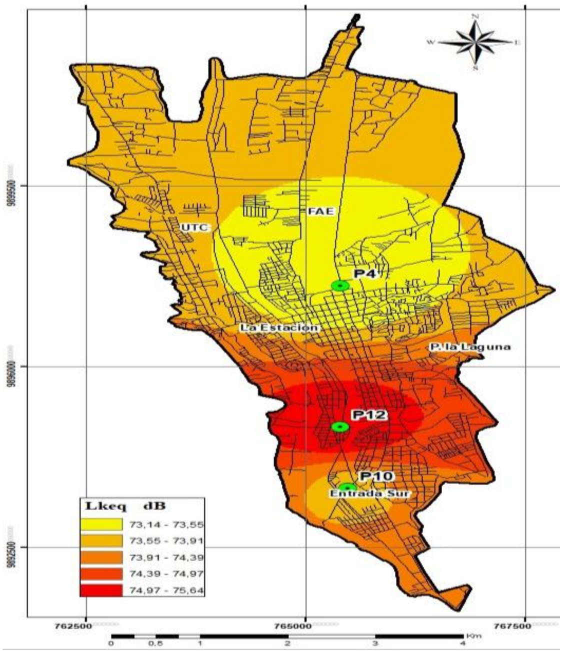

Figure 5: Areas with the highest noise levels in Latacunga.

3.3.2 Corrected equivalent continuous sound pressure level (Lkeq).

During the seven-week monitoring period, 84 measurements were taken, of which only 5% met the maximum noise levels set by regulations. In specific weeks, measurements within the limit were recorded at some points, such as point 2 during weeks 2 and 7, and points 4 and 7 during week 5. The remaining 95% of the measurements exceeded the permitted limits. This excess in noise levels is attributed to the high concentration of people and vehicles in commercial areas, shopping centers, and parks during the Christmas season.

3.3.3 Statistical analysis: Chi-Square test and graph determination.

A statistical analysis was performed using the chi-square test to compare the average values of the corrected equivalent continuous sound pressure level (Lkeq) with the expected values, defined according to the maximum permissible noise levels for commercial land use. The results of the analysis showed that the calculated chi-square value was 10.53, with 12 degrees of freedom. According to the chi-square distribution table, the critical value was 19.68. Since the calculated value falls within the rejection region, the null hypothesis, which stated that the noise levels were influenced by land use, is rejected. This suggests that noise is an independent variable in urban planning, as it does not directly affect compliance with sound-level regulations.

According to the results, Lkeq levels above the permitted limits are mainly due to daily activities in the city, such as mobility, commercial activities, and recreation. Tolerance zones for noise are also defined based on the land use of each sector and the schedule established in regulations, such as daytime and nighttime hours.

Furthermore, noise maps are presented, indicating the areas with the highest Lkeq levels, obtained during peak hours in the morning, afternoon, and evening at different points in the central canton. Qualitative analyses are presented through the comparison of noise measurements between three different points at the same time and week.

In the time frame from 7:00 to 8:00, it was observed that points located in areas such as ESPE and Canada Plaza exhibited high noise levels due to vehicular circulation and the traffic of students near educational institutions. During the 16:00 to 17:00 interval, the critical point identified was "El Salto," with a level of 82.5 dB, influenced by vehicular traffic and the influx of people due to commercial activities and the proximity of government establishments.

In the 19:00 to 20:00 period, greater impact was observed in sectors such as San Felipe, where levels close to 75 dB were recorded due to the presence of bars, restaurants, and shops that increase noise during nighttime hours. Finally, between 12:00 and 13:00, the point at the intersection of Eugenio Espejo and Eloy Alfaro avenues showed levels of 77.76 dB, primarily due to vehicular flow generated by the proximity of bus stops and congestion at traffic lights.

Graph analysis: In Figure 6, a representation of the neutrosophic-directed graph from the research conducted is shown. It identifies the supervertex (V_{13}, V_{23}) aimed at determining the most affected areas, zones, or critical points by pollution. On the other hand, the n-SuperHyperEdge contains the indeterminate vertex (V_4), which represents that a significant portion of the population in the study has partial knowledge of the regulations governing and controlling noise pollution. Additionally, the supervertex (V_{11}, V_{12}, V_{21}, and V_{22}) focuses on determining the exposure levels of the city to noise pollution, as well as the sound pressure levels encountered. In fact, this grouping, together with the vertex V_3, defines the consequences of exposure to pollution for the city's residents. Another visual characteristic observed in the graph is the dominance among its elements, where vertices V_{11} and V_{23} represent the prevalence over the other elements of the supervertex.

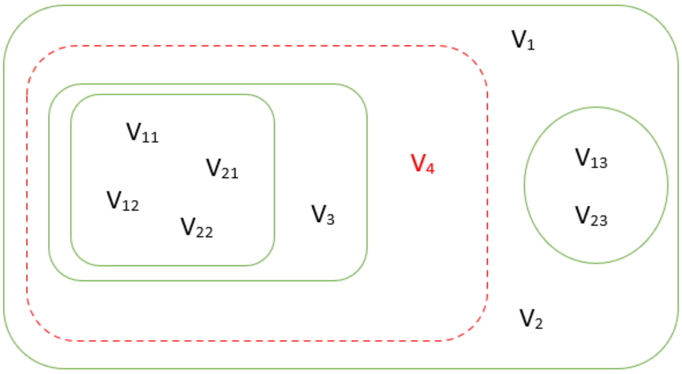

Figure 6: Representation of the neutrosophic directed graph in the study.

The graph analysis allows for the inclusion of other points to consider, such as promoting healthy lifestyle habits, educating the population on the effects of noise and existing regulations, and encouraging the use of quieter technologies. These are some of the measures that contribute to reducing decibel levels, as well as ensuring compliance with acceptable sound pressure limits. Additionally, it is crucial to study, validate, and properly manage noise to ensure the protection of the health and environmental well-being of the population.

It is therefore imperative to adopt concrete actions to reduce the impact of noise in Latacunga and improve the well-being of its residents. Among the recommended measures are the regulation of vehicular traffic, the promotion of more sustainable transportation options, and the installation of acoustic barriers in the most affected areas.

On the other hand, public policies must focus on the sustainable management of noise by implementing measures that not only regulate noise sources but also promote citizen awareness of the impact of noise on health and well-being. The creation of noise maps and continuous monitoring of sound pressure levels are key tools to identify the most affected areas and guide the necessary interventions.

4 Conclusion

The research has demonstrated the utility of the Plithogenic n-SuperHyperGraph model in addressing acoustic pollution in Latacunga by identifying the interactions between noise sources, exposure levels, and regulatory knowledge. The results highlighted the need to strengthen public policies with tools such as noise maps and continuous monitoring, as well as awareness strategies to mitigate the impact on the health and well-being of the population. It not only has local applications but also provides a foundation for future projections, with the inclusion of intelligent monitoring technologies and the evaluation of the effectiveness of interventions in noise reduction.

References

[1] J. Chakraborty and J. J. Aun, "Social inequities in exposure to traffic-related air and noise pollution at public schools in Texas," *International Journal of Environmental Research and Public Health,* vol. 20, no. 7, p. 5308, 2023.
[2] J. Govea, W. Gaibor-Naranjo, S. Sanchez-Viteri, and W. Villegas-Ch, "Integration of Data and Predictive Models for the Evaluation of Air Quality and Noise in Urban Environments," *Sensors,* vol. 24, no. 2, p. 311, 2024.
[3] E. Bernat-Ponce, J. A. Gil-Delgado, and G. M. López-Iborra, "Recreational noise pollution of traditional festivals reduces the juvenile productivity of an avian urban bioindicator," *Environmental Pollution,* vol. 286, no. October pp. 2-6, 2021/10/01/ 2021.
[4] R. Sordello, O. Ratel, F. Flamerie De Lachapelle, C. Leger, A. Dambry, and S. Vanpeene, "Evidence of the impact of noise pollution on biodiversity: A systematic map," *Environmental Evidence,* vol. 9, no. September, pp. 1-27, 2020.
[5] D. Wang, L. Ying, Y. Jia, L. Zhang, F. Zhang, and W. Wang, "Noise pollution mitigation method for substations

in urban communities based on a smart silencing unit," *Journal of Cleaner Production,* vol. 245, no. February pp. 1-4, 2020/02/01/ 2020.

[6] W. Yang, J. He, C. He, and M. Cai, "Evaluation of urban traffic noise pollution based on noise maps," *Transportation Research Part D: Transport and Environment,* vol. 87, no. October pp. 1-4, 2020/10/01/ 2020.

[7] M. H. Masum, S. K. Pal, A. A. Akhie, I. J. Ruva, N. Akter, and S. Nath, "Spatiotemporal monitoring and assessment of noise pollution in an urban setting," *Environmental Challenges,* vol. 5, no. December, pp. 2-10, 2021/12/01/ 2021.

[8] J. M. Gavilanes, O. D. Inga, I. V. Galindo, D. E. Saquicela, and F. S. Castillo, "EVALUATION OF URBAN POLLUTION BY NOISE EMISSIONS REGISTERED WITH A SOUND LEVEL METER AND SENSOR NODES," *La Granja,* vol. 40, no. 2, pp. 78-91, 2024..

[9] D. E. del Pozo Meza, N. C. Donoso Pantoja, and B. G. Valle Esparza, "Mapping and Mitigating Urban Noise: A Case Study of Loja, Ecuador's Soundscape," *Canadian Acoustics,* vol. 52, no. 3, pp. 1-7, 09/08 2024.

[10] M. Y. Peer, M. S. Mir, K. R. Vanapalli, and B. Mohanty, "Road traffic noise pollution and prevalence of ischemic heart disease: modelling potential association and abatement strategies in noise-exposed areas," *Environmental Monitoring and Assessment,* vol. 196, no. 8, p. 749, 2024.

[11] V. Puyana-Romero, J. L. Cueto, G. Ciaburro, L. Bravo-Moncayo, and R. Hernandez-Molina, "Community response to noise from hot-spots at a major road in Quito (Ecuador) and its application for identification and ranking these areas," *International journal of environmental research and public health,* vol. 19, no. 3, p. 1115, 2022.

[12] S. Kumari, A. Sharma, and A. K. Ghosh, "A comprehensive review of noise pollution monitoring studies at bus transit terminals," *Noise Mapping,* vol. 11, no. 1, pp. 1-15, 2024.

[13] L. J. Reales-Chacón *et al.*, "Study of the Efficacy of Neural Mobilizations to Improve Sensory and Functional Responses of Lower Extremities in Older Adults with Diabetic Peripheral Neuropathy Using Plithogenic n-SuperHyperGraphs," *Neutrosophic Sets and Systems,* vol. 74, no. Special, pp. 1-12, 2024.

[14] M. Rahmati and M. Hamidi, "On Strong Super Hyper EQ Algebras: A Proof-of-Principle Study," *Plithogenic Logic and Computation,* vol. 2, no. August, pp. 29-36, 08/04 2024. [Online]. Available: https://sciencesforce.com/index.php/plc/article/view/351.

[15] F. Smarandache, "Foundation of SuperHyperStructure & Neutrosophic SuperHyperStructure," *Neutrosophic Sets and Systems,* vol. 63, no. 1, p. 21, 2024.

[16] Martin, N., Smarandache, F., & Sudha, S. (2023). A novel method of decision making based on plithogenic contradictions. Neutrosophic Systems with Applications, 10, 12-24.

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