



# Spatial Analysis of the Impact of Traffic Noise on Vegetation Physiology, Flora Diversity, and Soundscape Quality in Urban Green Spaces

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**Abstract.** This study investigates the influence of traffic induced noise on vegetation physiology, flora diversity, and soundscape quality within urban green spaces in the Simpang Lima area of Semarang City. Noise measurements were conducted using a Type 1 Sound Level Meter (SLM), complemented by acoustic calibration and continuous monitoring using Autonomous Recording Units (ARUs). Vegetation parameters including plant height, DBH, and chlorophyll index (SPAD) were assessed, while flora diversity was quantified through quadrat sampling and the Shannon–Wiener index ( $H'$ ). Soundscape quality was evaluated using acoustic indices (ADI, AR, AE), and spatial patterns of Leq were modelled using ordinary kriging interpolation. Results revealed a pronounced spatial gradient of noise, with the highest Leq recorded in Zone 1 (82.3 dBA) and the lowest in Zone 3 (65–67 dBA). Elevated noise levels were strongly associated with reductions in chlorophyll index ( $r = -0.876$ ;  $p < 0.01$ ), vegetative growth, and flora diversity. Zones with lower noise exposure exhibited richer biotic acoustic activity and higher diversity indices. Spatial modelling further identified noise hotspots that overlapped with areas of vegetation degradation. These findings demonstrate that chronic traffic noise acts as a substantial ecological stressor, affecting plant physiological performance, community composition, and acoustic habitat quality. The study underscores the importance of integrating noise mapping, vegetation structure analysis, and soundscape assessments into urban green space planning and ecological management.

**Keywords:** traffic noise; vegetation physiology; flora diversity; soundscape; spatial modelling; kriging.

## 1 INTRODUCTION

Urbanisation and the rapid expansion of transportation networks have accelerated the growth of traffic-induced noise in major cities. Traffic noise has become one of the most pervasive forms of environmental pollution, affecting human health through stress, sleep disturbances, and cardiovascular risks [1], while also degrading the ecological integrity of urban green spaces. As urban areas intensify, green spaces serve dual ecological functions: mitigating noise levels and acting as acoustic refuges that support flora and fauna [2]. However, the effectiveness of vegetation in attenuating noise varies widely depending on species composition, canopy structure, and spatial configuration [4–6].

Existing studies have shown that vegetation can reduce noise by 5–10 dB depending on structural density, foliage characteristics, and distance from noise sources [5,6]. In addition, landscape metrics such as patch size, shape complexity, and fragmentation strongly influence the propagation of sound across urban green spaces [2,7]. Yet, despite this progress, most studies focus primarily on either noise reduction performance or vegetation structure, while few have integrated these aspects with ecophysiological responses and soundscape characteristics.

Beyond the physical dimension, anthropogenic noise also affects biotic communities. Research in urban acoustic ecology indicates that elevated noise levels can alter bird communication, reduce acoustic diversity, and disrupt natural soundscape patterns [14–16]. Vegetation structure and species richness further influence the resilience of biotic

acoustic activity, as denser and more diverse vegetation tends to support greater bird presence and richer natural sounds [13,17,18]. Integrating vegetation attributes with soundscape indicators provides a comprehensive framework for evaluating the ecological quality of green spaces.

Despite growing interest in noise–vegetation interactions, several research gaps remain. First, there is limited empirical evidence that simultaneously examines traffic noise, plant physiological performance, flora diversity, and biotic soundscape quality within the same spatial framework [8–10,23,24]. Second, few studies have incorporated spatial interpolation techniques such as kriging to map noise gradients and link them directly to vegetation conditions and acoustic ecological responses [21,22]. Third, studies evaluating how vegetation degradation correlates with biodiversity loss and changes in the acoustic environment are still scarce, particularly in dense Southeast Asian urban contexts where traffic intensity is consistently high [19,20].

This study addresses these gaps by integrating noise measurements, vegetation physiology assessments, flora diversity analyses, and soundscape indices within the urban green spaces of the Simpang Lima area in Semarang City. Specifically, the research investigates: (i) spatial patterns of traffic noise, (ii) physiological responses of vegetation to noise exposure, (iii) changes in flora diversity along noise gradients, and (iv) differences in biotic acoustic activity among zones. The novelty of this study lies in its multidimensional analytical approach, combining noise ecology, plant ecophysiology, biodiversity metrics, and soundscape analysis into a unified spatial framework. The findings contribute to urban acoustic ecology and provide practical recommendations for designing greener, quieter, and more ecologically resilient urban environments.

## 2 METHODOLOGY

### 2.1 Research Design

This study employed a quantitative observational design with a correlational approach to examine the relationships between traffic noise, vegetation physiological parameters, flora diversity, and soundscape characteristics in the Simpang Lima urban green space of Semarang City. Observations were conducted from January to December 2025 to capture daily and seasonal variations in noise patterns, vegetation conditions, and biotic acoustic activity. The research design aligns with current practices in urban acoustic ecology, which integrate noise measurements with ecological indicators [13,16,18].

### 2.2 Study Area and Zoning

The study area covered a 1 km radius from the Simpang Lima roundabout, a high density commercial and traffic hub. To evaluate spatial noise gradients, the area was divided into three zones based on distance from the dominant noise source (major roads). The study area was classified into three concentric zones following common spatial exposure assessment methods in noise studies [1–3]. This approach is based on the principle that noise intensity decreases with increasing distance from the primary source. Accordingly, the Simpang Lima area was divided into Zone 1 (0–250 m), representing the highest exposure due to its proximity to major traffic corridors; Zone 2 (251–500 m), which experiences moderate noise levels; and Zone 3 (501–750 m), the farthest zone where noise exposure is lowest. This zonation facilitates a more systematic analysis of ecological responses across the noise gradient. Sampling points were selected using stratified random sampling, considering road proximity, vegetation cover, traffic intensity, and accessibility. A total of 45 sampling points were distributed proportionally across zones. This zoning and sampling approach is consistent with widely applied noise exposure assessment protocols in urban environments [2,3].

### 2.3 Instruments and Calibration

Traffic noise was measured using a Type 1 Sound Level Meter (SLM) compliant with IEC 61672-1 standards, as recommended in environmental noise studies [1,19]. The SLM was calibrated using an acoustic calibrator before and after measurements to minimise instrument drift. Traffic flow was monitored through manual vehicle counting to correlate noise intensity with traffic density. Vegetation assessments included plant height, stem diameter (DBH), and chlorophyll index using a SPAD-502 meter. The SPAD meter is widely used for evaluating plant physiological status under environmental stress [8,10,23]. Autonomous Recording Units (ARUs) with calibrated microphones were used for passive acoustic monitoring, following best practices in soundscape ecology [13,16,17]. A co-location test between IoT sensors and Type 1 SLMs was performed to validate long-term acoustic recordings, ensuring measurement accuracy [19].

## 2.4 Data Collection Procedures

**Noise Measurements.** Noise measurements were conducted during four time intervals morning, afternoon, evening, and night on both weekdays and weekends. Each recording session lasted for 10 minutes and generated a complete set of standard acoustic parameters, including the equivalent continuous sound level ( $L_{eq}$ ), maximum and minimum sound levels ( $L_{max}$  and  $L_{min}$ ), percentile noise levels ( $L_{10}$ ,  $L_{50}$ , and  $L_{90}$ ), and the day night average sound level ( $L_{dn}$ ). These metrics collectively provide a comprehensive representation of both the intensity and temporal variability of traffic noise at each sampling point. These parameters follow environmental noise monitoring standards derived from IEC 61672-1 and national SNI adaptations, consistent with international guidelines for urban noise studies [1,19].

**Vegetation Physiology.** Vegetation conditions were assessed by measuring plant height, DBH, and chlorophyll index. Leaves were sampled from the sun-exposed canopy layer to ensure measurement consistency. Visual assessments of leaf health were recorded to support physiological interpretations. These methods align with established approaches in plant ecophysiology under environmental stress [8,10,23,24].

**Flora Diversity.** Flora composition was recorded using the quadrat sampling method. Species richness ( $S$ ), abundance ( $N$ ), and the Shannon–Wiener diversity index ( $H'$ ) were calculated using established ecological diversity metrics [11,12]. This technique follows standard protocols used in urban biodiversity studies.

**Soundscape Recording.** Biotic and anthropogenic acoustic components were recorded using Autonomous Recording Units (ARUs) installed at standardized heights and orientations to ensure consistency across sampling locations. The collected audio data were subsequently processed using bioacoustic software to compute a set of quantitative soundscape indices, including the Acoustic Diversity Index (ADI), Acoustic Richness (AR), and Acoustic Evenness (AE). These indices provide an objective evaluation of soundscape composition and biotic acoustic activity within each zone. These indices are commonly used in soundscape ecology to characterize ecological acoustic patterns [13,16–18].

## 2.5 Spatial Analysis

Spatial distributions of  $L_{eq}$  were modelled using ordinary kriging, one of the most accurate and widely used interpolation techniques for environmental variables [21,22]. Vegetation maps at a 1:5000 scale were digitized and analyzed to derive a series of spatial metrics that characterize the structural configuration of green space patches. These metrics included patch size, shape index, edge density, and distance to major roads, all of which are critical indicators for assessing how vegetation structure influences noise attenuation and ecological responses across the study area. Overlay analysis was used to examine spatial interactions between noise levels, vegetation structure, and ecological responses, following methods applied in noise landscape studies [2,4,7,22].

**Statistical Analysis.** Data normality was assessed using the Shapiro–Wilk test. Relationships between noise levels and ecological variables were analysed using Pearson's or Spearman's correlation as appropriate. Multiple linear regression models were used to evaluate predictors of vegetation physiology and flora diversity. Multivariate analysis (PCA/CCA) identified dominant ecological gradients across zones. These analytical methods follow standard frameworks used in ecological and environmental noise research [8,9,14,18,23].

**Quality Assurance and Control.** Quality assurance and quality control (QA/QC) procedures were implemented throughout the study to ensure the reliability and consistency of all measurements. These procedures included pre- and post-measurement calibration of the Sound Level Meters (SLMs), as well as co-location validation of ARU and IoT acoustic sensors to verify the accuracy of long term acoustic recordings [19]. In addition, flora species identification was confirmed through expert verification to maintain taxonomic accuracy [12]. For each sampling event, comprehensive metadata including weather conditions, time of measurement, and traffic intensity were recorded to control for external factors that could influence acoustic or ecological observations. These steps collectively enhanced the robustness of the dataset and strengthened the validity of the analytical results. All procedures adhered to international guidance for environmental noise monitoring and ecological field assessments [1,19].

## 2.6 Ethics

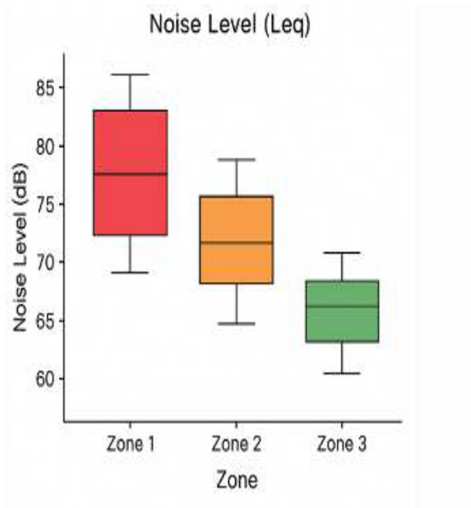
The study involved non-invasive observational methods and complied with institutional ethical guidelines. Fieldwork was conducted with permission from local authorities to ensure minimal disturbance to flora and fauna.

### 3 RESULTS AND DISCUSSION

#### 3.1 Traffic Noise Levels Across Zones

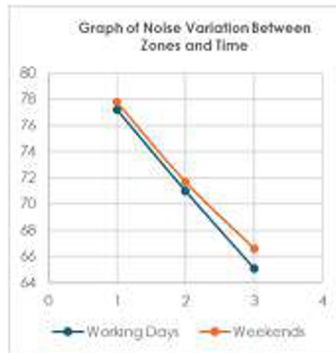
As shown in Figure 1, noise levels vary across the three zones, indicating traffic noise exhibited a clear spatial gradient across the study area. Zone 1, located closest to high-density road segments, recorded the highest noise intensity (up to 82.3 dBA), followed by moderate values in Zone 2 (72–74 dBA), and the lowest in Zone 3 (65–67 dBA).

Figure 1. Noise Levels Across Three Zones



This spatial pattern reflects well-established relationships between road proximity, traffic density, and environmental noise levels [1–3]. Temporal variation also showed consistently elevated noise during morning and evening peaks, with nighttime levels decreasing but still exceeding recommended ecological thresholds [19]. These trends reaffirm that traffic volume and road network geometry are primary determinants of urban noise distribution [2]. As depicted in Figure 2, noise levels vary substantially across zones and measurement periods.

Figure 2. Graph of Noise Variation Between Zones and Time



Vegetation configuration influenced noise propagation, where denser canopy clusters produced minor attenuation effects although not enough to counter heavy traffic loads. Similar findings have been reported in studies showing that vegetation provides modest but measurable noise reduction depending on structural density and continuity [4–6].

### 3.2 Vegetation Physiological Responses

Vegetation exposed to higher noise levels exhibited clear physiological stress symptoms. In Zone 1, the characteristics of the vegetation showed a marked decline in performance, as reflected by lower chlorophyll index (SPAD) values, reduced plant height, and smaller stem diameters (DBH) compared to vegetation in Zone 3. These conditions indicate that elevated acoustic pressure directly influences plant physiological processes, including light absorption efficiency and the structural stability of plant tissues. The strong negative relationship between noise intensity and chlorophyll index ( $r = -0.876$ ;  $p < 0.01$ ) reinforces these observations, demonstrating that increasing noise levels are closely associated with a reduction in photosynthetic capacity. This correlation is consistent with previous studies showing that environmental noise exposure can inhibit photosynthetic processes and disrupt key metabolic pathways in plants [8,10,23]. These findings reaffirm that noise is not only an acoustic pollutant for humans but also an ecological stressor with measurable impacts on vegetation health. Table 1 summarizes the measured vegetation growth indicators, illustrating distinct differences in height, stem diameter, and chlorophyll index among the sampling zones.

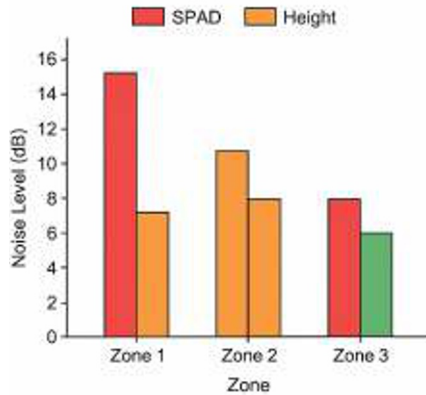
Table 1. Vegetation Growth Measurement Results

Zone	Dominant Species	Average Height (m)	Stem Diameter (cm)	Chlorophyll Index (SPAD)	General Conditions
Zone 1 (0–250 m)	Pole	4.2 ± 0.8	12.5 ± 2.3	32.8 ± 5.2	Poor
	Angsana	5.8 ± 1.2	18.7 ± 3.5	35.4 ± 6.1	Poor
	Mahogany	6.5 ± 1.5	22.3 ± 4.2	38.2 ± 5.8	Moderate
	King Palm	7.2 ± 1.1	28.5 ± 3.8	40.5 ± 4.9	Moderate
<b>Average Zone 1</b>		<b>5.9</b>	<b>20.5</b>	<b>36.7</b>	Moderate
Zone 2 (251–500 m)	Glodokan Pole	5.6 ± 0.9	15.8 ± 2.7	36.5 ± 4.8	Moderate
	Angsana	7.2 ± 1.3	24.3 ± 3.9	42.7 ± 5.5	Good
	Mahogany	8.3 ± 1.6	28.7 ± 4.5	45.3 ± 6.2	Good

	King Palm	8.9 ± 1.2	32.6 ± 4.1	47.8 ± 5.3	Good
<b>Average Zone 2</b>		<b>7.5</b>	<b>25.4</b>	<b>43.6</b>	Good
	Glodokan Pole	6.8 ± 1.0	18.9 ± 2.9	42.3 ± 4.5	Good
	Angsana	8.5 ± 1.4	28.5 ± 4.2	48.5 ± 5.8	Very Good
<b>Zone 3 (501–750 m)</b>	Mahogany	9.7 ± 1.7	34.2 ± 4.8	51.7 ± 6.5	Very Good
	King Palm	10.3 ± 1.3	38.4 ± 4.5	54.2 ± 5.7	Very Good
<b>Average Zone 3</b>		<b>8.8</b>	<b>30.0</b>	<b>49.2</b>	Very Good

Noise stress may inhibit stomatal activity, reduce carbon assimilation, and redirect energy toward stress-response mechanisms rather than growth [23][24]. These results align with previous work observing noise-induced physiological suppression across various plant species subjected to chronic anthropogenic noise [10][23].

Figure 3. Comparative Graph of SPAD, Plant Height, and DBH Among Zones



As illustrated in Figure 2, the comparative patterns of SPAD values, plant height, and DBH across the three zones clearly show a progressive decline in vegetation performance as noise exposure increases. The spatial trend confirms that vegetation closer to major roads experiences more severe decline, reducing its ecological ability to buffer noise an effect also noted in studies linking vegetation degradation with anthropogenic disturbance [4][7].

### 3.3 Flora Diversity

Flora diversity varied substantially across zones, with Zone 3 showing the highest species richness and Shannon–Wiener diversity index ( $H'$ ) and Zone 1 displaying the lowest. Urban biodiversity studies indicate that elevated noise levels can reduce species diversity by limiting the establishment of sensitive species and altering microhabitats [12,18]. As shown in Table 2, the Shannon–Wiener diversity values differ markedly across the three zones.

**Table 2. Shannon-Wiener Diversity Index (H')**

Zone	Number of Species (S)	Number of Individuals (N)	Shannon-Wiener Diversity Index (H')	Diversity Category
Zone 1	12	248	1.85	Moderate
Zone 2	18	367	2.43	High
Zone 3	24	452	2.87	High

Noise can also impact pollinator activity and seed dispersal, which may indirectly suppress plant species recruitment in high-noise areas [15]. This pattern supports the notion that biodiversity in urban green spaces is shaped jointly by spatial structure and environmental stressors, including noise exposure [7,12].

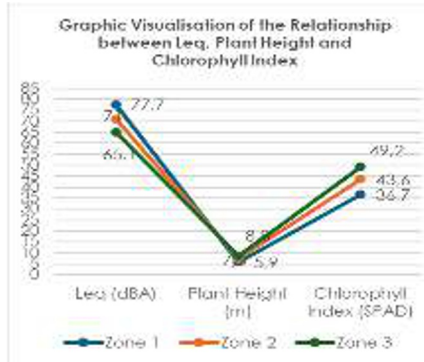
### 3.4 Soundscape Characteristics

Soundscape analysis revealed clear differences across zones. Zone 3 exhibited higher Acoustic Diversity Index (ADI) and Acoustic Richness (AR), indicating greater biotic acoustic activity primarily birds and insects. These results align with established evidence that quieter environments with richer vegetation support more robust biotic acoustic communities [13,16–18]. In contrast, Zone 1 was dominated by anthropogenic noise, reflected in elevated AE values that indicate masking of natural sounds. Chronic noise exposure is known to disrupt wildlife communication, alter behavioral patterns, and diminish acoustic biodiversity [14–16]. This confirms that soundscape indices are effective indicators of ecological quality and reflect broader interactions among noise, vegetation structure, and wildlife presence [13,17].

### 3.5 Spatial Analysis of Noise Vegetation Soundscape Interactions

Spatial interpolation using **ordinary kriging**, a method widely used for mapping environmental gradients with high accuracy [21,22], produced noise surfaces showing pronounced hotspots near major roads. Overlaying the noise maps with vegetation metrics and soundscape indices revealed consistent spatial relationships. Noise hotspots overlapped with areas of reduced vegetation vigor, while zones with higher Leq values showed lower species diversity. Likewise, biotic acoustic activity was noticeably weaker in noise-dominated patches, indicating the suppressive effect of traffic noise on ecological conditions. As illustrated in Figure 3 above, the spatial comparison of Leq values, plant height, and chlorophyll index reveals a coherent trend in which vegetation health progressively declines in areas exposed to higher noise intensities. This pattern indicates that zones with elevated noise not only experience physiological suppression, but also show reductions in key growth indicators that collectively reflect weakened ecological performance. These patterns are consistent with findings in landscape acoustic ecology, which emphasize the multiscale interactions among noise, vegetation structure, and biotic communities [2,4,7]. Vegetation not only acted as a physical buffer but also shaped soundscape quality and ecological resilience, reinforcing the concept that noise is a major ecological driver in urban systems [13,18,19].

Figure 4. Visualisation of the Relationship between Leq, Plant Height and Chlorophyll Index



3.6 Implications for Urban Green Space Management

The findings highlight the importance of adopting integrated planning strategies that explicitly address the ecological impacts of traffic noise. Key recommendations include enhancing vegetation density and structural diversity to strengthen natural attenuation capacity [4–6], and implementing layered vegetation belts as an effective ecological barrier against noise propagation [5,6]. Protecting interior green areas that support high biotic acoustic activity is also essential for maintaining ecological resilience [13,16]. In addition, soundscape based ecological assessments should be incorporated into routine management practices to better capture biological responses to noise [17,18]. Finally, spatial noise modelling should be integrated into urban green space design to ensure that ecological planning aligns with actual noise exposure patterns [2,21].

These measures support the development of greener and acoustically healthier urban environments, consistent with modern approaches to sustainable urban ecology [19,20].

4 CONCLUSION

This study demonstrates that traffic noise exerts significant impacts on vegetation physiology, flora diversity, and soundscape quality within the Simpang Lima urban green space of Semarang City. Spatial noise analysis revealed clear gradients associated with proximity to major roads, a pattern consistent with established urban noise dynamics. Vegetation exposed to higher noise levels showed reduced chlorophyll index, diminished growth, and signs of physiological stress, supporting previous findings on noise-induced impairment of plant health and photosynthetic performance.

Flora diversity was also lower in high noise zones, reflecting the sensitivity of plant communities to chronic acoustic disturbance and its indirect effects on microhabitats and pollinator activity. Soundscape assessments indicated enhanced biotic acoustic activity in quieter areas, aligning with soundscape ecology research demonstrating the dependence of acoustic biodiversity on vegetation structure and reduced anthropogenic noise.

The integrated spatial analysis linking kriging-based noise mapping with vegetation and acoustic indicators highlights noise as a critical ecological stressor influencing multiple components of urban ecosystems. Overall, the findings emphasize the need for noise aware green space planning, including vegetation based buffering strategies and sound-scape informed ecological management, to enhance resilience and ecological quality in rapidly urbanising environments .

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