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MITIGATING NOISE ANNOYANCE THROUGH GREEN SPACES: HEALTH IMPACTS IN EUROPEAN URBAN ENVIRONMENTS

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ABSTRACT

Tranquil areas are recognized for their positive impact on well-being, offering relief from urban noise and stress. Green spaces are a crucial component of these tranquil areas, contributing to their calming effects. This study evaluates the health benefits of tranquil areas in European agglomerations by quantifying reductions in noise annoyance from road traffic and railway noise through increased green space exposure. Noise exposure data were sourced from Environmental Noise Directive (END) mapping. Green space exposure was assessed using the Normalized Difference Vegetation Index (NDVI). Noise annoyance was estimated using WHO exposure-response functions, with the modifying effect of green space derived from a Swiss survey. Two scenarios were considered: (1) achieving WHO recommendations for green space access (0.5 hectares within 300m) and (2) a 10% green space increase across all agglomerations. Meeting WHO targets could reduce noise annoyance by 1.1% (104,486 individuals) for road traffic and 0.7% (10,210 individuals) for railway noise, preventing 1,149 and 112 DALYs, respectively. A 10% green space increase could reduce annoyance by 9.6% (882,673 individuals) for road traffic and 6.8% (92,940 individuals) for railway noise, preventing 9,709 and 1,022 DALYs. These results highlight the potential of tranquil areas to mitigate noise-related health impacts.

Keywords: *Green spaces, noise annoyance, health impact assessment, quietness, tranquillity.*

1. INTRODUCTION

Urban noise pollution represents a critical public health challenge globally. In Europe, 113 million adults—over 20% of the population—are exposed to road traffic noise exceeding the recommended threshold of 55 dB L_{den} [1]. Chronic exposure to such high levels of noise is associated with various health outcomes including noise annoyance, sleep disturbance, and cardiovascular diseases, contributing to an estimated 1 million healthy life lost annually in Europe alone [2-3]. Of this, noise annoyance—a stress response that can trigger cardiovascular disease—accounts for approximately 453,000 Disability-Adjusted Life Years (DALYs), underscoring its significant impact [1].
The Environmental Environment Agency (EEA) emphasizes reducing noise pollution while preserving quiet areas—tranquil spaces blending low noise levels with restorative green infrastructure [1,4]. These areas are posited to reduce perceived noise annoyance through both acoustic shielding and also psychological restoration [5-7], though their continent-scale health benefits remain poorly quantified.
This study conducted a health impact assessment to quantify potential reductions in noise annoyance prevalence and associated DALYs by increasing green space exposure in European agglomerations. Building on research showing

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that green spaces mitigate noise annoyance perception, we evaluated two scenarios: (1) achieving universal access to WHO-recommended green spaces (≥ 0.5 hectares within 300 m of residences)) [9] and (2) implementing a 10 % NDVI increase across all agglomerations.

2. METHODS

2.1 Mitigating effects of residential green on noise-related health effects

A scoping review was conducted to evaluate whether and to what extent green spaces mitigate noise-induced health effects [10]. A key study identified was a national survey from Switzerland involving 5,592 participants [11]. This study modeled exposure-response functions (ERFs) linking L_{den} (road traffic, railway) to annoyance across varying green space levels, quantified using Normalized Difference Vegetation Index (NDVI).

NDVI measures vegetation density (range: -1 to 1, with positive values used for greenness) and captures all greenery, such as trees, parks, and private gardens. NDVI thresholds were defined as low (< 0.3), moderate (0.3 – 0.5), and high (> 0.5). Schäffer et al. [11] found that high greenery (95th percentile, NDVI = 0.72) shifted the ERFs, interpreted as an equivalent sound pressure level change (ΔL) of 6.3 dB for road traffic and 3.6 dB for railway noise, compared to low greenery (5th percentile, NDVI = 0.33). This indicates residents in greener areas tolerate higher noise levels before reporting equivalent annoyance (see Fig.1 reproduced from [11]).

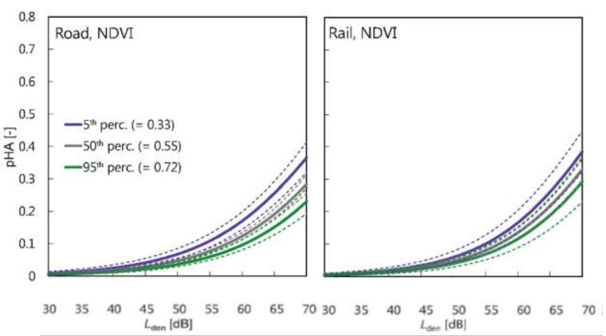

Figure 1. Exposure-response curves for the probability of high annoyance (pHA) as a function the sound pressure level (L_{den}) and residential green (NDVI) for road traffic (left) and railway noise (right), including 95 % Confidence Interval

2.2 Data sources

Noise exposure data were sourced from the Environmental Noise Directive (END) for 2022, providing 24-hour equivalent noise levels (L_{den}) for road and railway sources at the agglomeration level across Europe. Green space exposure was quantified using NDVI. Baseline mean NDVI values for each agglomeration were derived from the ISGlobal ranking of 1,000 European cities [12]. The NDVI levels were retrieved for each grid (250 x 250 m) using the Terra MODIS satellite imagery (MOD13Q1) sourced from the US Geological Survey [13].

2.3 Counterfactual scenarios

Two scenarios were modeled to assess the impact of increased green spaces on noise annoyance:

Scenario 1: WHO green space access target

This scenario aligns with WHO guidelines, ensuring all residents have access to ≥ 0.5 hectares of green space within a 300-meter radius (approximately a 5-minute walk) [9]. City-specific "target NDVI" values, approximating this WHO threshold, were obtained from the ISGlobal ranking of cities which is an urban health study in 1,000 European cities study [12]. They derived the target values via a generalized additive model linking NDVI to a 25% green area proportion within 250 x 250 m grid cells, reflecting local vegetation patterns. Cities already meeting this threshold were excluded, and the target NDVI served as the counterfactual exposure level.

Scenario 2: Uniform 10% NDVI increase

This scenario applies a uniform 0.1 NDVI increase (10% on the scale) across all agglomerations, including those meeting WHO targets, to evaluate the benefits of widespread greening.

2.4 Health impact assessment

The HIA targeted adults aged 18 or older in European agglomerations (> 100,000 residents) reporting to the END [14]. Baseline and counterfactual percentages of highly annoyed individuals (%HA) were estimated for populations exposed to > 55 dB L_{den}, using ERFs from the WHO Environmental Guidelines [15] (see Tab.1). For each 1-dB noise band, the number of HA residents was calculated, and results were summed across bands. Counterfactual L_{den} adjustments incorporated ΔL scaled to NDVI changes and the functions used to estimate the % HA are show in Tab.1. A disability weight of 0.011 per highly annoyed person was applied to estimate DALYs averted [16]. Results were aggregated at agglomeration and country levels. All analyses were conducted in R (v4.3.2).

Table 1. Exposure-response functions for percentage of highly annoyed people (%HA) in relation to the annual 24-hour noise level (L_{den}) for road traffic and railway noise used in the HIA, based on [11-12]

Road traffic noise	
Baseline	$\%HA = (78.9270 - 3.1162 \times L_{den,\ road} + 0.0342 \times L_{den,\ road}^2)/100$
Scenario 1	$L_{den,\ road,\ S1} = L_{den,\ road} + [-6.3/(0.72 - 0.33)] \times (\text{target NDVI} - \text{mean NDVI})$
Scenario 2	$L_{den,\ road,\ S2} = L_{den,\ road} + [-6.3/(0.72 - 0.33)] \times (\text{mean NDVI} + 0.1)$
Railway noise	
Baseline	$\%HA = (38.1596 - 2.05538 \times L_{den,\ railway} + 0.0285 \times L_{den,\ railway}^2)/100$
Scenario 1	$L_{den,\ railway,\ S1} = L_{den,\ railway} + [-3.6/(0.72 - 0.33)] \times (\text{target NDVI} - \text{mean NDVI})$
Scenario 2	$L_{den,\ railway,\ S2} = L_{den,\ railway} + [-3.6/(0.72 - 0.33)] \times (\text{mean NDVI} + 0.1)$

3. RESULTS

3.1 Population coverage and baseline annoyance

The health impact assessment covered 121.9 million adults across 417 European agglomerations reporting exposure to road traffic noise, with 9.2 million (7.6%) suffering from high annoyance at baseline. For railway noise, 116.3 million adults in 396 European agglomerations were included, of whom 1.4 million (1.2%) were highly annoyed at baseline (see Tab.2). Estimated reductions in highly annoyed individuals under two counterfactual scenarios are also presented in Tab.2.

3.2 Scenario-specific health gains

Under Scenario 1, 46.4 million adults (38.1% of the total population) in 100 agglomerations resided in areas with suboptimal NDVI levels. Meeting the city-specific targets in these agglomerations could reduce the annual number of highly annoyed adults by 104,486 (1.1% reduction, or 86 fewer cases per 100,000 adults) for road traffic noise, preventing 1,149 DALYs. For railway noise, 45.6 million adults (39.1% of the total population) in 91 agglomerations benefited, with a reduction of 10,210 cases (0.7% reduction, or 9 fewer cases per 100,000) and 112 DALYs prevented.
Scenario 2 yielded larger benefits: road traffic noise annoyance dropped by 882,673 cases (9.6% reduction, or 724 fewer cases per 100,000) with 9,709 DALYs prevented, while railway noise annoyance declined by 92,940 cases (6.8% reduction, 82 fewer cases per 100,000) and 1,022 DALYs prevented. France and Germany have the highest potential in reducing annoyance.

Table 2. Estimated baseline and reduction in highly annoyed adults by road traffic and railway noise due to green spaces exposure in the included European agglomerations in 2022

Noise source	**Baseline HA (n)**	**Reduction (n/%)**	**DALYs Prevented**
Road traffic	9,218,282	Scenario 1	
		104,486 (1.1%)	1,149
		Scenario 2	
		882,673 (9.6%)	9,709
Railway	1,364,867	Scenario 1	
		10,210 (0.7%)	112
		Scenario 2	
		92,940 (6.8%)	1,022

3.3 Spatial heterogeneity in benefits

For road traffic noise under Scenario 1, France accounts for 55.0% of total reductions (57,513 individuals), followed by the Netherlands (8.7%), Germany (8.1%), and Italy (6.0%). The cities with the greatest potential reductions include Paris and Lyon in France, Amsterdam and The Hague in the Netherlands, and Berlin in Germany. Railway noise reductions under Scenario 1 are similarly dominated by France (49.5%, 5,056 individuals) and Germany (17.1%, 1,744 individuals), with Paris, Aubergenville, and Berlin emerging as key cities.
Under Scenario 2, spatial disparities intensify. France remains the largest contributor to road noise reductions (197,608 individuals, 22.4% of total), though Germany (149,874, 17.0%) and Spain (116,694, 13.2%) gain prominence. For railway noise, Germany overtakes France as the leader (26,265 individuals, 28.3%), with

Italy (10,861, 11.7%) and Spain (6,426, 6.9%) showing increased contributions. Cities such as Madrid, Prague, and Rome rise in importance under stricter green space targets. See [10] for detailed country- and agglomeration-level results.

4. DISCUSSION

This HIA underscores the potential of increasing green space availability to reduce noise annoyance in urban Europe, offering quantifiable public health benefits. Our analysis reveals that meeting WHO recommendations for universal green space access (Scenario 1) could decrease the number of individuals highly annoyed by road traffic noise by 1.1% and railway noise by 0.7%, averting 1,149 and 112 DALYs, respectively, across 417 and 396 urban agglomerations. A more ambitious 10% NDVI increase (Scenario 2) yields greater reductions—9.6% for road traffic noise and 6.8% for railway noise—preventing 9,709 and 1,022 DALYs, respectively. These findings highlight green spaces as a viable strategy for mitigating noise-related health burdens in urban settings.

Regional differences in reduction potential reflect variations in baseline noise levels, population size, and greenness gaps. For instance, Paris, with high baseline annoyance and a moderate NDVI shortfall (current 0.421 v. target 0.475), shows substantial benefits, while Cadiz, despite a larger NDVI gap (current: 0.155 vs. target: 0.231), exhibits smaller gains due to lower population and annoyance levels. A uniform NDVI increase in Scenario 2 produces consistent percentage reductions (9 % for road traffic, 7 % for railway) across agglomerations, suggesting scalability of green interventions. Notably, road traffic noise annoyance decreases more than railway noise, likely due to higher baseline exposure and greater sensitivity to noise level changes, amplified by the broader coverage of road traffic data (417 vs. 396 agglomerations). Effects are most pronounced in lower noise bands (<55 dB L_{den}), where the majority of the exposed population resides, though benefits diminish at higher noise levels due to fewer affected individuals.

Mechanistically, green spaces mitigate noise annoyance through physical sound attenuation—dense vegetation reduces low-frequency traffic noise [17-18]—and psychological benefits, such as stress reduction and improved noise perception [19]. These align with European greening initiatives (e.g., EU Biodiversity Strategy, SDG 11.7) [20], exemplified by various projects like Barcelona's superblocks [21] or Malmö's green roofs [22], which integrate noise mitigation with co-benefits like heat reduction and biodiversity enhancement.

However, this HIA likely underestimates total benefits. It focuses on adults residing in urban areas, where approximately 75% of the European population lives [23], excluding those in rural regions who may also experience significant benefits from increased greenery. It also omits broader health outcomes such as cardiovascular disease focusing solely on annoyance. Additionally, NDVI captures total greenness but does not reflect quality or accessibility, potentially undervaluing usable green spaces. Aircraft noise exclusion, informed by its increased intrusiveness in green settings [11], further limits scope. Future HIAs should incorporate detailed green metrics and longitudinal data to strengthen causal links and assess wider health impacts.

5. CONCLUSION

This HIA demonstrates that expanding green spaces—through WHO targets or a 10% NDVI increase—lowers population noise annoyance and DALYs in European agglomerations. These results support embedding tranquil green areas into urban planning and health strategies, promoting vibrant, well-being-focused cities with enhanced tranquility. Nevertheless, mitigation of transportation noise by promoting speed reductions, low noise pavement, low noise tires, foot and bicycle traffic as well as appropriate city planning is key for reducing health effects from transportation noise.

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