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Authors: Estrella, Ivan, Pacheco, Alex, Marin, Wilson, Pacheco-Pumaleque, Liz, Cuba-Carbajal, Nestor, et al.

Source: Environmental Health Insights, 18(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/11786302241235013

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Environmental Health Insights
Volume 18: 1–11

DOI: 10.1177/11786302241235013

Ivan Estrella[1], Alex Pacheco[2], Wilson Marin[1], Liz Pacheco-Pumaleque[3], Nestor Cuba-Carbajal[4], Félix Pucuhuayla-Revatta[5], Edwin Felix-Poicon[6] and Marco Añaños-Bedriñana[7]

[1]Carrera de Ingeniería de sistemas, Facultad de Ingeniería y Arquitectura, Universidad Cesar Vallejo, Lima, Perú. [2]Carrera de ingeniería de sistemas, Facultad de Ingeniería, Universidad Nacional de Cañete, Lima, Perú. [3] Carrera de Administración, Facultad de Ciencias Empresariales, Universidad San Ignacio de Loyola, Lima, Perú. [4]Universidad Ricardo Palma, Lima, Perú. [5]Universidad Tecnológica del Perú, Lima, Perú. [6]Universidad Nacional de Jaen, Cajamarca, Perú. [7]Universidad Nacional Autónoma de Chota, Cajamarca, Perú.

ABSTRACT: Noise pollution derived from motor vehicles, especially those with noisy engines, constitutes a significant challenge in urban environments, impacting quality of life and public health. In this context, the present study focuses on the implementation of an advanced technological solution: a web-based system specifically designed to monitor and manage noise pollution in Tarapoto, Peru. The execution of this project was structured in 4 key phases. The first phase involved extensive data collection and definition of the project scope. In the second phase, the system architecture was established based on initial observations. The third phase focussed on evaluating and improving system functionalities, while the fourth involved rigorous testing and corrections. The successful implementation of this system led to a significant improvement in the noise pollution monitoring process, reducing reporting times and improving data-driven decision making. This project not only provides a valuable tool for authorities in the management and mitigation of noise pollution, but also encourages community awareness and active participation in the sustainable management of the urban acoustic environment.

KEYWORDS: Web system, noise pollution, monitoring, innovation

RECEIVED: October 9, 2023. **ACCEPTED:** February 8, 2024.

TYPE: Original Research

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was financed by the Universidad San Ignacio de Loyola.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Liz Pacheco-Pumaleque, Facultad de Ciencias Empresariales, Carrera de Administración, Universidad San Ignacio de Loyola, Av. La Fontana 550, Lima 15024, Perú. Email: lpacheco@usil.edu.pe

Introduction

Noise pollution is an environmental phenomenon that has gained increasing relevance in recent decades due to the rapid and continuous growth of urban areas and rapid industrial development.[1] Accelerated urbanisation and the expansion of industrial activity have contributed to a proliferation of noise in urban environments, which has raised the importance of addressing this problem to ensure the quality of life of the inhabitants. It refers to the excessive and constant presence of noise in the environment, generated by various anthropogenic sources such as vehicular traffic, industrial machinery in full operation, construction in progress, recreational activities with loud music and noisy public events, among others.[2] Noise sources are diverse and often interdependent, making mitigation a multifaceted challenge. The proliferation of vehicular traffic and industrial expansion have intensified these sources, contributing to widespread noise exposure in urban environments.[3]

Sources of noise pollution are classified as stationary, which include industrial facilities and airports, and mobile, which encompasses vehicular traffic and outdoor activities.[4] These sources are interconnected and can exacerbate each other, creating a complex sound environment. For example, industrial areas can contribute to an increase in noise levels from nearby traffic and vice versa. It is important to note that noise levels can vary significantly depending on geographic location and time of day, being more intense in densely populated urban areas and during certain time zones.[5] Noise patterns can be influenced by population density, infrastructure and economic activity. In urban areas, high concentrations of people and commercial activities can increase noise exposure, especially during rush hours. Additionally, seasonal variability and special events can add temporary noise spikes that require careful consideration in noise pollution management. In addition to anthropogenic sources, there are additional factors that contribute to aggravating noise pollution.[6] High noise levels have significant impacts on various environments, including residential areas, parks and natural ecosystems.[7,8]

At the human level, continuous exposure to noise pollution can have serious health consequences.[9] Among the most common effects are chronic stress, sleep disturbances, cardiovascular and hearing problems, and impaired cognitive performance. In the specific case of children, early exposure to high noise levels can negatively affect language development and learning.[10] Constant exposure to noise can cause anxiety and depression, affecting the quality of life and emotional well-being of people living in noisy areas.[11]

In this context of growing concern about noise pollution, technology has emerged as a crucial ally to address various environmental problems. Web-based systems have emerged as

highly effective tools for monitoring, analysing and controlling noise levels in urban environments and sensitive areas.[12] These systems, often based on sound sensors strategically located at key points in the city, can collect real-time data on noise levels at different locations and times of the day. The integration of advanced sensors enables accurate capture of noise variations and patterns, providing detailed information to better understand the dynamics of noise pollution in a specific area.[13]

This section explores the application of web-based systems in relation to noise pollution, highlighting their potential to generate real-time information and promote more effective management actions.

Web-based systems, thanks to their ability to perform continuous, real-time monitoring of noise levels in specific areas, have become an invaluable tool in the fight against noise pollution.[14] These systems make use of a network of strategically connected sensors to collect accurate and up-to-date data on noise pollution at various locations in the city. The availability of real-time information provides the possibility of a rapid and effective response to emergency situations, which can minimise the negative impacts of noise on people's health and the environment.[15] But their role goes beyond simple monitoring, as web-based systems also provide interactive platforms that play a key role in public awareness and education about noise pollution. These platforms provide data, analysis and useful tips to reduce noise exposure and improve citizens' quality of life. By making this information available to the community, they promote awareness of the importance of protecting oneself from excessive noise and encourage greater citizen participation in noise pollution management.[11] In emergency situations or unexpected events that may significantly increase noise levels, the real-time responsiveness of web-based systems becomes essential. By providing up-to-date information on noise levels in real time, authorities can make quick and coordinated decisions to minimise the detrimental effects of noise on people's health and the natural environment. This agile response can make a big difference in the protection and safety of the community in critical situations.[16]

Study area

In the Tarapoto region, an upward trend in noise pollution has been observed over the last decade. Specifically, in central urban areas, such as the vicinity of the Mercado Modelo and the Plaza de Armas, notable increases in noise levels have been documented, mainly attributable to vehicular flow and commercial dynamics. Festive events, such as the Tarapoto Carnival and the Feast of San Juan, despite their traditional and cultural nature, have shown noise levels that exceed the recommendations stipulated by the World Health Organisation (WHO).[17] Additionally, the expansion of the tourism sector in Tarapoto has led to an increase in vehicle density and recreational activities, generating additional sources of noise. This situation is particularly noticeable in renowned tourist destinations, such as the Blue Lagoon and the Ahuashiyacu Falls.[18]

On the other hand, residential areas located in the vicinity of the Tarapoto airport have reported increases in noise levels attributed to air traffic, with direct consequences on the well-being of the local population.[19] Similarly, recent infrastructure projects, such as road and building construction, have generated temporary increases in noise pollution, affecting the resident community and the commercial sector.[20]

Given the growing problem of noise pollution in Tarapoto, it is imperative to adopt innovative and technological approaches to its mitigation. In this context, the implementation of web-based systems emerges as a promising solution. These systems, by leveraging real-time monitoring and data analysis capabilities, can provide detailed insight into noise dynamics in different areas of the city. Data visualisation through these platforms facilitates informed decision-making and promotes public awareness of the severity of the problem. In the following section, several related studies will be presented that support the effectiveness and feasibility of these web-based systems in managing and reducing noise pollution.

Web systems and noise pollution

In the Chinese context, research has been carried out that makes use of existing data to design systems with user-friendly interfaces. These systems, in turn, facilitate data visualisation and analysis in different ways. A notable example is the work presented by the authors in Cardenas Alayo[19] who introduced a seismic activity mapping system. Through this tool, it is possible not only to track seismic events, but also to incorporate and share data relevant to such events. Similarly, researchers cited in Delgadillo Mendoza and Pérez Carpio[20] explored the potential of web-tracking technology and data mining from social networks. Their approach focussed on mapping areas affected by noise pollution levels resulting from the rapid growth of urban areas. The results of their study showed that prominent sources of pollution include construction industries, which was established after careful analysis. Both examples highlight how information technologies are being harnessed for data management and decision-making in this context. An analysis conducted in Colombia,[21] focussed on noise pollution around medical facilities, using mapping software for this purpose. This study concluded that considerable levels of pollution are attributable to vehicular traffic and commercial activities. Therefore, it is suggested that urban planning measures be implemented to address this problem. In a similar vein, an analysis carried out in Chile[8] focussed on a major city, where analytical software was used. The results indicated that a preeminent source of noise pollution is the vehicle fleet, exceeding the stipulated limits. Coincidentally, in the same context, the work presented in Ceballos Cogollo and Acevedo Buitrago[22] introduced an innovative system based on the Internet of Things (IoT) to monitor noise pollution. The data collected using this technology revealed levels that exceed the permissible limits in certain areas. Furthermore, this innovation has proven to be effective in significantly reducing the time required

to process and analyse the data. In addition, Gozalo et al.[23] has developed a mobile application that allows the assessment of noise pollution using a dispersion formula. A distinctive aspect of this approach is its active involvement of the community and government authorities in data collection. This type of collaboration engenders a collective awareness of the importance of addressing noise pollution. Finally, in a Peruvian context, researchers in Chanchi[24] conducted a study focussed on assessing the impact of noise pollution on people's health. Through the use of technological tools, they were able to identify considerably high noise levels, which raises serious concerns about the health of the population exposed to these levels of environmental noise.

In Peru, the problem of noise pollution has been affecting the health and well-being of the population, manifesting itself in effects such as stress, anxiety, irritability and hearing loss.[25,26] Although the impact on the quality of the urban environment is significant, noise pollution has not been considered a priority to address, despite its known capacity to cause irreparable damage to health.[27,28] For example, the city of Tarapoto, a place in the midst of urban development, has brought with it a prominent problem: noise pollution. This problem directly affects the population and generates discomfort, manifesting itself in effects such as stress, irritability and insomnia. The district municipality of Tarapoto carries out enforcement operations to address this situation, but the time needed to process the diagnosis and map the affected areas is considerable, making it difficult to make efficient decisions. During the development of the web-based system, collaborative work with the municipality was highlighted, as they provided the necessary information to improve the noise pollution monitoring process.

Void of knowledge and objective

Previous studies have highlighted noise pollution as a major problem in cities, with car horns being a major source. Excessive noise affects the quality of life of pedestrians and drivers. The implementation of technological systems, such as mobile applications and monitoring sensors, has shown promise in addressing this issue. However, the technology literature lacks solid evidence on specific web-based systems to manage noise pollution in urban districts such as Tarapoto. This work seeks to fill this gap by analysing and developing a web-based system for monitoring noise pollution in Tarapoto. The research gathered information, defined the architecture, added functionalities and performed tests to optimise the monitoring process. The objective of this study is to provide an effective technological solution through a web-based system to address noise pollution in Tarapoto. This research contributes to timely data-backed decision making to address noise pollution in urban areas. It also changes the way authorities manage the problem, allowing them to assess effects, adjust long-term strategies and foster community awareness and participation in noise pollution management.

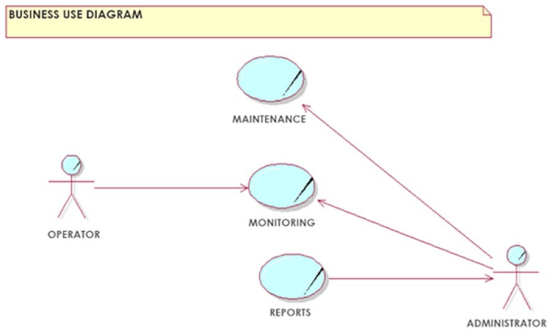

Figure 1. Business use case diagram.

Method

A laptop Intel Core i5-1135G7 (up to 4.2 GHz with Intel Turbo Boost Technology, 8 MB L3 cache and 4 cores) PCIe NVMe 256 GB solid state processor and 8 GB DDR4-3200 MHz RAM were used, and the agile RUP methodology was used, taking into account its 4 phases.

In the identification of the monitoring stations, an urban map was used to strategically locate the sampling points within the city, especially considering the areas with the highest incidence of vehicular traffic during trafficable hours. This selection was based on the need to capture representative data on noise pollution generated by vehicular traffic.

For the collection of aquatic data, a high quality sound level metre, the Casella model CEL-63x, was used, which allowed precise measurements to be taken in the places chosen as having the highest incidence of vehicular traffic. It is important to note that the device used was previously calibrated and certified by an accredited laboratory, following the guidelines established by the ISO/IEC 17025 standard.

In the field of noise data collection, High Fidelity Sound Sensors and Sound Pressure Level Sensors were implemented, strategically distributed at various points within Tarapoto, covering a variety of urban environments. Each sensor was subjected to a meticulous calibration process, carried out using controlled sound standards and certified reference equipment. This process ensured the reliability of the data collected by carefully adjusting each sensor, minimising possible deviations and guaranteeing consistent and accurate measurements. Calibration, in accordance with rigorous standards, contributed to the reliability and validity of the results obtained in this environmental monitoring study.

An analysis of the requirements for the development of the system was carried out, with meetings and coordination with the competent areas in order to rescue the relevant information for the project, as seen in Annex 1. The processes were identified from the location of the areas, the collection of data with the sound level meter to the mapping of the contaminated areas, finding the transportation system within the urban ecosystem as a disturbing factor in the state of well-being of the people. However, once the data was collected, the design of the system architecture was carried out according to the guidelines established previously, see Figure 1.

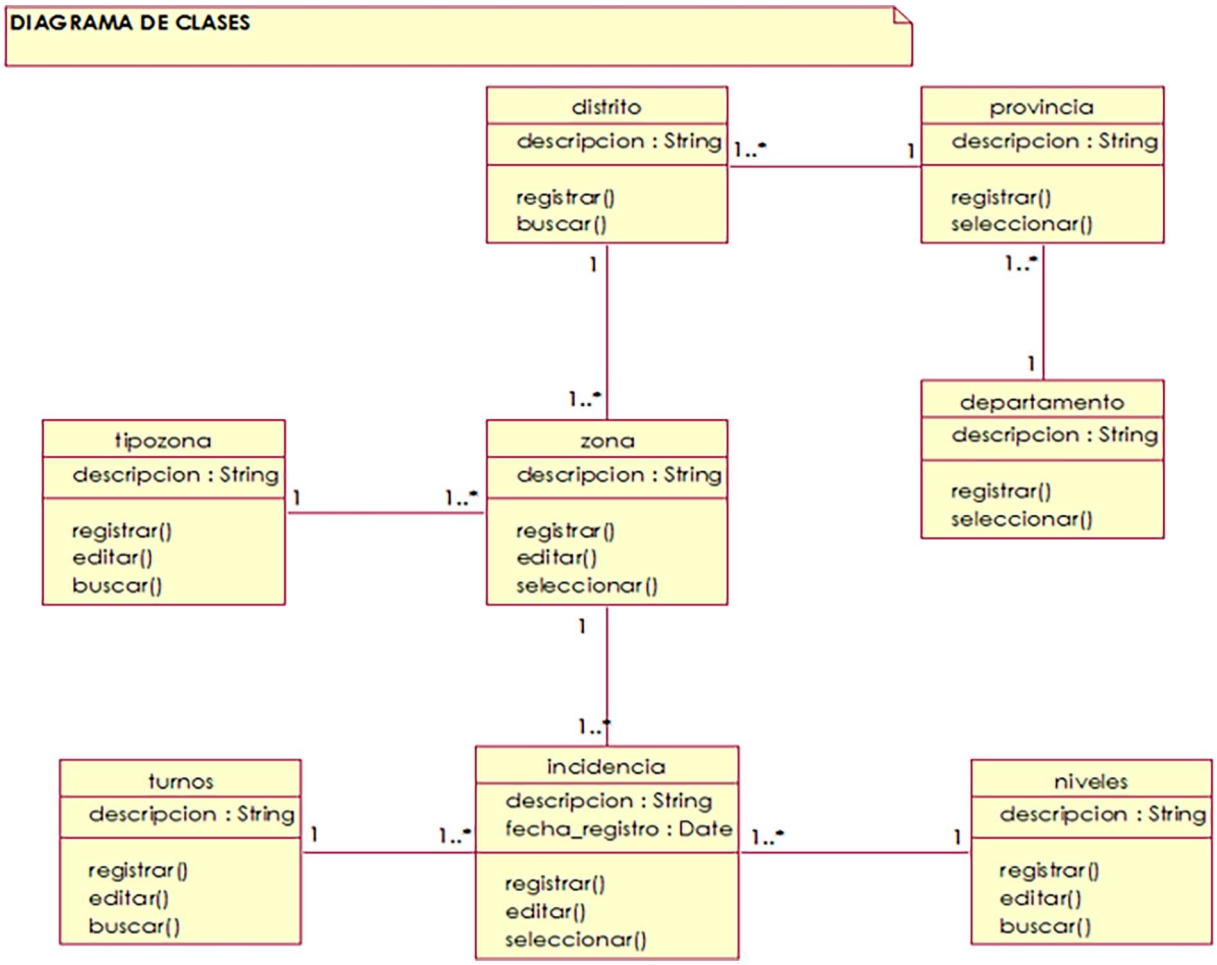

Figure 2. Class diagram.

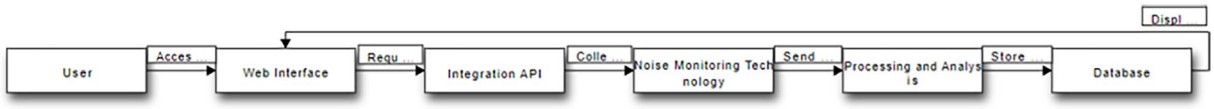

Figure 3. Block diagram of the operation of the system.

Once the design and architecture were defined, we proceeded to develop the system using JavaScript programming language, HTML, CSS and other technologies such as DBeaver, JQuery and MySql database manager was used. Subsequently, the system was verified and the appropriate tests were carried out to correct the errors identified and improve the process in collaboration with the institution's managers, as shown in Figure 2.

In order to ensure a clear and detailed understanding of the system developed, a block diagram has been developed in Figure 3 to show the overall architecture of the system. This diagram facilitates the visualisation of how each component interacts with the others, allowing a more intuitive interpretation of the data flow and the operations performed. The operation of the system is based on the collection of noise monitoring data, its processing and subsequent presentation in a user-friendly web interface. This interface not only displays the data in real time, but also allows for retrospective analysis and future projections based on historical trends.

The diagram shows how the user accesses and queries the web interface. The web interface, in turn, requests data via an integration API that collects real-time data from the noise monitoring technology. This raw data is sent for processing and analysis. Once processed, the data is stored in a database and subsequently displayed to the user via the web interface.

An essential feature of our system is its ability to interface with existing noise monitoring technology in Tarapoto. Through standardised APIs and communication protocols, the web-based system integrates seamlessly with the monitoring devices, enabling real-time data transmission without interruption. It is crucial to discuss this interaction in more detail, as it represents a point of convergence between pre-existing technology and the innovations introduced by our system.

Regarding the selection of hardware and software, specific criteria were adopted based on efficiency, scalability and robustness. The hardware was chosen considering its processing, memory and storage capacity, thus ensuring that the system can handle large volumes of data without compromising its performance. On the other hand, software choices were based on compatibility, security and ease of integration. The combination of these strategic choices has resulted in a highly efficient system, capable of delivering accurate and reliable results. It is essential to develop this information so that users and stakeholders understand the reasons behind each choice and how these decisions contribute to the overall success of the project.

Noise pollution measurement software provides a comprehensive solution for assessing and quantifying ambient noise levels. This type of programme, such as the one presented in this research 'Monitoring-System-Noise-Pollution',[29] uses advanced algorithms and acoustic analysis technology to record and analyse the various sound sources present in a given area.

Quality Assurance/Quality Control (QA/QC)

The present research is committed to ensuring the quality and reliability of the data collected throughout the noise pollution monitoring process. The implementation of a robust Quality Assurance/Quality Control (QA/QC) methodology is essential to ensure the validity of the results and their applicability in urban environments.

Sensor calibration and maintenance. All acoustic sensors used were subjected to a strict calibration protocol before and after the data collection period. Calibration was performed with controlled sound standards and certified reference equipment to minimise any deviation and ensure consistent measurements. In addition, a regular maintenance programme was established to check and adjust the sensors, ensuring their optimal performance throughout the study.

Representative sampling process. Measures were implemented to ensure a representative sampling of noise pollution in Tarapoto. Sensors were strategically distributed in different zones, considering the diversity of urban environments, from residential areas to commercial and industrial zones. This equitable distribution contributes to a complete representation of noise variability in the city.

Cross data validation. A data cross-validation process was carried out to corroborate the consistency and accuracy of the measurements. Results from different sensors located in nearby areas were compared to detect possible discrepancies and to ensure the consistency of the data collected.

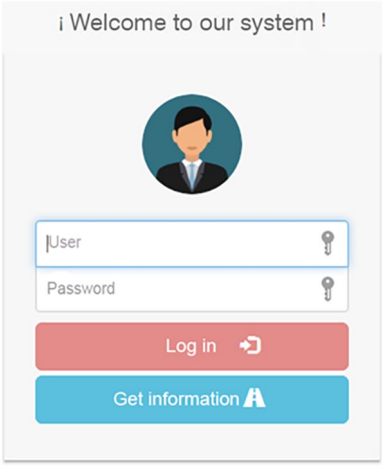

Figure 4. Web system login screen.

Results and Discussion

Figures 4 and 5 illustrate the process of accessing the system, highlighting the login stage using a username and password. This authentication is essential to safeguard data security by limiting access to authorised users. In addition to its visual representation, this step emphasises the confidentiality and privacy of information, allowing entry only to those with valid credentials.

The depiction of these figures highlights how the web system not only addresses functionality, but also aesthetics and the user experience when interacting with the system. This user-centred design dimension can be instrumental in fostering participation and engagement in urban noise pollution management. The presented concept aligns with the observations of Díaz-Barreto[30] who emphasises the importance of an intuitive graphical interface for effective data management. The visual and aesthetic presentation of the web system can influence the way users perceive and engage with information. Attractive and user-friendly visual interfaces can capture users' attention, encourage their active participation and motivate them to explore and understand the data presented. Incorporating interactive graphs and maps into the platform not only enhances the user experience, but also makes complex information easier to understand. Visualising data in the form of interactive graphs can enable users to identify trends and patterns more quickly, contributing to informed, evidence-based decision-making. In addition, comparison with the Meza Chumbes and Sarmiento Borda[25] approach that involves collecting data from the source of the problem via a mobile application is valuable. This highlights the versatility and accessibility of the system, which could be a critical factor in collecting accurate, real-time data.

Figure 6 shows a function of the system where users can report incidents related to noise pollution by registering information from affected areas. This option provides an active and participatory interaction by users, which can enrich the

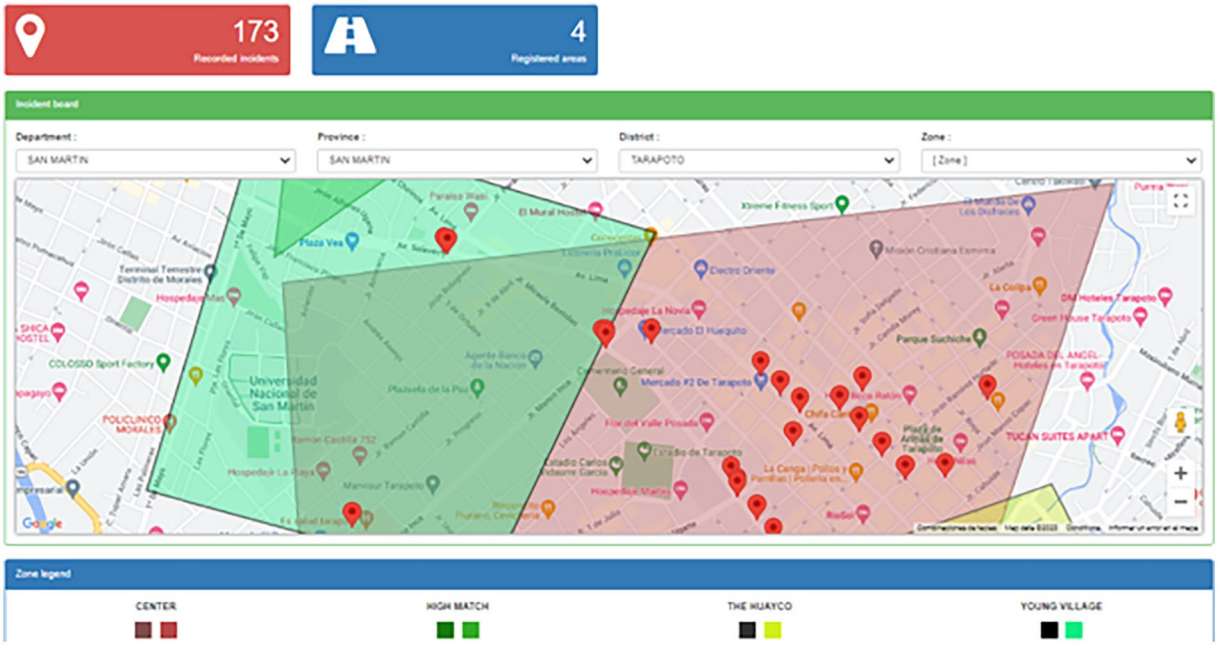

Figure 5. Interactive geographical map of the Tarapoto area, with incidence indicators and coloured zoning according to specific areas of interest.

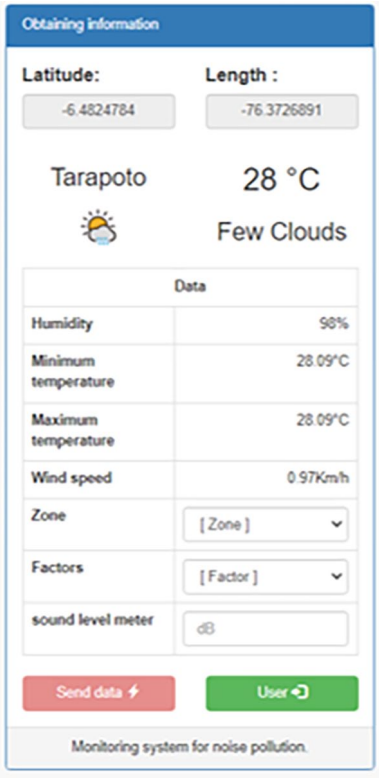

Figure 6. Tarapoto, Peru climate monitoring system interface with detailed data and selection options.

database and improve the community's perception of pollution management.

This figure highlights how the collection of data from contaminated areas provides significant time optimisation, as the input of information occurs directly at the site of the occurrence. This approach presents a clear convergence with the findings presented in Barba Carrión and Vásquez Aguirre[11] where it highlights how time optimisation in dispatch control monitoring leads to a noticeable increase in productivity. The on-site collection strategy not only optimises time, but also improves the quality of the data collected. By recording information at the point of occurrence, the possibility of errors or distortions due to data transcription is minimised. In addition, this methodology can capture real-time data, which is essential for accurate monitoring of patterns and fluctuations in noise pollution levels. The availability of real-time information allows for a more agile response to critical situations and the possibility to take immediate corrective action. The speed of data acquisition is crucial in noise pollution management, as it can directly influence the ability to implement timely and effective solutions. By eliminating the delays inherent in data entry at remote locations, this on-site collection approach reduces barriers that could limit a rapid response to noise pollution situations.

The generation of reports and incident lists, visible in Figure 7, simplifies the consolidation of data and the creation of detailed reports. This process allows detailed tracking of hotspots and patterns. Community participation broadens the coverage and perception of pollution, providing a more complete picture of the urban problem.

The table of recorded incidents illustrates various environmental parameters in different regions, with a notable focus on temperature, humidity and wind speed. The data suggest different areas of interest, such as 'Pueblo joven', 'Centro' and 'El huayco', with varying noise level measurements, possibly indicating differences in urban or anthropogenic activities in these areas. These results are comparable to other studies that highlight the influence of various environmental factors such as

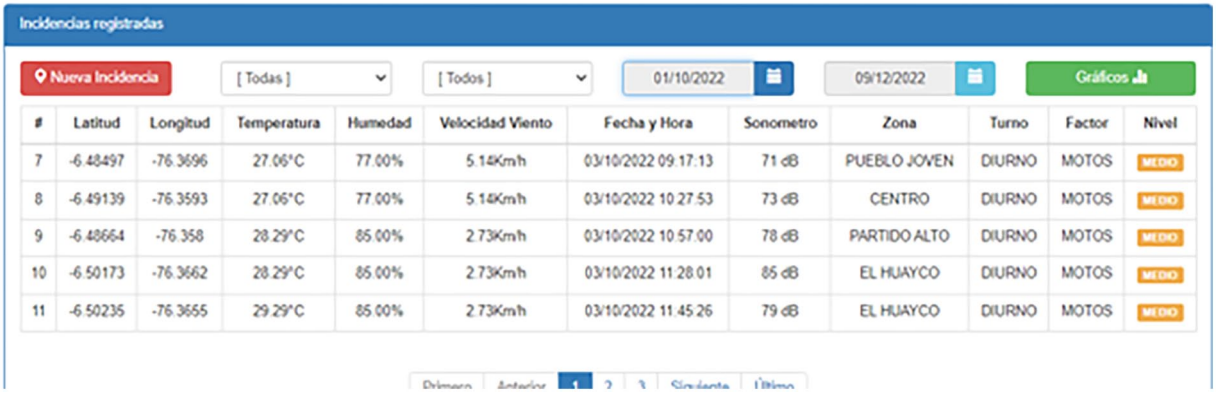

Figure 7. Table of occurrences recorded with detailed climatic and zonal data.

Figure 8. Reporting of contaminated areas through a bar chart.

temperature, humidity and wind speed on noise pollution.[31] This is because temperature influences how sound waves travel; they travel faster in warmer air. They also mention that humidity can also affect sound propagation because moist air, being less dense than dry air, makes it easier for sound waves to travel.[32] On the other hand, wind speed and wind direction can amplify or attenuate noise pollution.[33] Understanding the interaction of these environmental variables is therefore crucial when assessing the actual impact of noise pollution at a specific location.

Figure 8 highlights the visual processing of noise pollution data with bar charts and traffic lights. The bar charts allow comparison of levels between zones, facilitating the identification of problem areas. Traffic lights, based on colours, provide immediate perception of risk by levels, improving public understanding and informed decisions. This visual representation not only provides an instant status of affected areas, but also highlights the potential consequences of prolonged exposure. This effective visualisation methodology aligns with the observations of Ceballos Cogollo and Acevedo Buitrago[22] who highlight the impacts of chronic exposure to noise pollution. The incorporation of traffic lights and graphics in data presentation has the potential to clearly communicate noise pollution levels and their associated risks, which can be a powerful tool for public awareness and informed decision making. To the same way, Gonzales Herry and Ayala José Elías[34] highlight the importance of taking timely action to address this problem by making use of technology.

In Figure 9, it is visualised that the web-based system further deepens the understanding of noise pollution events in different urban areas. This detailed section, which provides a date-based analysis, allows a chronological tracking of events in

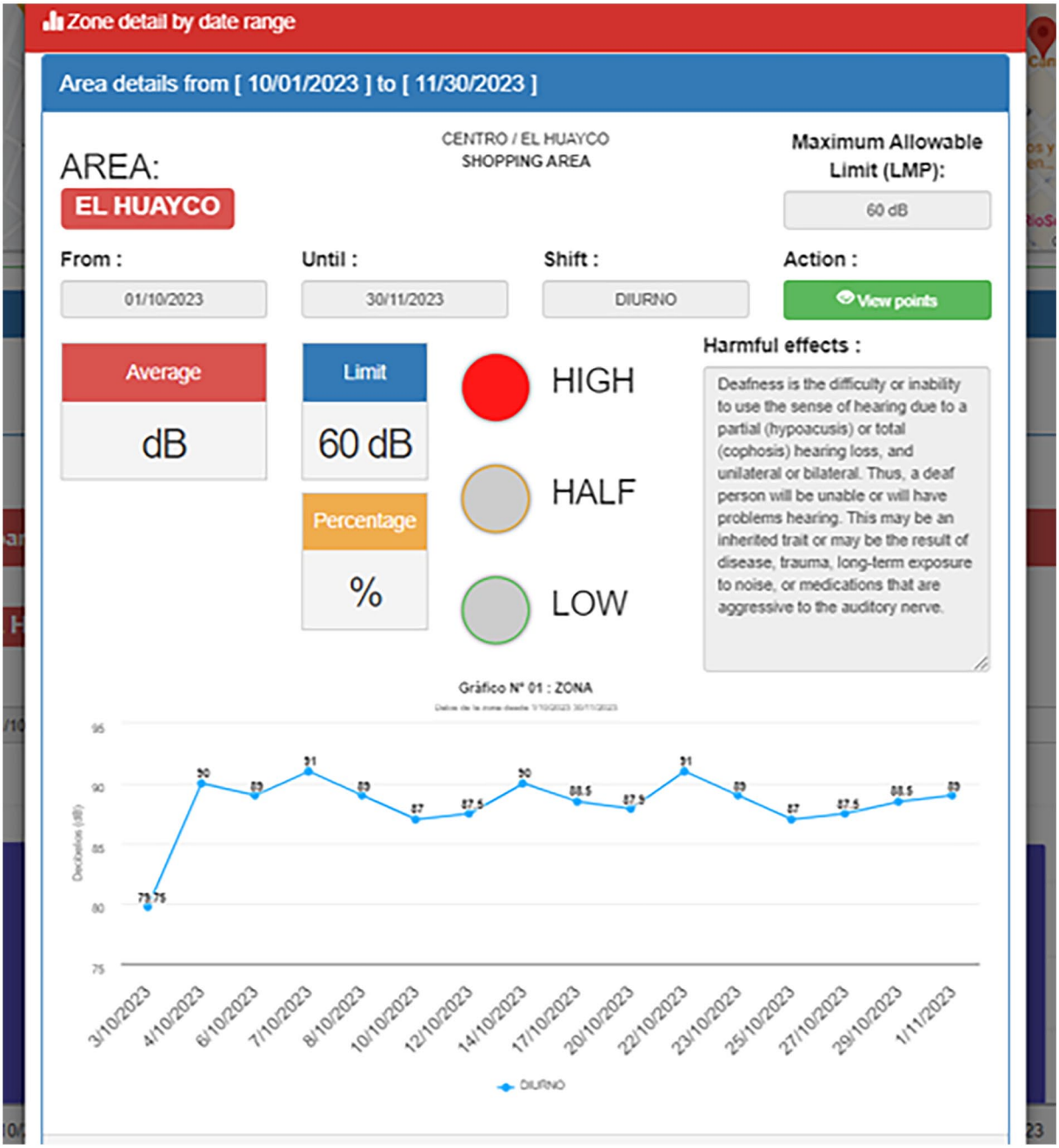

Figure 9. Detailed summary of noise levels and harmful effects in the area by dates.

each specific area. This temporal visualisation plays a key role in providing information on the patterns and fluctuations of noise pollution over time.

The results discussed above highlight how the visual representation in Figures 4, 6 and 8 of the web system not only addresses functional aspects, but also user experience and aesthetics in the interaction with the system. This user-centred design dimension becomes a key element in fostering participation and engagement in urban noise pollution management.[35] The intuitive graphical interface and the ability to interact with interactive maps can simplify the identification of trends and patterns, which influences informed decision making.[36,37]

Efficient management of noise pollution through web-based systems involves not only data collection and analysis, but also consideration of ethical and privacy issues. While the main purpose is to monitor noise levels, it is crucial to ensure that no sensitive data or data that may compromise the privacy of individuals or entities is collected. It is therefore pertinent that any document or proposal that addresses the implementation of such systems includes a detailed section on the security and privacy measures adopted.

On the other hand, the sustainability and success of any monitoring system depends to a large extent on the acceptance and active participation of the community and local authorities. It is essential that collaboration and communication

mechanisms are established to enable the integration of these actors in the process. The engagement strategy should be detailed in the document, providing a clear framework on how it is planned to sensitise, train and collaborate with the community and authorities in the adoption and maintenance of the system. In addition, to improve the comprehensiveness of the document, it would be beneficial to include contextual information that may influence the dynamics of noise pollution, such as demographic factors, traffic patterns and urban characteristics specific to the region under study.

In that sense, the figures discussed in this context evidence the importance of user-centred design in web-based noise pollution management systems. In situ collection capability optimises efficiency and decision making. Visual representation through traffic lights and graphics highlights risks and promotes awareness. These strategies align with previous findings and emphasise the importance of technology to effectively address urban noise pollution issues.

Conclusions

Noise pollution in urban areas, such as Tarapoto, has emerged as an environmental and social challenge of growing concern. Excessive noise, mainly caused by vehicular and commercial activities, not only disturbs daily tranquillity, but also has implications for the health and well-being of the population. In this context, the implementation of a web-based system to monitor and manage noise pollution is presented as an innovative and necessary solution.

Our research has shown that this web-based system, specifically designed for Tarapoto, is able to efficiently collect, analyse and present data, facilitating decision making based on accurate and up-to-date information. The system's ability to generate rapid and detailed reports on noise levels in real time represents a significant advance in the city's environmental management. Furthermore, by providing a holistic view of the noise landscape, it allows authorities and the community to identify critical areas and act proactively. However, the model is not without its challenges. Its implementation can be complex, requiring specialised technical and human resources. While data collection is emphasised, concerns may arise about the privacy and security of the information collected. In addition, its reliance on advanced technologies could present problems in case of technical failures.

The applicability of the model is broad, being relevant to a variety of urban contexts. It can be adapted to different levels of population density, traffic patterns and geographical characteristics, making it suitable for both densely populated areas and regions that are beginning to face noise pollution problems. However, the research has its limitations. Its focus may have been on specific geographic areas, which could restrict its applicability to other regions. The lack of consistent historical data may limit the model's ability to predict long-term trends. In addition, while the importance of external factors, such as socio-economic, political or climatic changes, is acknowledged, these may not have been fully considered, which could affect the accuracy of the model. Finally, while the importance of community participation is stressed, achieving effective and sustained collaboration can be a challenge in practice.

Limitations

The applicability of the model is broad, being relevant to a variety of urban contexts. It can be adapted to different levels of population density, traffic patterns and geographical characteristics, making it suitable for both densely populated areas and regions that are beginning to face noise pollution problems. However, the research has its limitations. Its focus may have been on specific geographic areas, which could restrict its applicability to other regions. The lack of consistent historical data may limit the model's ability to predict long-term trends. In addition, although the importance of external factors, such as socio-economic, political or climatic changes, is recognised, these may not have been fully considered, which could affect the accuracy of the model. Also, the cross-validation processes implemented, inherent limitations in sensor accuracy and measurement variability could introduce some uncertainty in the results. Finally, while the importance of community participation is stressed, achieving effective and sustained collaboration can be challenging in practice.

Recommendations

The implementation and effectiveness of a web-based system to manage noise pollution in Tarapoto requires careful consideration of several key aspects. First, continuous validation of the system is essential. To ensure its functionality and usability, it is imperative to establish a periodic testing protocol. These tests, which should involve real users, both expert and lay, will provide valuable feedback for adjustments and improvements. A comprehensive description of these validation steps, including methodologies and evaluation criteria, will not only strengthen the reliability of the system, but also facilitate its acceptance and adaptation by the community.

Second, given the dynamic nature of the technology, regular maintenance and updating of the system is crucial. To keep up with innovations and ensure its long-term effectiveness, it is advisable to establish a structured maintenance plan. This plan should include systematic software reviews, integration of new functionalities and adaptation to emerging technological changes. A detailed discussion of these plans, addressing timelines, responsibilities and methodologies, will ensure the sustainability and relevance of the system in a constantly evolving technological environment.

Finally, given the potential for success of the system in Tarapoto, scalability and expansion are aspects that should not be overlooked. The design of the system should be modular and flexible, allowing for its adaptation to larger areas or areas with different characteristics. In addition, it is essential to consider the replicability of the system in other regions, adapting

its functionalities according to the specific needs of each location. The discussion on scalability should be holistic, addressing technical, logistical and financial aspects to ensure successful implementation in diverse contexts.

Acknowledgements

Thanks to Universidad San Ignacio de Loyola for supporting this research over the years and for allowing us to develop this research in collaboration with other universities.

Author Contributions

Software, Ivan Estrella; writing—original draft preparation, Alex Pacheco; formal analysis, Wilson Marin; writing—review and editing, Liz Pacheco-Pumaleque; methodology, Nestor Cuba-Carbajal; acquisition and interpretation of the data, Félix Pucuhuayla-Revatta; Study concept, Edwin Felix-Poicon; Data curation, Marco Añaños Bedriñaña.

Ethical Approval and Consent to Participate

This study does not meet the definition of human subjects research and therefore an exemption was granted. The workers understood the objectives and methods of the study and gave their written informed consent.

Software Availability

https://github.com/STARVAN007/Monitoring-System-Noise-Pollution

REFERENCES

1. Ogurtsova K, Soppa VJ, Weimar C, et al. Association of long-term air pollution and ambient noise with cognitive decline in the Heinz Nixdorf recall study. *Environ Pollut*. 2023;331:1-12.
2. Yu Y, Su J, Jerrett M, et al. Air pollution and traffic noise interact to affect cognitive health in older Mexican Americans. *Environ Int*. 2023;173:34-49.
3. Baffoe PE, Duker AA, Senkyire-Kwarteng EV. Assessment of health impacts of noise pollution in the Tarkwa mining community of Ghana using noise mapping techniques. *Glob Heal J*. 2022;6:19-29.
4. Baptista N, Januario JF, Cruz CO. Social and financial sustainability of real estate investment: evaluating public perceptions towards blockchain technology. *Sustainability*. 2023;15:12288.
5. Berkhout BW, Budria A, Thieltges DW, Slabbekoorn H. Anthropogenic noise pollution and wildlife diseases. *Trends Parasitol*. 2023;39:181-190.
6. Hener T. Noise pollution and violent crime. *J Public Econ*. 2022;215:104748.
7. Lee J, Cho K. Effects of science, technology, and innovation official development assistance on foreign direct investment in developing countries. *Sustainability*. 2023;15:12293.
8. Wang Y, Wang G, Li H, Gong L, Wu Z. Mapping and analyzing the construction noise pollution in China using social media platforms. *Environ Impact Assess Rev*. 2022;97:106863.
9. León CJ, Hernández-Alemán A, Fernández-Hernández C, Araña JE. Are rural residents willing to trade-off higher noise for lower air pollution? Evidence from revealed preferences. *Ecol Econ*. 2023;207:107784.
10. Ore J, Pacheco A, Roque E, Reyes A, Pacheco L. Augmented reality for the treatment of arachnophobia: exposure therapy. *World J Eng*. 2021;18:566-572.
11. Barba Carrión B, Vásquez Aguirre B. 2019 Sistema de monitoreo remoto para mejorar el control de recojo de desechos en el Mercado La Hermelinda, Trujillo 2019 [Internet]. Repositorio Institucional - UCV. [TRUJILLO]. Universidad Cesar Vallejo. 2020. Accessed August 11, 2022. https://repositorio.ucv.edu.pe/handle/20.500.12692/44856
12. He X, Huang Y. Web content management systems as a support service in academic library websites: an Investigation of the world-class universities in 2012–2022. *J Acad Librariansh*. 2023;49:102716.
13. Castilla R, Pacheco A, Franco J. Digital government: mobile applications and their impact on access to public information. *SoftwareX*. 2023;22:101382.
14. Lin Q, Lin B, Zhang D, Wu J. Web-based prototype system for flood simulation and forecasting based on the HEC-HMS model. *Environ Model Softw*. 2022;158:105541.
15. Fernández AM, Reyes MJ, López MIV. Tecnologías de la información y comunicación (TIC) en formación y docencia. *FMC*. 2022;29:28-38.
16. Fernández R. • TI y telecomunicaciones: gasto mundial por segmento de negocio 2015-2022 | Statista [Internet]. 2021. Accessed August 19, 2022. https://es.statista.com/estadisticas/571960/gasto-en-tic-y-telecomunicaciones-en-el-mundo-por-segmento-de-negocio/
17. World Health Organization. Global standard for safe listening at music venues and events [Internet]. 2022. Accessed January 9, 2024. https://www.who.int/es/publications/i/item/9789240043114
18. Cardenas Alayo C. Los efectos sociales de la contaminación acústica del transporte urbano en la ciudad de Tarapoto - Región San Martín. Repositorio - UNSM [Internet]. 2015. Accessed November 1, 2023. http://repositorio.unsm.edu.pe/handle/11458/2618
19. Cardenas Alayo C. Los efectos sociales de la contaminación acústica del transporte urbano en la ciudad de Tarapoto - Región San Martín. Repositorio - UNSM [Internet]. 2015. Accessed January 9, 2024. http://repositorio.unsm.edu.pe/handle/11458/2618
20. Delgadillo Mendoza MC, Pérez Carpio JE. Evaluación de contaminación sonora vehicular en el centro de la ciudad de Tarapoto, San Martín, 2015. *Rev de Investig Cienc Tecnol Y Desarro*. 2018. Accessed January 4, 2024. https://repositorio.upeu.edu.pe/handle/20.500.12840/505
21. Wu X, Xu C, Xu X, et al. A Web-GIS hazards information system of the 2008 Wenchuan earthquake in China. *Nat Hazards Res*. 2022;2:210-217.
22. Ceballos Cogollo JD, Acevedo Buitrago B. Evaluación de la contaminación acústica en zonas aledañas a entornos sensibles y su relación con el planeamiento territorial en la ciudad de Bogotá. *Respuestas*. 2022;26:181-191.
23. Gozalo GR, Lizana MAC, Pérez GSV. Análisis del ruido en la ciudad de concepción (Chile) en relación a la funcionalidad de las vías urbanas / análise do ruído na cidade de Concepción (Chile) em relação à funcionalidade das estradas urbanas. *Braz J Dev*. 2020;6:90348-90362.
24. Chanchi G. Sistema IoT para la monitorización y análisis de niveles de ruido IoT system for monitoring and analyzing noise levels. 2020.
25. Meza Chumbes D, Sarmiento Borda F. Propuesta de desarrollo de una aplicación móvil que permita medir la contaminación acústica en el distrito de Cercado de Lima [Internet]. Universidad Tecnológica del Perú. [Lima]. Universidad Tecnológica del Perú. 2020. Accessed August 19, 2022. http://repositorio.utp.edu.pe/handle/20.500.12867/3357
26. Grau W. The environmental noise and the health in the inhabitant of Cajamarca's historic center. *Mangrove*. 2019;16:11-18.
27. Mamani Q, Elías C. Impacto de la contaminación sonora en la salud de la población de la ciudad de Juliaca, Perú. *Cienc Lat Rev Cient Multidiscip*. 2021;5:331-337.
28. Gamero Motta HG, Motta G. Comparación de los niveles de ruido, normativa y gestión de ruido ambiental en Lima y Callao respecto a otras ciudades de Latinoamérica. *Revista Kawsaypacha: Sociedad y Medio Ambiente*. 2020;5:107-142.
29. Estrella I, Pacheco A. Monitoring system noise pollution [Internet]. 2023. Accessed February 1, 2024. https://github.com/STARVAN007/Monitoring-System-Noise-Pollution
30. Díaz-Barreto A. Desarrollo de un prototipo de sistema de información para la aplicación del modelo de clusterización para el ruteo de vehículos para una red de distribución de mercancías de un operador logístico en Colombia [Internet]. [Bogota]. Universidad Católica de Colombia. 2021. Accessed August 17, 2022. https://repository.ucatolica.edu.co/handle/10983/25610
31. D'Azevedo García G. Contaminación sonora y su relación con el clima local e impacto de su valoración económica en la ciudad de Iquitos - 2012. Universidad Nacional de la Amazonía Peruana [Internet]. 2014. Accessed November 1, 2023. https://repositorio.unapiquitos.edu.pe/handle/20.500.12737/4088
32. Thompson R, Smith RB, Bou Karim Y, et al. Noise pollution and human cognition: an updated systematic review and meta-analysis of recent evidence. *Environ Int*. 2022;158:106905.
33. Sordello R, Flamerie De Lachapelle F, Livoreil B, Vanpeene S. Evidence of the environmental impact of noise pollution on biodiversity: a systematic map protocol. *Environ Evid*. 2019;8:1-7.
34. Gonzales Herry L, Ayala José Elías P. Contaminación sonora vehicular de los años 2015 al 2019 en el distrito de San Martín de Porres, Lima [Internet]. Repositorio Institucional - UCV. [Chiclayo]. Universidad Cesar Vallejo. 2020. Accessed August 19, 2022. https://repositorio.ucv.edu.pe/handle/20.500.12692/54398
35. Castilla R, Pacheco A, Robles I, Reyes A, Inquilla R. Digital channel for interaction with citizens in public sector entities. *World J Eng*. 2021;18:547-552.
36. Fan X, Li L, Zhao L, et al. Environmental noise pollution control of substation by passive vibration and acoustic reduction strategies. *Appl Acoust*. 2020;165:107305.
37. Eminson K, Cai YS, Chen Y, et al. Does air pollution confound associations between environmental noise and cardiovascular outcomes? - a systematic review. *Environ Res*. 2023;232:116075.

Annexes (Estrella and Pacheco, 2023)

Questionnaire on Noise Pollution in Tarapoto:

1. Demographic Information
   - 1.1 Age:
   - 1.2 Genre:
   - 1.3 Educational level:
   - 1.4 Residence time in Tarapoto:

2. Perception of Noise Pollution
   - 2.1 How would you describe the noise level in your area of residence?
     Very low
     Low
     Moderate
     High
     Very high
   - 2.2 What noise sources do you identify as the most annoying in Tarapoto? (Specify, eg,: traffic, construction, events, etc.)

3. Daily Exhibition
   - 3.1 How much time do you spend daily in noisy environments? (eg, busy streets, commercial areas)
   - 3.2 How do you think this exposure affects your quality of life?

4. Knowledge of Noise Control Measures
   - 4.1 Are you aware of measures implemented by local authorities to control noise pollution in Tarapoto?
     Yeah
     No
   - 4.2 Do you think these measures are effective?

5. Impact on Health and Wellbeing
   - 5.1 Have you experienced any negative impact on your health due to noise pollution? (eg, stress, sleeping difficulties)
     Yeah
     No
   - 5.2 How do you think noise pollution affects the general well-being of the community?