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Original Article

Spatial-Temporal Analysis of Noise Pollution and Its Relationship with Land Use in Tehran's District 6 Using GIS

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Abstract
Introduction: Noise pollution is a major environmental challenge in metropolitan areas. Tehran, with its 14 million population and heavy traffic, suffers from severe noise pollution due to inadequate land use planning and inefficient transportation systems. This study examines the spatiotemporal characteristics of noise pollution and its relationship with land use in District 6 of Tehran using GIS technology.
Methods: Noise levels were measured at 170 stations across three time intervals (morning, noon, evening). Key indices (LNP, Leq, TNI, Lmax) were calculated following ISO 1996-2 standards. Spatial analysis and noise mapping were done using ArcGIS 10.1, with land use relationships examined through comparative layer analysis.
Results: The highest noise levels occurred during morning (LNP = 89.106 dB, Leq = 80.294 dB, TNI = 84.965 dB) and evening periods (89.593 dB, 80.464 dB, 86.278 dB). Spatial analysis identified the eastern sector as the noisiest area, exceeding permissible limits at all measurement points. Strong correlations were observed between noise levels and commercial/residential land uses, while vegetated areas showed noise levels 15–20% lower than non-vegetated areas.
Conclusion: This study demonstrates that GIS-based noise mapping effectively identifies critical pollution zones. The findings emphasize the need for land use policy reforms, including traffic management in high-density areas and green space development. The methodology provides a replicable framework for urban noise assessment in similar metropolitan contexts.
Keywords: Tehran noise pollution, Noise mapping, GIS and spatial analysis, Noise pollution indices (Leq, LNP, TNI)

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Introduction
Environmental pollution is a global challenge that has extensive impacts on human health and the Earth's sensitive ecosystems. In recent years, the significant increase in environmental pollution has posed a serious threat to human life, and noise pollution has been recognized as one of the most important forms of environmental pollution.[1] Noise pollution, due to the characteristics of its sources and propagation patterns, differs from other types of pollution and requires specific monitoring and management methods.[2,3] Over the past century, the intensity of noise pollution caused by human activities has continuously increased, doubling every decade.[4] This type of pollution, depending on its duration and intensity, has numerous adverse effects on human health, including hearing loss, increased blood pressure, stress, and reduced productivity.[5,6]

Controlling and monitoring noise sources in urban areas is of great importance, as identifying high-pollution areas enables the implementation of management and engineering measures to reduce associated risks.[7] In this context, one important tool is noise maps, which provides valuable support for managers and policymakers in planning noise control strategies and evaluating their effectiveness.[8] A notable example is the London Noise Map, created in 2004, which has served as a reference for mitigating noise-related issues and identifying high-risk zones.[9]

Noise mapping using Geographic Information Systems (GIS) was developed in the mid-1990s and has become a powerful tool for spatial and temporal noise analysis.[10,11] This system integrates spatial and acoustic data, enhancing the quality of the maps produced. Furthermore, the use of GIS allows for the examination of the relationship between noise levels and land use in various urban areas.[12]

Tehran, as one of the world's most populous metropolitan cities, faces numerous environmental challenges, including noise pollution.[13] District 6 of Tehran Municipality is considered one of the most noise-polluted areas due to its high population density, heavy traffic volume, and diverse land uses.[14] Therefore, the aim of this study was to analyze the spatial-temporal characteristics of noise pollution in this district using GIS and to investigate its relationship with land use.

Materials and Methods

Study Area

This study was conducted in the metropolitan area of Tehran during the winter of 2023 (Figure 1). According to the latest census (2023), Tehran's metropolitan population is approximately 9.2 million, with around 8.5 million residing within the city limits and the rest in surrounding areas (Tehran counties). Tehran spans an area of 606 km^2, making it one of the largest and most populous cities in the country.

The elevation of Tehran ranges from about 2,000 m in the northern mountainous regions to 1,050 m in the southern desert areas. As a result, Tehran has diverse climatic conditions: the northern areas experience cold and dry weather, while the southern areas are characterized by warm and dry climates.

Tehran is divided into 22 municipal districts. Among these, District 6 was selected for noise assessment and mapping because of its status as the area with the highest noise pollution levels, as indicated by Tehran's fixed noise monitoring stations. This district experiences heavy traffic throughout the day and has a higher population density compared to many other districts in Tehran. In addition, the district features a great concentration of residential and commercial buildings.

In this district, intercity vehicles and trucks are absent, and only buses and urban and construction vehicles operate. Diesel-powered buses, particularly those operating on Bus Rapid Transit (BRT) lines with high sound pressure levels, are common in the area. Motorcycles also have a higher prevalence in this district compared to others. Also, the density and expansion of highways and freeways in District 6 exceed those of other regions.

Noise Measurement and Assessment

In this study, 170 sampling stations were selected at intersections, streets, and major highways within District 6 of Tehran during the winter of 2023 (Figure 1). Temperature conditions during this period ranged from -3 to 18 degrees Celsius. The geographic location of each station was determined and recorded using a GIS device (Magellan 315).

Noise levels at the selected stations were measured using an advanced sound level meter (KIMO DB300-2) manufactured in France. The sound level meter was calibrated daily using a B&K Type 4231 acoustic calibrator

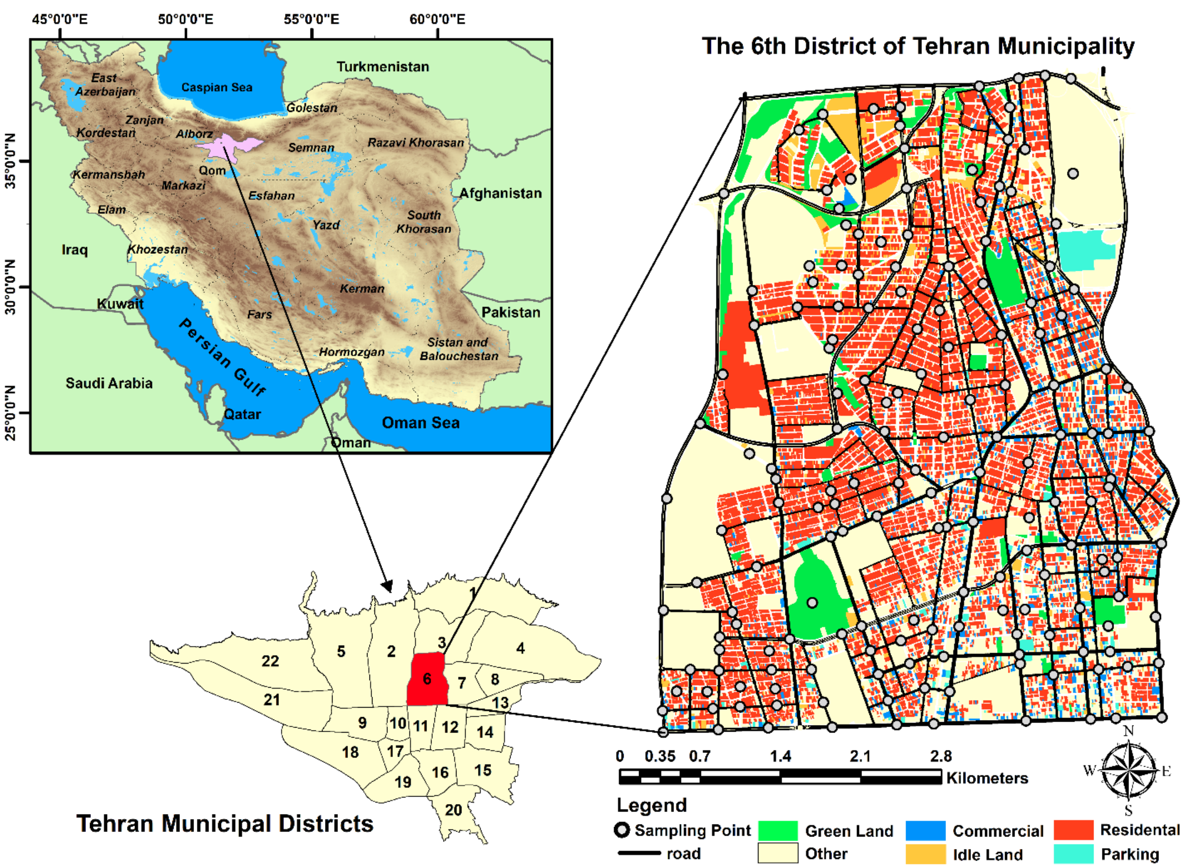

Figure 1. Noise Measurement Stations in District 6 of Tehran

(94 dB at 1 kHz) to comply with ISO 1996-2 standards. To validate field measurements, 10% of sampling stations (17 locations) were cross-checked with Tehran's fixed noise monitoring stations, showing a mean deviation of ± 1.5 dB ($P < 0.05$). Measurements adhered to the A-weighting network and complied with the ISO 1996-2 standard. The devices were installed at a height of 1.5 meters above ground level and 3 meters away from reflective surfaces.[15]

Noise measurements were conducted over 15 consecutive weekdays (Sunday to Thursday) to capture peak urban activity patterns, as weekends in District 6 exhibit significantly lower traffic volumes due to reduced commercial operations (Tehran Traffic Department Report, 2023). To account for diurnal variability, three time intervals were selected:

- Morning (7–11 AM): Peak commuting hours with high traffic density.
- Noon (12–3 PM): Moderate activity period with reduced vehicular movement.
- Evening (3–7 PM): Secondary peak hours due to return commutes and commercial closures.

Measurements were taken every 5 minutes (12 readings/hour) to ensure temporal resolution. The data collected from each station were processed for statistical analysis and the calculation of noise indices.

Calculated Noise Indices

The Traffic Noise Index (TNI) is based on a social survey conducted by BRS in 1967, with its results published in 1968.[16-18] This survey was designed to evaluate noise levels near urban highways. The TNI aims to account for noise variations by considering the L10 level. The TNI is calculated based on a weighted combination of L10 and L90 values over 24 hours using multiple regression analysis. Subsequent analyses and findings led to the recommendation of using the L10 level during an 18-hour period (06:00–24:00) as a representation of noise annoyance and as a unit for planning and legal purposes.[9]

Further developments resulted in the introduction of the composite index, Noise Pollution Level (LNP), by Robinson, which can predict noise annoyance caused by various sound characteristics and sources.[19] Another indicator, the Day average sound level (DL), provides a general measure of the acoustic environment over a specific period based on hourly equivalent sound levels.[20] This indicator aggregates hourly equivalent levels over a specific period into a single equivalent level for the entire duration.

In 1960, the Helsinki Conference published ISO 1996, which proposed the equivalent continuous sound pressure level (Leq) as an indicator of environmental noise. Later, in 1978, ISO 1996-1 recognized the proposed Leq as an international standard.[21]

In this study, Leq was utilized as a standard for measuring environmental noise levels. Other key and appropriate indices used to describe environmental noise pollution include the LNP, which represents the equivalent sound level over a specified period and the distribution of statistical sound pressure levels, and TNI, derived from the statistical distribution of L10 and L90 levels.

After collecting the sound pressure level data, noise pollution indices, including Leq, LNP, and TNI, were calculated. Leq was calculated using Equation 1.

$$L_{eq}\left(\text{dBA}\right) = L_{50} + \left[\frac{\left(L_{10} - L_{90}\right)^2}{60}\right] \quad (1)$$

The environmental LNP was determined through Equation 2.

$$L_{NP}\left(\text{dBA}\right) = L_{eq} + \left(L_{10} - L_{90}\right) \quad (2)$$

Equation 3 was also used to calculate the TNI.

$$TNI\left(dBA\right) = L_{90} + 4\left(L_{10} - L_{90}\right) - 30 \quad (3)$$

In Equations 1, 2, and 3, the parameters L10, L50, and L90 with indices n:10, 50, 90 represent the statistical levels (in dB) that were exceeded during n percent of the total measurement time.

Additionally, the Daytime Average Level (DL) was determined based on Equation 4.

$$DL\left(dBA\right) = 10\log\frac{1}{11}\left[4\times10^{L_{D1}} + 3\times10^{L_{D2}} + 4\times10^{3}\right]^{\frac{1}{10}} \quad (4)$$

In Equation 4, LD1 (dBA) represents the equivalent sound level during the time period from 7 to 11 AM. LD2 (dBA) represents the equivalent sound level during the time period from 12 to 3 PM, and LD3 (dBA) represents the equivalent sound level during the time period from 3 to 7 PM. And, Microsoft Excel 2010 software was used to calculate the acoustic indices.

Examining the Relationship between Land Use and Noise Pollution Levels

Previous studies have identified road traffic as the primary source of noise pollution in urban environments.[12] The configuration of streets and alleys noticeably influences the spatial distribution of noise levels across different areas. To examine the relationship between land use and noise pollution, a land use map of District 6 in Tehran was first developed (Figure 1).

Geographic layers corresponding to various land use types—including roads, vegetated areas, commercial zones, residential areas, and parking lots—were extracted separately. Density maps were then generated for each land use category and compared with the noise pollution zoning map of the study area. This comparison revealed the extent to which land use type contributes to variations in noise pollution levels. ArcGIS version 10.1 was used to prepare and analyze the noise maps, which subsequently served as the basis for interpreting the findings. Land use data were obtained from the Tehran Municipality Geodatabase (2023, scale 1:2000) and validated through field surveys at 30 randomly selected points using Google Earth Pro imagery. Any discrepancies, which were below

5%, were corrected through ground-truthing, leading to a classification accuracy of 93%.

Results and Discussion

Noise Pollution Measurement at Different Time Intervals

The data collected from 170 points in District 6 of Tehran showed that the indices LNP, Leq, and the TNI were significantly higher than the allowable standards during all three time periods. In the morning period (07:00 to 11:00), the average values of these indices were 89.106, 80.294, and 84.965 dB, respectively. During the afternoon period (12:00 to 15:00), these values slightly decreased to 89.088, 79.757, and 85.893 dB. In the evening period (15:00 to 19:00), the indices again increased, reaching 89.593, 80.464, and 86.278 dB, respectively (Table 1). The data indicated that even the lowest recorded values exceeded the permissible standards.

Spatial Distribution of Noise Pollution

The observations illustrated that the spatial distribution of noise pollution in District 6 of Tehran is dependent on land use types, population density, and traffic patterns. The noise maps (Figure 2) indicate that the eastern areas of the district had the highest values of noise indices (LNP, Leq, and TNI). Figure 2A shows the distribution of LNP, Figure 2B illustrates Leq levels, and Figure 2C presents the TNI pattern across the district, while the southwestern areas had the lowest values of these indices. This spatial distribution clearly demonstrates that human activity patterns and the structural layout of the area influence the intensity of noise pollution.

The LNP combines Leq with statistical fluctuations (L10-L90), reflecting both average noise and its variability—critical for assessing human annoyance. For instance, the eastern sector's high LNP (89.593 dB) indicates not only loudness but also erratic noise from stop-and-go traffic. The TNI, emphasizing peak noise (L10), exceeded 85 dB near highways, focusing on inadequate urban buffering.

Table 1. Measured Noise Indices in the Morning, Noon, and Evening Periods, Compared with International and Domestic Standards

Indices	Time Periods	7-11 AM	12-15 PM	15-19 PM
LNP (dB)	Min	70.417	128.65	89.106
	Average	68.838	116.817	89.088
	Max	68.6	115.204	89.593
Leq (dB)	Min	66.2	96.2	80.294
	Average	66.5	91	80.464
	Max	64.5	90	79.757
TNI (dB)	Min	46	150	84.965
	Average	48	132	86.278
	Max	43.5	126.5	85.893
DL (dB)	Min	64.88	-	-
	Average	79.214	-	-
	Max	90.75	-	-

(The permissible limit for the equivalent sound level (Leq) according to the Iranian Department of Environment and US EPA standards is 55 dB.)

Comparatively, Leq values (80.464 dB) were consistently above Iranian Department of Environment and US EPA standards (55 dB), emphasizing chronic noise exposure in residential zones.

Relationship with Land Use Type

The analysis of land use density maps revealed that areas with high-traffic streets and a high concentration of commercial and residential land uses experience the highest levels of noise pollution. In contrast, areas with vegetation cover and public parking lots exhibited the lowest noise levels (Supplementary Figure S1–S5). These findings indicate that land use type and density play a key role in shaping noise pollution patterns..

Vegetation cover: As shown in Supplementary Figure S4, areas with dense vegetation, such as parks, effectively reduce noise pollution levels. These results emphasize the value of preserving and expanding urban greenery to mitigate noise pollution.

Parking lots: According to Supplementary Figure S5, areas with a high concentration of parking lots, particularly in busy commercial and residential districts, experience elevated noise pollution. Strategic management of parking lot distribution can help reduce vehicle congestion and, in turn, lower noise levels.

It was found that the noise levels in District 6 of Tehran exceeded the permissible standards during all time periods (morning, noon, and evening). The highest noise indices (LNP, Leq, and TNI) were observed in the eastern areas of the district, while the lowest values were found in the southwestern areas. The findings showed that noise indices were lower during the noon period compared to the morning and evening periods, which could be attributed to reduced human activity during this time. Overall, the variations in noise pollution levels throughout the day were significantly influenced by traffic patterns, urban structure, and population density in different areas.[9-13]

The high levels of noise pollution in the eastern areas are dependent on factors like dense street networks, alleys, and the presence of commercial and residential activities in these regions. Furthermore, the noise maps indicated that the southern and southwestern areas of the district had lower noise pollution levels, which could be because of the higher presence of vegetation, lower building density, and reduced traffic. These differences in noise levels emphasize the impact of daily commuting patterns on the intensity of noise pollution, particularly during peak traffic hours observed in the eastern and central regions.[22-24]

The results of this study were consistent with those from previous research. For example, studies done in cities such as London and Seoul reported that high traffic density and commercial and residential land uses are the main contributors to increased noise pollution.[9,22] A study in Tehran also found that Enghelab Square and Tajrish are recognized as the most noise-polluted squares, while Bahman Square had the least noise pollution.[25] In addition,

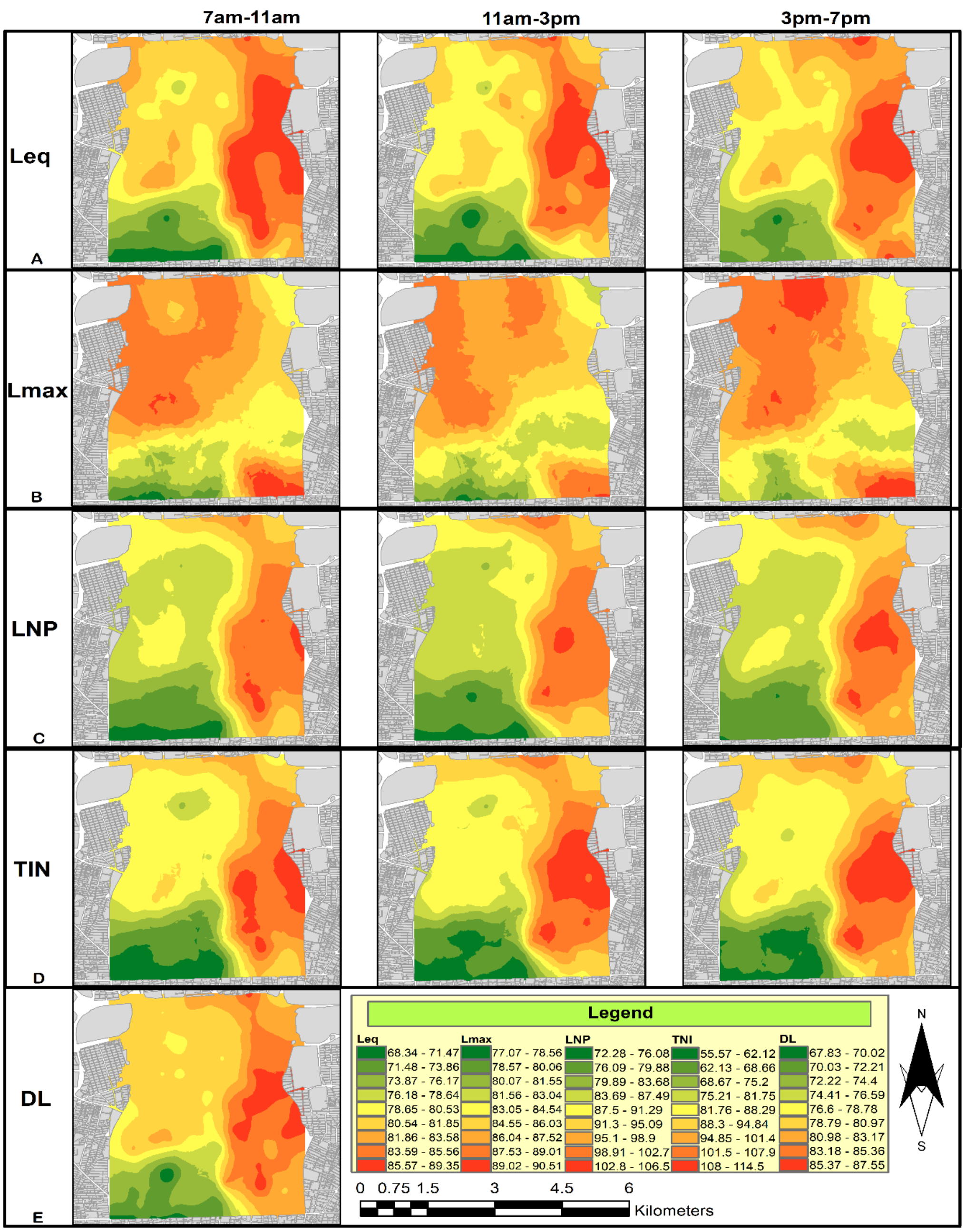

Figure 2. Map of the Distribution of Various Noise Indices (LNP, Leq, and TNI) in District 6 of Tehran

another study examining noise pollution distribution in different parts of Tehran confirmed that traffic density and proximity to highways are key factors contributing to higher noise levels.[26] Moreover, research conducted in major cities such as London has demonstrated the positive impact of green spaces in reducing noise pollution[13], a result also confirmed in this study.[27] Also, studies in densely populated areas with major road networks have shown that urban design and traffic management play a significant role in reducing noise pollution.[23]

Our findings align with similar studies in other metropolitan areas. For instance, Ryu et al stated comparable LNP values (>85 dB) in commercial corridors of Seoul, linking high noise levels to dense traffic and mixed land use. However, Tehran's District 6 exhibits higher TNI values (86.278 dB vs. 82 dB in Seoul), suggesting less effective traffic management or urban design. This discrepancy underscores the need for context-specific noise mitigation strategies, particularly in cities with rapid urbanization like Tehran.[22] Besides, the findings reported by Wickramathilaka et al showed 15–20% noise reduction in vegetated areas mirrors results from London's green space studies, reinforcing the universal role of green infrastructure in noise abatement.[28]

The results of this research suggest that proper land-use planning, reducing vehicle traffic in high-density areas, and developing green spaces can help reduce noise pollution. Additionally, the use of GIS-based noise maps can serve as a powerful tool for policymakers and urban managers to identify critical points and make effective decisions.[25,29]

One of the strengths of this study was the application of GIS tools for spatial and temporal analysis of noise pollution and the provision of accurate noise maps. However, there were some limitations, including the inability to cover all areas of Tehran due to time and human resource constraints. It is recommended that future studies cover the entire city of Tehran to provide a more comprehensive and precise map of the noise pollution status.

Study Limitations

The study was limited to District 6 and did not account for temporary noise sources such as construction activities or public events. In addition, the spatial resolution of GIS data and the static nature of land use layers may not fully reflect dynamic urban changes. Future studies should consider seasonal variations, event-driven noise, and higher-resolution data.

Conclusion

The research found that all stations showed noise pollution exceeding national and international standards during all time intervals. The results also showed that during peak hours of the day, namely morning and evening, noise pollution was higher, with LNP values reaching 89.106 dB and 89.593 dB, respectively, indicating that traffic flow has a major influence on noise pollution.

The results also showed that the eastern part of the district has higher noise pollution, especially because of dense road networks and mixed land use patterns. In contrast, areas with higher vegetation cover, especially in the southwestern part of the district, showed lower noise pollution.

It was also confirmed that there is a strong correlation between the type of land use and the intensity of the noise pollution. The commercial and mixed land use areas located along major transportation routes were associated with the highest levels of noise pollution, while the areas with vegetated land use were associated with significantly lower levels of pollution.

Noise mapping using the GIS system is an effective tool in identifying the critical hotspots of the noise pollution problem and visualizing the spatial patterns of the pollution levels.

Based on the results of the research, the following evidence-based recommendations are proposed to policymakers and planners of the metropolitan district:

1. Revising the land use policies to restrict the mixed land use along the residential zones,
2. Installing traffic calming devices along the major transportation routes, especially in the eastern and central areas of the district,
3. Expanding the green space along the major highways and intersections.

It is important to addressing noise pollution using the proposed measures to improve the health outcomes and quality of life in the metropolitan district of Tehran

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Authors' Contribution

Conceptualization: Masoud Rezaee, Asad Fathi, Bafrin Moloudpourfard.
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Validation: Asad Fathi, Bafrin Moloudpourfard.
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Writing–Original Draft: Masoud Rezaee, Asad Fathi, Bafrin Moloudpourfard.
Writing–Review & Editing: Masoud Rezaee, Asad Fathi, Bafrin Moloudpourfard.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

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Supplementary Files

Supplementary file 1 contains Figures S1–S5.

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