NOISE POLLUTION IN URBAN AREAS: MEASUREMENT AND ANALYSIS OF TRAFFIC NOISE IMPACTS ON HEALTH AND EDUCATION SERVICES IN BANDUNG CITY

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Abstract

Traffic noise is a significant environmental issue in urban areas, adversely affecting public health and the quality of essential services. This study aims to evaluate the noise pollution levels at sensitive locations, consist of a health clinic and two schools in Bandung City, Indonesia. The research involves measuring noise levels, mapping their distribution, and analyzing the data. Measurements were conducted over four days using a smartphone application, Decibel X, to record noise levels every 5 seconds for 10-minute sessions across various times of the day. Simultaneously, vehicle counts were recorded to establish a correlation between traffic volume and noise levels. A questionnaire survey was administered to gather perceptions of noise impact from teachers, students, clinic staff, and patients. The findings revealed that noise levels at several points, particularly near busy roads, exceeded recommended standards, significantly disrupting concentration and causing physical symptoms such as headaches among respondents. Noise hotspots identified included Point1 and Point6, where average noise levels were consistently high, while Point4 and Point5 showed lower but more variable noise levels. To mitigate traffic noise, the study recommends a combination of installing noise barriers, creating green spaces, and enhancing building insulation. Regular noise monitoring and public awareness campaigns are essential for effective noise management and improving the quality of life in Bandung City.

Keywords: *noise impact, noise measurement, traffic noise*

Introduction

Traffic noise is a major issue in urban areas, posing significant risks to public health and overall quality of life. Bandung City, a bustling urban center in Indonesia, is grappling with this problem. This study focuses on evaluating noise pollution in key areas like a health clinic and two schools. The aim is to measure noise levels, map their distribution, and analyze the data following the guidelines set by the Ministry of Environment Regulation No. 48 of 1996 on Noise Level Standards.

Previous studies have shown that traffic noise negatively affects both educational and healthcare environments. For instance, Shukla and Tandel (2023) found that noise significantly disrupted teaching and learning in schools, with levels exceeding WHO recommendations, leading to distractions and concentration problems among students. Similarly, European studies (2022) have linked high noise annoyance to increased rates of ischemic heart disease mortality, emphasizing the need for standardized noise mapping and mitigation. Research in

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Kayseri, Turkey by Kasagici and Ateş (2021) identified elevated noise levels in schools and hospitals, contributing to health issues such as headaches and stress. Lakhtaria et al. (2021) noted high noise levels along busy corridors in Ahmedabad, India, stressing the need for effective noise mitigation measures. Ali et al. (2020) reported that most areas in Quetta surpassed permissible noise standards, significantly affecting the healthcare and educational sectors. These findings underscore the urgent need for actions to reduce noise pollution and safeguard public health.

Traffic noise not only affects hearing but also contributes to various health issues. In Pisa, Italy, Bustaffa et al. (2022) found a link between traffic noise and higher cardiovascular disease risks, particularly ischemic and cerebrovascular diseases, with increased mortality and hospitalization rates among those highly exposed. Münzel et al. (2024) further highlighted that transportation noise can lead to cardiovascular morbidity and mortality through mechanisms like sleep disturbance, elevated stress hormones, and oxidative stress. Yadav and Yadav (2023) identified significant psychological effects of traffic noise in India, including increased stress and annoyance, with limited research on physiological impacts, pointing to a critical area for future studies. A review by Warren and Bell (2023) stressed the need for policy improvements to address both auditory and non-auditory health impacts of roadway noise.

Children's cognitive development and learning processes are especially vulnerable to traffic noise. Shukla and Tandel (2023) found that school noise levels significantly exceeded WHO recommendations, causing high distraction rates and impairing speech intelligibility and concentration among students. Boyle (2023) observed that road traffic noise at home negatively impacted adolescents' cognitive performance, particularly affecting memory and concentration. In Barcelona, Foraster et al. (2022) linked school traffic noise exposure to slower development of working memory and increased inattentiveness in children. Boothe and Baldauf (2020) highlighted that traffic emissions, including noise, could delay cognitive development and cause health issues in children, especially those in disadvantaged neighborhoods. Brumm et al. (2021) used animal models to show that traffic noise disrupts vocal development and suppresses immune function, suggesting similar stress effects in children, and impacting their learning capabilities.

Long-term exposure to traffic noise has been shown to cause significant health issues in both school and hospital environments. Shukla and Tandel (2023) reported cognitive problems among students due to high noise levels, affecting their academic performance and well-being. Cole-Hunter et al. (2021) found associations between long-term road traffic noise exposure and increased risk of stroke among Danish nurses. Kasagici and Ateş (2021) noted increased reports of headaches, frustration, and stress due to elevated noise levels in schools and hospitals. De Kluizenaar (2015) emphasized the link between long-term exposure to traffic noise and cardiovascular issues, including ischemic heart disease, highlighting its impact on sleep disturbance and overall stress levels. Additionally, de Kluizenaar et al. (2013) linked traffic noise and air pollution to increased risks of hospital admissions for ischemic heart disease and cerebrovascular events.

This study aims to expand the existing knowledge by measuring and analyzing traffic noise levels at sensitive locations in Bandung City, mapping their distribution, and assessing their impact on healthcare and educational services. It also seeks to evaluate local respondents' perceptions of noise through questionnaires, offering a comprehensive view of the implications of traffic noise in these crucial areas.

Research Methodology

Study Locations

This research was carried out in three sensitive locations in Bandung City: a health clinic, School 1, and School 2. These sites were chosen due to their sensitivity to traffic noise and its potential effects on healthcare and education.

Figure 1. Study Locations

Traffic Noise Measurement

Noise levels were assessed using a smartphone app called Decibel X, adhering to the Ministry of Environment Regulation No. 48 of 1996 on Noise Level Standards.

Measurement Protocol

Noise measurements were conducted over four days, including both weekdays (Monday and Friday) and weekends (Saturday and Sunday). Each noise measurement session lasted for 10 minutes. Data Collection: Readings were recorded every 5 seconds, resulting in 120 data points per session. Noise levels were recorded over a full 24-hour period, with daytime (06:00-22:00) divided into four intervals and nighttime (22:00-06:00) into three intervals. The intervals are as follows:

- L1 at 07:00, covering 06:00-09:00
- L2 at 10:00, covering 09:00-11:00
- L3 at 14:00, covering 13:00-15:00
- L4 at 17:00, covering 16:00-18:00
- L5 at 21:00, covering 20:00-22:00
- L6 at 01:00, covering 00:00-03:00
- L7 at 04:00, covering 03:00-06:00

Noise Level Calculation

The recorded noise data were analyzed using the following Ls (Leq, daytime) Average noise level during the day, Lm (Leq, nighttime) Average noise level during the night, and Lsm (Leq, 24-hour) Average noise level over a full day.

The data derived from direct field measurements will be calculated to produce a single data point representing the noise level at each monitoring point during the respective time interval, called Ltm5, using the following formula:

$$Ltm5=10\log \left(\frac{1}{n}\sum n \left(Tn\cdot 10^{0.1.Ln}\right)\right) \quad (1)$$

Description:

- Ltm5 = Equivalent continuous noise level with sample collection every 5 seconds
- N = Number of data points
- Ln = Noise level result
- Tn = 5 (reading interval, i.e., every 5 seconds)

The calculation of Ltm5 is performed for all data, each representing a sampling interval point, so the results are considered to represent noise data for each sample from L1 to L7. Then, the calculation of daytime noise level (Ls) and nighttime noise level (Lm) to obtain noise levels during the day and night can be performed using the formula:

$$Ls=10\log\left(\frac{1}{16}\sum_{i=1}^{4}(Ti.10^{0.1.Li})\right) \text{dBA} \quad (2)$$

Description:

- T = 16, the duration of sample collection during the daytime, i.e., 16 hours
- Li = Noise level result for each calculation, L1, L2, L3, L4
- Ti = Sampling interval (daytime, every 4 hours)

$$Ls=10\log\left(\frac{1}{16}\sum_{i=5}^{7}(Ti.10^{0.1.Li})\right) \text{dBA} \quad (3)$$

Description:

- T = 8, the duration of sample collection during nighttime, i.e., 8 hours
- Li = Noise level result for each calculation, L5, L6, L7
- Ti = Sampling interval (nighttime, every 3 hours)

After obtaining the noise level results for both daytime and nighttime, the overall noise level for both day and night can be calculated using the formula:

$$Lsm=10\log\left(\frac{1}{24}\sum_{i=1}^{8}(16.10^{0.1.Ls}+8\cdot10^{0.1.(Lm+5)})\right) \text{dBA} \quad (4)$$

Description:

- Lsm = Equivalent continuous noise level for both day and night
- Ls = Equivalent continuous noise level for daytime
- Lm = Equivalent continuous noise level for nighttime

Noise Distribution Mapping

Noise distribution maps were generated to visually represent noise levels at the study locations, based on the data collected with the sound level meter application.

Questionnaire Survey

A survey was conducted to gather opinions on traffic noise from different respondent groups in the study areas. The respondents consist of 25 teaching and non-teaching staff, 144 students from the schools, 15 employees, and 93 patients from the health clinic.

Questionnaire Design

The survey included questions about the respondents' understanding of noise levels and its impact, with responses recorded on a Likert scale Strongly Agree (SS), Agree (S), Neutral (N), Disagree (TS), and Strongly Disagree (STS).

This methodology ensures a thorough assessment of traffic noise levels and their effects on healthcare and educational services in Bandung City, offering valuable insights for future noise mitigation strategies.

Result and Discussion

Noise Measurement Data

Traffic noise levels measured at various times and locations over four days: Monday, Friday, Saturday, and Sunday are summarized in table 1.

Table 1. Summary of Noise Levels

Measurement Date & Time	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7
1/7/2024 7:00	78.72	76.37	66.96	50.11	53.02	78.46	78.31
1/7/2024 10:00	82.12	78.21	72.60	52.44	60.95	73.65	74.73
1/7/2024 14:00	81.32	73.78	63.52	50.17	53.32	77.04	77.22
1/7/2024 17:00	86.08	75.43	51.25	45.61	44.81	78.81	77.99
1/7/2024 21:00	73.34	70.90	47.85	42.81	42.91	71.23	75.12
1/8/2024 1:00	68.50	63.37	50.38	44.83	43.90	69.44	68.99
1/8/2024 4:00	72.01	61.09	51.17	49.60	48.85	71.06	68.84

Measurement Date & Time	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7
1/8/2024 7:00	78.21	72.74	61.98	57.56	59.76	79.23	76.20
1/8/2024 10:00	81.47	74.22	62.04	55.06	55.43	80.56	77.61
1/8/2024 14:00	80.24	73.10	60.00	49.82	54.69	78.61	77.00
1/8/2024 17:00	80.99	71.25	58.10	49.82	54.70	78.61	76.19
1/8/2024 21:00	80.06	70.98	57.86	49.26	53.60	78.49	75.13
1/9/2024 1:00	70.72	54.23	43.66	40.38	41.19	67.61	67.14
1/9/2024 4:00	71.30	55.51	44.58	40.41	41.95	68.80	68.65
1/12/2024 7:00	84.30	76.80	74.99	76.03	75.11	79.66	78.51
1/12/2024 10:00	83.27	75.56	77.93	71.30	65.14	80.27	79.18
1/12/2024 14:00	84.98	74.01	74.30	70.84	65.63	80.16	80.96
1/12/2024 17:00	82.62	74.60	68.70	65.85	60.72	81.62	83.25
1/12/2024 21:00	79.53	72.09	64.94	56.64	51.26	76.46	76.17
1/13/2024 1:00	72.57	62.96	59.29	52.34	47.11	70.49	67.67
1/13/2024 4:00	74.86	64.06	61.23	53.24	49.21	71.75	67.96
1/13/2024 7:00	78.35	57.68	56.65	51.81	53.11	76.28	74.88
1/13/2024 10:00	76.83	70.75	54.99	53.98	55.98	74.46	74.05
1/13/2024 14:00	79.48	70.47	67.87	55.20	47.62	76.58	74.85
1/13/2024 17:00	81.03	61.84	55.91	63.96	53.66	76.13	73.64
1/13/2024 21:00	68.80	57.88	49.98	42.83	47.27	71.26	61.96
1/14/2024 1:00	66.76	65.80	55.19	42.15	41.81	68.32	67.77
1/14/2024 4:00	70.11	67.02	57.04	49.32	46.71	70.22	70.97

Based on the measurement Point1 and Point6 consistently showed higher average noise levels compared to other locations, indicating potential hotspots. Point 3 and Point 4 exhibited more variability and had some of the lowest minimum values, indicating more fluctuation at these points. Point 2, Point 3, Point 4, and Point 5 had higher standard deviations, suggesting more variation in measurements.

Point 1 and Point 6 recorded the highest average noise levels, suggesting consistently high measurements likely due to environmental factors or location-specific conditions. Point4 and Point5 had the lowest average values, indicating these areas might be less active or have cooler conditions. Variability and Consistency: Point3 and Point4 showed higher variability, suggesting sensitivity to external influences. Conversely, Point6 showed consistent measurements with a lower standard deviation, indicating stable conditions.

Point1 and Point6 might represent areas with higher activity or environmental influences, necessitating further investigation. The higher variability in Point3 and Point4 suggests these areas might benefit from more frequent monitoring. The consistently lower measurements at Point 4 and Point 5 could serve as control points for comparison.

Noise Distribution Mapping

Figure 1 shows the noise levels at measurement locations. Noise distribution maps were created to visually represent the noise levels at the study locations, providing a clear visual aid for understanding noise impact. The box plot shows the distribution of noise levels at different measurement locations.

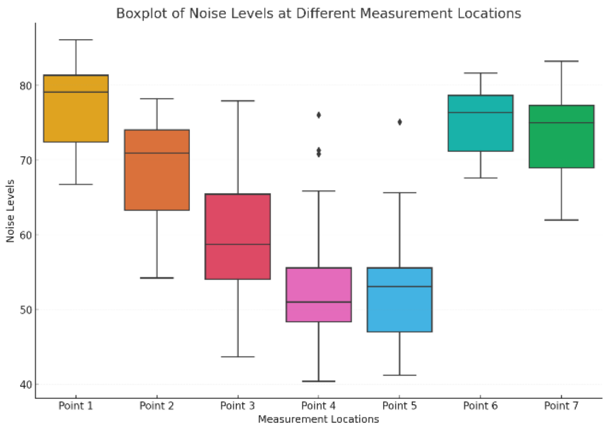

Figure 2. Noise Levels at Measurement Locations

This visualization provides a clear comparison of noise level variability across the different points, highlighting the range and central tendency of the data. Point1 and Point6 have the highest average noise levels, indicating that these locations consistently experience high noise levels. Point4 and Point5 have the lowest average noise levels, suggesting that these locations are relatively quieter. Point4 and Point5 show the highest variability, indicating that noise levels at these points fluctuate widely. Point6 has the lowest variability, indicating stable and consistently high noise levels.

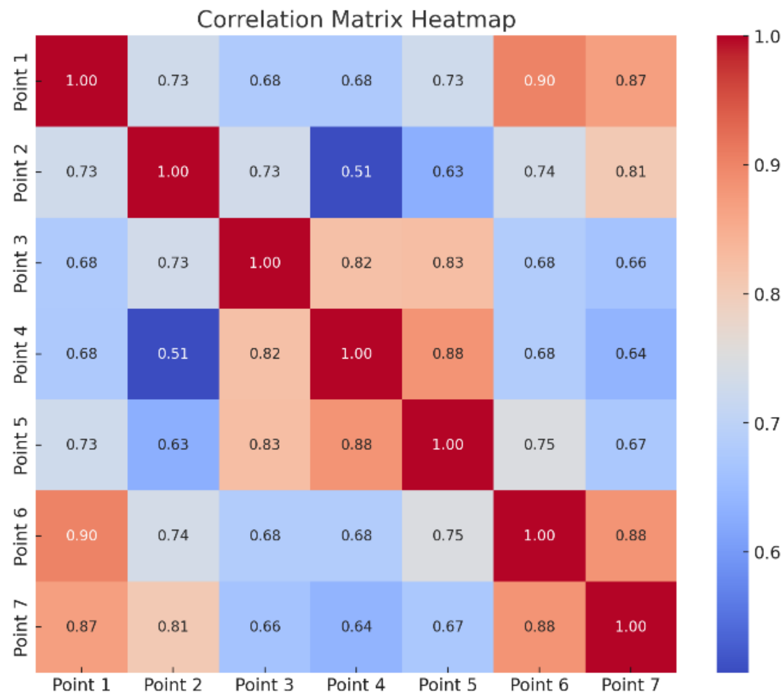

Figure 3. Heatmap Correction Matrix

The heatmap gives visualization highlights the strength and direction of relationships between the noise levels recorded at various points, providing insights into how noise levels at different locations are related. This detailed visualization can help in understanding the relationships and dependencies among the noise levels at various locations, aiding in targeted noise mitigation efforts. Based on the heatmap matrix Point1 with Point6 (0.75), Point6 with Point7 (0.78), and Point1 with Point7 (0.71). Common among adjacent points like Point1-Point2, Point2-Point6, Point3-Point4, etc. Generally observed with Point4 and Point5 compared to others, indicating they might be more isolated in terms of noise level influences.

Understanding these correlations helps identify which locations' noise levels are more closely linked, guiding targeted interventions and noise management strategies. The strong correlations between Point1, Point6, and Point7 suggest that these points are likely close to each other or share a significant common noise source, such as a heavily trafficked road or major urban thoroughfare. These are observed between points like Point2 and Point6, and Point3 and Point4. This suggests that these points are somewhat influenced by similar noise factors but to a lesser extent than the strongly correlated pairs. The weak correlations between points like Point4 and Point7, and Point5 and Point6 suggest that these locations are more isolated in terms of noise influence, possibly due to physical barriers, distance, or differing local environments.

Areas with strong correlations, like Point6 and Point7, may benefit from shared noise mitigation strategies, such as installing noise barriers along a shared noise source. Points with weaker correlations might require more localized solutions tailored to their specific noise environments. Points with moderate correlations could be studied further to identify shared noise sources and devise appropriate interventions. Overall, analyzing these relationships aids in developing effective noise management strategies tailored to the specific conditions of each location.

Questionnaire Survey Results

Questionnaire Analysis Survey responses were analyzed to understand perceptions of noise impact, with results visualized using pie charts. This methodology ensures a robust assessment of traffic noise levels and their impact on healthcare and educational services in Bandung City, providing valuable insights for future noise mitigation strategies.

Based on the questionnaire, Majority of teachers have a strong understanding of noise and its impact, with significant portions reporting disruption in concentration and the need to raise their voices while teaching. Similar to teachers, non-teaching staff reported high awareness of noise and its disruptive effects, with many agreeing that noise levels are worsening. Many students reported that noise affects their concentration, causes headaches, and makes it difficult to crossroads, indicating substantial impacts on their daily activities. A significant portion of clinic staff understands noise and acknowledges its disruptive impact, although some have become accustomed to it. Most patients strongly agree that they understand what noise is.

Correlation between Noise Levels and Perception Survey responses confirmed the measurement data, revealing substantial impacts on concentration and well-being. Both teachers and non-teaching staff reported significant disruptions due to noise, aligning with the high levels recorded at their locations. Students also experienced concentration issues and physical symptoms like headaches, which were more common in areas with higher noise levels. Clinic staff and patients reported disruptions too, although some staff indicated they had adapted to the noise.

These results echo previous studies. For example, Shukla and Tandel (2023) found that high noise levels in schools disrupt students' cognitive functions, while Kasagici and Ateş (2021) noted health issues like headaches and stress in noisy environments. Our correlation analysis underscores the need for mitigating noise pollution to protect the health and performance of individuals in sensitive environments.

The spatial analysis showed that areas with high noise levels, such as Point1 and Point6, likely have more traffic or are closer to major roads. In contrast, Point4 and Point5, with lower noise levels, might be in quieter zones or have natural barriers reducing noise. This variability is crucial for planning effective noise reduction strategies.

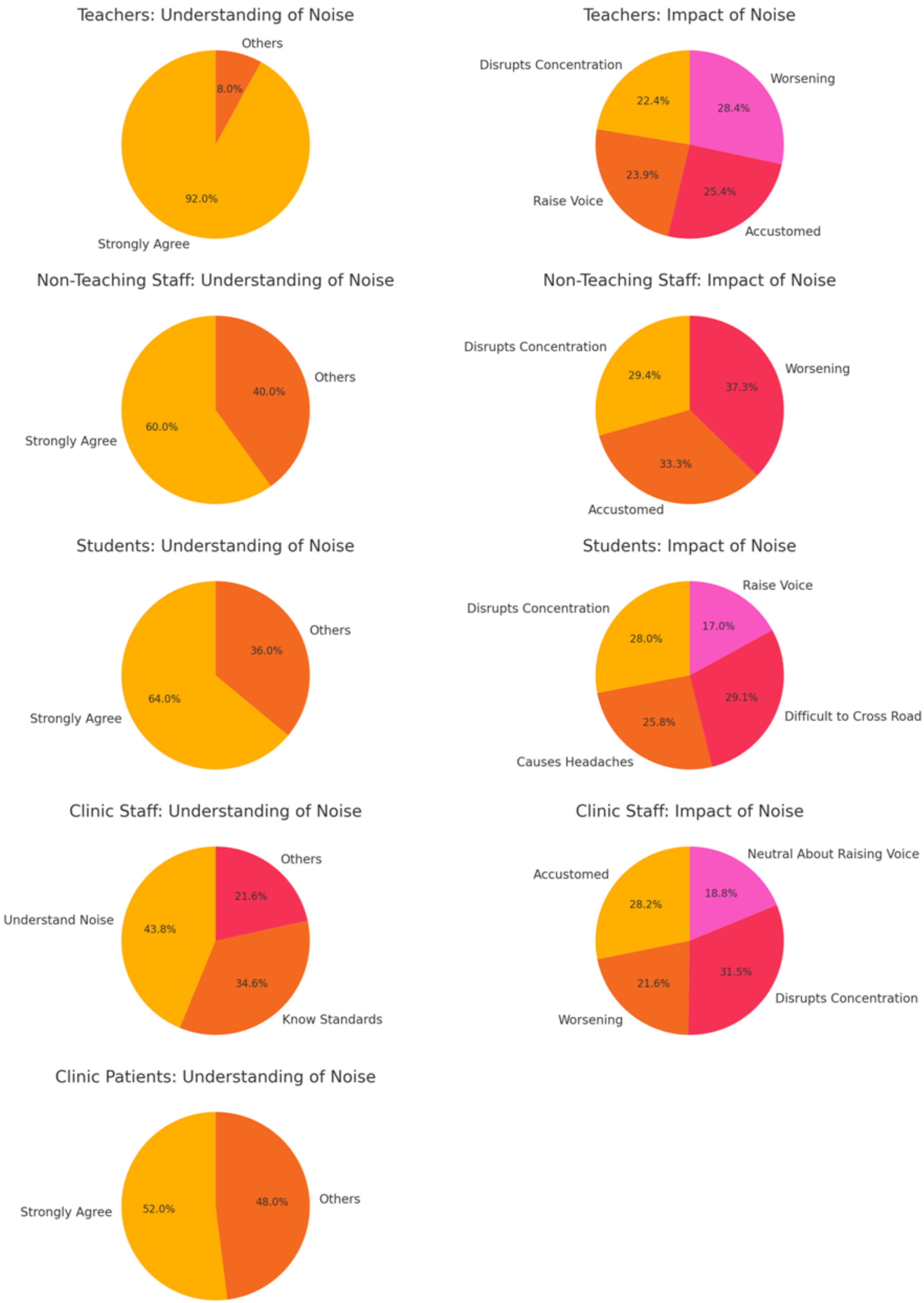

Figure 4. Questionnaire Response of Noise Impact Perception.

Recommendations

Based on the findings, several recommendations are proposed to mitigate traffic noise and improve conditions in healthcare and educational environments namely installing noise barriers, creating green spaces, and enhancing building insulation can effectively reduce noise levels in high-impact areas like Point1 and Point6. Using quieter road surfaces and promoting electric vehicles can help lower overall traffic noise. Implementing traffic management measures, zoning regulations, and speed limits can help manage noise distribution and reduce noise exposure. Regular noise mapping and monitoring, along with public awareness campaigns, can help maintain low noise levels and promote community involvement in noise reduction efforts.

Future Research

Future studies should focus on monitoring noise levels over an extended period to understand long-term trends and impacts. Identifying specific noise sources contributing to high noise levels and targeting them for mitigation. Investigating the direct health impacts of traffic noise on different population groups to develop more effective noise control policies.

Conclusions

The data collected and analyzed reveals significant findings regarding noise levels and their correlations across different locations.

Point1 and Point6 consistently exhibited the highest average noise levels, indicating they are hotspots for traffic noise. These points also showed strong correlations with each other, suggesting that noise mitigation strategies implemented at one location could benefit the other. Point4 and Point5 had the lowest average noise levels but displayed high variability, indicating fluctuating noise conditions. These points require tailored noise control measures to address the irregular noise patterns.

Strong correlations were observed between several points, notably between Point1, Point6, and Point7. This indicates that these locations are likely influenced by the same noise sources, such as a major road. Noise reduction strategies such as installing noise barriers and using quieter road surfaces in these areas could be effective.

Moderate correlations were found between points like Point2 and Point6, suggesting shared but less direct influences. Implementing complementary noise control measures could help manage noise levels at these locations.

Weak correlations between points like Point4 and Point7 indicate that these areas are relatively independent in their noise environments. Localized solutions specific to each site's conditions are necessary.

The survey results revealed significant impacts of traffic noise on the respondents, especially among teachers and students who reported disruptions in concentration and physical symptoms like headaches. Clinic staff and patients also experienced noticeable disruptions, although some staff have adapted to the noise.

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