(day-evening-night) 53 dB and L_{night} 45 dB to minimise impacts to human health (World Health Organisation, 2018).

Environmental exposure studies have noted that the distribution of residential exposures to road traffic noise is often not equitable (Dreger et al., 2019; Trudeau et al., 2023). Although evidence is limited, research suggests that different socioeconomic groups are exposed to higher levels of road traffic noise or have a higher prevalence of noise exposure (Dale et al., 2015; Carrier et al., 2016; Mueller et al., 2018, Verbeek, 2019). However, drawing conclusions from the limited number of studies is often complicated due to mixed research findings and methodological differences in research techniques. Moreover, environmental health inequalities may arise not only due to differences in exposures but also from an inter-connected system of environmental, social and biological determinants (Marmot, 2005; Riedel et al., 2021). Nevertheless, exposures to high noise levels can contribute to an increased vulnerability within a population which can exacerbate health inequalities across and within cities (Tonne et al., 2018).

Greenspaces within urban environments are widely documented for their potential positive impact on individual and community well-being (Gidlöf-Gunnarsson and Öhrström, 2007; Jabbar et al., 2022; Wang'ombe, 2024). Urban greenspaces are defined as public or private spaces that primarily consist of vegetated land, which could contain water, within an urban area (Taylor and Hochuli, 2017). Such spaces, including formally designated parks and playing fields, areas set aside under legislation (e.g., allotments), and more natural areas such as nature reserves (Comber et al., 2008), contribute to physical activity and social interaction, promote biodiversity, and help to regulate greenhouse gases and elevate urban heat (Lee et al., 2015; Paudel and States, 2023). Greenspaces offer relief and sense of tranquillity from pervasive noise by providing a multisensory experience which feature pleasant soundscapes of 'winds, birds and water' (Ratcliffe, 2021; Jiang et al., 2025). Additionally, the absence of urban noise and restorative qualities of greenspace can promote mindfulness and reduce annoyance (Bray et al., 2022). From an environmental psychology perspective, it is argued that urban greenspaces have restorative qualities and epitomise the notion of 'soft fascination' – a gentle form of attention that does not require cognitive effort, and recover from Direct Attention Fatigue (DAF), as conceptualised through Attentional Restoration Theory (ART) (Kaplan and Kaplan, 1989; Kaplan, 1995). Thus, ART frames restoration as a psychophysiological response to environmental stimuli, where exposure to low-demand, natural settings facilitate the recovery of attentional function by reducing cognitive load and stressor exposure. However, the presence of unwanted environmental noise can cause a shift in focus, dramatically capturing attention and depleting cognitive resources that help to suppress distractions (Berman et al., 2008; Kaplan and Berman, 2010). Over time, this instead creates a conflict situation where a restorative environment is potentially exacerbating DAF rather than restoring it. Despite this, much recent research related to ART and other environmental psychology theories, such as Stress Reduction Theory (SRT) (Ulrich, 1983), have either focused on the emotional response arising from the subjective perception of greenspace noise or from visual engagements with the natural environment. This study instead builds on existing environmental research by addressing the variability in objective greenspace noise levels.

Epidemiological research has further shown that exposure to greenspaces contributes positively to the physical and mental health of individuals (Mensah et al., 2016), through improvements in psychological well-being (Kondo et al., 2018), alleviating mental stress (Woo et al., 2009; Alcock et al., 2014; Kondo et al., 2018), and some associations in cognitive and brain development in children (Wallner et al., 2018; Sprague et al., 2022). Additionally, epidemiological studies have documented positive cardiometabolic health outcomes related to increased physical activity levels by walking, jogging, or partaking in other sporting activities (Mensah et al. 2016; Kondo et al. 2018). However, greenspaces are not always quiet and exposures to high noise levels may negatively impact individuals' experience, with studies suggesting that greenspaces with high noise levels can impact the decision to visit, the length of their visit, and the quality of relaxation enjoyed (Ridgley et al., 2020; Waters et al., 2023). While exposure studies have noted that the distributions in residential exposures to road traffic noise are not equitable, evidence related to exposures within urban greenspaces in the UK remains limited. Such restorative benefits provided by urban greenspaces could be at risk as spaces become 'noisier'. In turn, this could further elevate avoidable health inequalities, particularly amongst disadvantaged communities. Therefore, it is of importance to understand the distribution of traffic-related noise levels in urban greenspaces and assess the noise exposure equity within and between different communities.

Greater London is overall considered one of the less deprived regions in the UK, according to the most recent Index of Multiple Deprivation (Greater London Authority, 2020). However, despite being a global financial hub, areas of socioeconomic deprivation persist across the region (Environmental Audit Committee, 2020). Moreover, London is one of the greenest cities in the world, with public greenspaces covering nearly 40 % of the Greater London region (BOP Consulting, 2013). Nonetheless, the 2017 strategic noise mapping, undertaken to fulfil the requirements of the Environmental Noise (England) regulations as part of the European Noise Directive (DEFRA, 2006), revealed that 29 % of the 885 surveyed Greater London parks were impacted by traffic noise at 55 dB or above, with 25 % of the parks reporting noise above 60 dB in at least a quarter of their surface area (CPRE London, 2018). While the report documents the quality of noise levels of 885 greenspaces across London, noise level estimates for approximately ~2000 Greater London greenspaces were not unaccounted for. Additionally, strategic noise maps only account for the impact of road traffic noise generated from major roads, thereby overlooking the contribution from inner-city minor roads which may carry substantial volumes of traffic. Incomplete coverage of traffic flows can lead to an underestimation of noise levels and, subsequently, exposure misclassification.

This study provides a detailed analysis of the socioenvironmental inequalities in noise levels in greenspaces in Greater London. To do this, we mapped the spatial variation in road traffic noise exposure levels derived from the CNOSSOS-EU noise model across different types of greenspaces across Greater London. To improve and expand the basis for noise mapping we used a detailed model of road traffic flows to include all publicly accessible roads (Morley and Gulliver, 2016). Noise levels within greenspace were compared against levels for the daytime (07:00–19:00) and evening (19:00–23:00) periods derived from the WHO Environmental Noise Guidelines for the European region. Firstly, we contrasted the annual average road traffic noise levels within London's greenspace and quantified the spatial variation in noise exposures across the 33 London local authorities. We then assessed greenspace exposures across different levels of socioeconomic deprivation using two approaches: 1) the average noise level within greenspace areas nearest to residential locations and 2) by calculating the average noise level of all greenspace areas within 300 m, 2 km, and 5 km around each postcode. Greenspace noise levels within 300m align with the WHO recommendation for universal access to greenspaces (Jiang et al., 2025). Greenspace noise levels within 2 km and 5 km correspond to distances commonly associated with active travel. While there is no universal UK mandate that defines walkable or cycling distances, for most journey purposes, active travel typically refers to short-to medium-length trips (UK.Gov, 2011). This approach enabled us to assess the equity of greenspace noise levels across varying distances from a residential location.

2. Materials and methods

2.1. Datasets

2.1.1. Greater London Greenspace data

Road traffic noise within greenspaces was modelled across the

Greater London area, which includes 33 London local authority districts (LAD). Fig. 1 shows the 33 local authority areas, distinguished by Central and Outer London as defined by the Greater London Authority (2021). Greater London, UK, contains over 3000 publicly accessible greenspaces that serve as a critical infrastructure aimed at improving population health, conserving wildlife and mitigating the effects of climate change, promoting cultural and heritage experiences, and supporting economic growth (Greater London Authority, 2020). These greenspaces include a variety of different types, from the eight Royal Parks such as Hyde Park and Kensington Gardens, to smaller community gardens managed by local organisations.

Urban greenspace data was acquired from Ordnance Survey's (OS) 'Open Greenspace' data portal for the year 2019. The OS Open Greenspace dataset provides detailed information on the spatial distribution of greenspaces that are likely to be accessible by the public, at a 1:1250 scale. The dataset further classifies greenspace into 10 sub-categorises based on its function which include allotments and community growing spaces, bowling greens, cemeteries, golf courses, other sports facilities, play spaces, playing fields, public parks or gardens, religious grounds, and tennis courts (Fig. 2). The high spatial resolution and detailed subcategorization of the 'Open Greenspace' dataset provides a complete representation of the different greenspace types across Greater London.

Across Greater London, there are 2,532 unique greenspace areas that cover a combined area of 232.3 km^2 (14.8 % of the city's surface). The average size of a greenspace area is 300m x 300m (SD = 0.28 km^2). Public parks constitute the largest area of greenspace (50 %), followed by golf courses (18 %), playing fields (12 %), and other sports facilities (11 %). Public parks are typically 0.16 km^2 in size (SD = 0.49 km^2). Richmond Park is the largest area of greenspace covering an area of 9.5 km^2.

As the basis for assessing noise levels, the OS Greenspace polygon layer was converted into a series of 50m x 50m grid cells. Any grid cells that intersected roads or buildings were removed to prevent disruption in the propagation and attenuation of sound between source points and greenspace receptors. Geometric centroids were constructed for each cell and then assigned the associated greenspace area attributes by spatial join. In total, 75,211 receptor locations were created at which road traffic noise was estimated.

2.1.2. *Greenspace traffic noise*

To accurately model the distribution of noise levels across greenspaces, the receptor points were divided into 37,007 'exterior' points and 38,204 'interior' points to reflect the distinct acoustic environments at the greenspace boundary and centre. Exterior points were defined as receptor points within 50m of the boundary or within 100m of a major or minor road to capture the influence of surrounding noise sources. Interior points were defined as receptor points located beyond this threshold. Supplementary Fig. S1 shows the spatial distribution of exterior and interior receptor points across a greenspace area.

Two methodological approaches were undertaken to account for the variations in noise levels across each greenspace area. Greenspace noise levels at exterior receptor points were modelled using the CNOSSOS-EU framework (Section 2.1.2.1) which accounts for the complex geometric influences on the attenuation of traffic noise entering the greenspaces from all roads. This includes factors such as reflection and scattering from buildings and absorbance by landcover type. Greenspace noise levels at interior receptor points were calculated using the 'inverse square law' (ISL) of sound attenuation (Section 2.1.2.2), based on the distance-weighted influence of noise levels from receptor points closest to the sound source. Together, these approaches ensure a comprehensive representation of noise propagation across greenspaces.

Fig. 1. – Local authority districts (LADs) within Central London and Outer London.

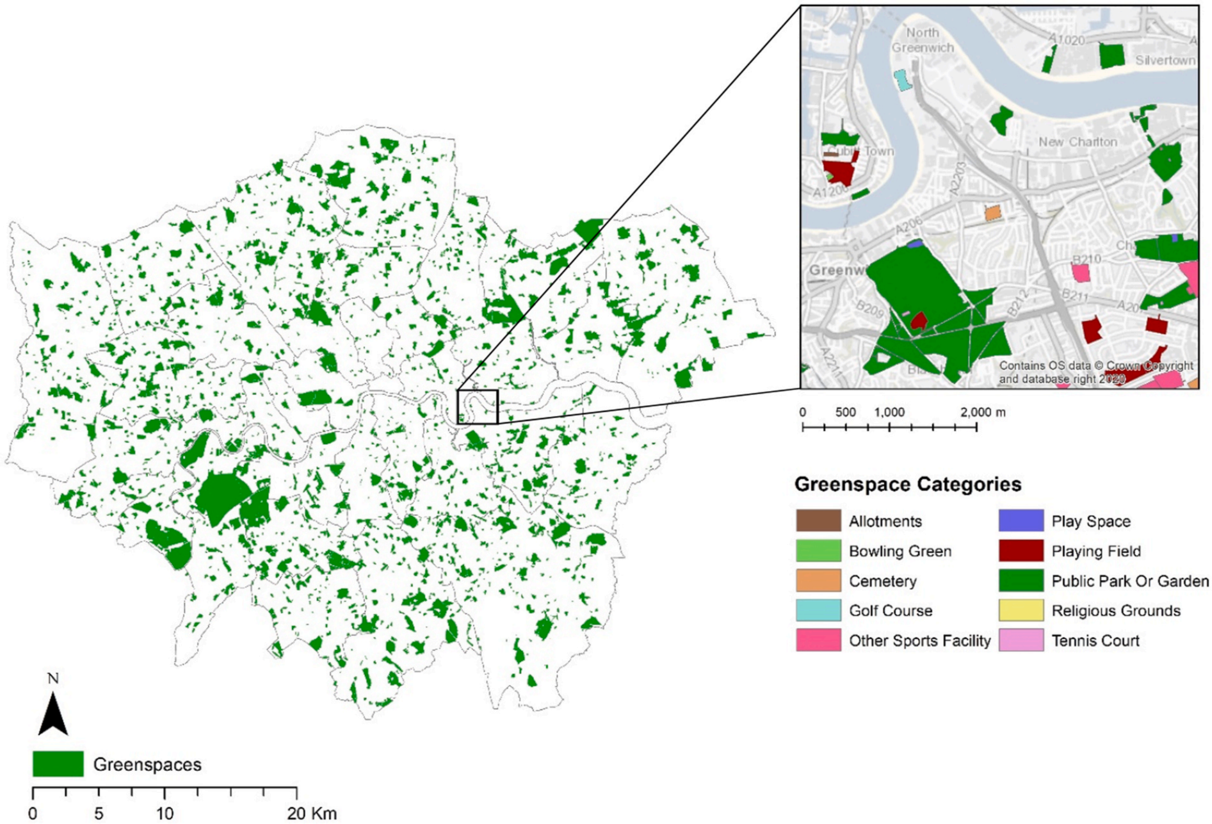

Fig. 2. – The spatial distribution of greenspaces across Greater London and greenspace categories (inset). Contains OS data © Crown copyright and database right (2019).

2.1.2.1. CNOSSOS-EU road traffic noise model. Road traffic noise was calculated in accordance to the 'Common Framework for Noise Assessment Methods' (CNOSSOS-EU), developed by the European Commission to report regulatory compliance with Environmental Noise Directive 2002/49/EC (Kephalopoulos et al., 2014). CNOSSOS-EU is a standardised framework that is used to assess environmental noise from the main sources of noise pollution (road and rail traffic, aircraft, and industry) in environmental exposure assessments across Europe.

Five main data inputs are required for the CNOSSOS-EU road traffic noise model: 1) receptors; 2) landcover; 3) building heights; 4) road geography with traffic information; and 5) meteorological data. Information on landcover was acquired from the Ordnance Survey (OS) Mastermap™ Topography dataset (1:1250 scale), providing detailed information on different landcover themes (land, buildings, water) and descriptive groups (primary classification of a feature). Information on buildings was extracted from Ordnance Survey's Building Height Attribute Layer and joined with Buildings within the Topography layer. Meteorological data (temperature and wind profiles) were derived from the 'Worldmet' package in R. Annual average daily traffic counts (AADT) for 2013 were taken from a traffic-flow estimation model (Morley and Gulliver, 2016).

CNOSSOS-EU noise calculations were implemented in PostgreSQL using the PostGIS v4.2 extension, following the protocol described in (Morley et al., 2015). Firstly, the CNOSSOS algorithms locate all major roads within a 1000m radius and all minor roads within a 100m radius of each greenspace receptor. Major and minor roads were then divided into a series of source points at 20m intervals along each road segment. Sound power levels were calculated at source based on traffic volume, speed, road surface, and gradient. For sound propagation, 'ray-paths' are projected from the receptor point to each source point as a straight line. For each ray-path, in turn, the noise level at each source point was calculated using traffic flow data and the empirical relationships defined by CNOSSOS-EU. Receptor noise levels were estimated with respect to land cover (e.g., ground corrections) and buildings (e.g., reflections and diffraction) along the ray-paths. The CNOSSOS-EU method is valid for determining noise in the frequency range from 63 Hz to 8 KHz and all calculations are performed in 1/1 octave bands.

2.1.2.2. Inverse square law (ISL) of sound attenuation. The Inverse Square Law (ISL) of sound attenuation was applied to 'interior' greenspace points to model the change in sound intensity as a function of distance from a sound source (major or minor road). The ISL states that with every doubling of distance away from the sound source, the sound will be four times less intense. In greenspaces, additional attenuation may occur because of ground attenuation and due to vegetation effects (Gaudon et al., 2022). However, ground cover and vegetation density are likely to change within and across greenspace, and throughout the year. Therefore, for the purpose of this study these effects were not included. Additionally, this approach allows for road-traffic noise levels to be calculated below the 38 dB noise floor for L_{day} in Morley et al.'s (2015) implementation of the CNOSSOS-EU model. Standard modelling at these distant locations would result in the overestimation of greenspace noise levels.

The ISL of sound attenuation is defined as:

$$S_{ij} = S_j - \left(20^* \log_{10}\left(\frac{R_j}{R_i}\right)\right) \quad \text{eq. 1}$$

Where $\mathbf{S_j}$ is the measured sound pressure level (dB) at location **j**, and $\mathbf{R_j}$ measures the distance (m) from location **j** to the noise source. $\mathbf{R_i}$ is the measured distance (m) between location **i** and the same noise source. $\mathbf{S_{ij}}$ represents the estimated sound pressure level at location **i** based on the spatial relationship between location **i** and **j**.

For an 'interior' greenspace receptor point (**i**), the six nearest 'exterior' points with CNOSSOS-EU modelled values were identified ($\mathbf{j_1}$ to $\mathbf{j_6}$), and the ISL shown in eq. (1) was calculated for each pairwise combination. The nearest road (major or minor) to each location is assumed to be the main contribution of traffic noise, the distance to which defined parameters $\mathbf{R_i}$ and $\mathbf{R_j}$.

An 'Inverse distance Weighting' approach was then used to define the influence of each 'exterior' noise level on the predicted 'interior' location:

$$W_{ij} = \frac{1 / (D_{ij})^2}{\sum_{j}^{n=6} \left[1 / (D_{ij})^2 \right]} \qquad \text{eq. 2}$$

Where $\mathbf{D_{ij}}$ is the measured distance (m) between location **i** and one of its six neighbours **j**, and $\mathbf{W_{ij}}$ is the row-standardised weight that observations at location j on predicting values at location **i**. $\mathbf{W_{ij}}$ values are fractions that sum to 1, which were used to calculate the weighted-average noise level $\mathbf{S_i}$ at location **i**:

$$S_i = 10^* \ \log_{10}\left(\sum_{j}^{n=6} \left[10^{\left(\frac{S_{ij}}{10}\right)} * W_{ij} \right] \right) \qquad \text{eq. 3}$$

Finally, noise levels for each greenspace receptor point were adjusted with an A-weighted correction (dBA) replicating the sensitivity of human hearing across the frequency range of 20Hz to 20 kHz) (Hansen and Hansen, 2021). This study evaluated noise levels in greenspaces during the L_{day} exposure period (07:00–19:00) and the L_{eve} exposure period (19:00–23:00) since these are the time periods that individuals are most likely to utilise these spaces.

A sensitivity analysis was performed to assess the differences in noise level measurements produced by Morley et al.'s (2015) implementation the CNOSSOS-EU noise model, both independently and in conjunction with the ISL decay function. The analysis found the approaches to have less than 1 percentage-point difference in the area of greenspaces that exceed the L_{day} guideline values (Supplementary Table S1). Differences in interior noise levels for 0–500m and >500m (a threshold where L_{day} values are <38 dB) from a greenspace boundary were evaluated to explore ISL and CNOSSOS-EU modelling errors, respectively (Supplementary Table S2). Median absolute differences of <3 dB were reported for L_{day} by the ISL approach close to the greenspace boundary, which equates to a modelling error of <6.7 %. CNOSSOS-EU was found to overestimate interior locations by 5–10 dB (leading to modelling errors of 8.5–26 %), therefore justifying the hybrid implementation of CNOSSOS and ISL.

2.1.3. Socioeconomic deprivation

The latest Index of Multiple Deprivation (IMD) from 2019 was used to measure the socioeconomic status (SES) of communities across Greater London. The IMD is the official measure of relative deprivation at small-area level in England used by researchers and policymakers to quantify the socioeconomic status of a neighbourhood (DLUHC, 2022). The index is based on an established methodological framework using seven domains to define deprivation: income (22.5 %), employment (22.5 %), education, skills training (13.5 %), health deprivation and disability (13.5 %), crime, barriers to housing and services (9.3 %) and living environment (9.3 %) (MHCLG, 2019). Each domain contains 39 separate indicators which are combined and weighted to measure the level of deprivation experienced by a population at a Lower-layer Super Output Area (LSOA - average population size of 1,700 in London). All LSOAs across the UK are then ranked according to their level of deprivation relative to that of other areas. IMD rank scores were classified into five quintiles to capture relative differences in deprivation across London (Sheridan et al. 2019), with quintile 1 representing areas that are in the 20 % most deprived nationally and quintile 5 representing areas that are in the 20 % least deprived nationally. IMD quintiles were summarised across Output Areas (OAs) to allow for comparisons between noise levels in greenspaces and relative deprivation at a localised scale. LSOAs typically contain four or five OA communities.

2.2. Analysis

Road traffic noise were modelled across 2,532 greenspaces in Greater London. The noise exposure assessment included 412 allotments or community growing spaces, 18 bowling greens, 145 cemeteries, 114 golf courses, 387 other sports facilities, 58 play spaces, 610 playing fields, 718 public parks or gardens, 36 religious grounds, and 34 tennis courts. Greenspace noise levels for the City of London are not included in this analysis since OS Greenspace polygons did not meet the required 50 m 'fishnet' grid size outlined in section 2.2.1.

Using the 50m grid of noise estimates, we created the following measures in GIS to assess greenspace noise levels in relation to residential locations, within each LAD (N = 33), and in relation to residential postcode (i.e., zipcode) locations (N = 140,786).

1) Average noise level for greenspaces within each LAD.
2) Average noise levels for the nearest area of greenspace to each residential location.
3) Average noise level of all greenspace areas falling within 300 m, 2 km, and 5 km of each residential location.

For the distance-based analyses, average noise levels were calculated using Euclidean buffers that measure the straight-line distance around each postcode centroid (the radius centre for the respective distance). Receptor points (sound receivers) that intersected the respective distance radii for each postcode were aggregated to obtain the average greenspace noise levels for each proxy of accessibility. The distance-based exposures were (a) analysed by postcode unit, and (b) transformed into population-weighted exposures across the 25,043 OA (2011) communities in Greater London to offer a more accurate representation of actual population exposures. This technique accounts for variations in population density by placing greater weight on road traffic noise levels with higher population density. Supplementary Fig. S2 shows the different geographic coverages and Supplementary Fig. S3 shows the influence of population density on postcode exposures.

2.2.1. Statistical and spatial analysis

We mapped greenspace noise levels, assessed them against L_{day} and L_{eve} values derived from WHO guidelines (see Section 2.2.2), and produced summary statistics (min, max, median, logarithmic mean) for LADs and by type of greenspace. The percentage area of greenspaces with noise levels that exceed the guidelines for either across the entire space (100 %) or any part (>1 %) was also determined by calculating the number of greenspace receptor points that exhibited noise levels above 51.2 dB (L_{day}) and 47.9 dB (L_{eve}), compared to the total number of greenspace receptors. Greenspace noise levels for all assessed measures (Section 2.2) were summarised across the Index of Multiple Deprivation quintile groups to determine if there was an inequality gradient in noise across the different deprivation groups. The assessment of both parametric (ANOVA) and non-parametric (Kruskal-Wallis) outcomes was conducted to test whether there are significant differences between two or more IMD Quintile pairings. These tests were used to remove the need for questionable tests of normality and homogeneity (Janta et al., 2021). If both tests yield significant results ($p < 0.05$), this increases confidence in hypotheses testing. Significant linear pairwise comparisons and post-hoc trends (i.e., Tukey test and Dunn's test) were conducted during residential scale and accessibility analysis to highlight significant differences in greenspace noise levels between IMD Quintile group pairings.

Spatial autocorrelation was calculated using the univariate Global Moran's I statistic (Moran, 1948), which assessed the level of connectedness between residence-based greenspace noise levels (section 2.2, point 3) and deprivation. In this analysis, deprivation was represented as a continuous variable using raw Index of Multiple Deprivation (IMD) scores, where higher IMD scores indicate higher levels of deprivation, and lower scores indicate lower levels of deprivation (DLUHC, 2022). Global Moran's I was explored through a row-standardised first-order Queen's contiguity weighting scheme, which assigns weights to OA communities based on their immediate neighbours that share a common edge or vertex. The level of spatial association between variables, as measured by Moran's I, ranges from −1 to +1, where −1 indicates dispersion, 0 indicates no association, +1 indicates clustering across geographic space. The bivariate Global Moran's statistics was calculated to assess the degree of spatial dependence between residence-based greenspace noise levels and lagged IMD scores, summarised at the OA level. This statistic evaluates whether high or low values of one variable at a given locations are spatially associated with values of another variable in neighbouring locations (i.e., the lagged variable). In this analysis, greenspace noise levels represent the attribute of interest at the ego location (i), while IMD scores the attribute of interest at the neighbouring location (j). As with univariate Moran's I, bivariate Moran's I values range from −1 to +1, where higher values reflect a stronger positive spatial association.

All statistical analyses were carried out in R software version 4.3.1. Moran's I statistics were carried out in GeoDA. Maps were produced in ArcGIS Pro v3.4.

2.2.2. Daytime and evening exposure guideline values

The current WHO guidelines recommend reducing exposures to road traffic noise below 53 dB L_{den} – L_{den} being the A-weighted sound level averaged over a 24-h period, with added penalties of 5 dB and 10 dB applied to the evening and night-time hours respectively. As this study focuses on noise exposures throughout the day and evening periods, the L_{den} noise exposure guideline was transformed into the equivalent metrics for the 07:00–19:00 day (L_{day}) and 19:00–23:00 evening (L_{eve}) time periods using empirically derived conversions published by Brink et al. (2018). The guideline value for averaged road traffic noise was adjusted by −1.8 dB to obtain the equivalent noise level for daytime noise of 51.2 dB, and −5.1 dB was applied to obtain the equivalent noise level of 47.9 dB for evening noise. All analysis was carried out to one decimal place, but is reported to the nearest integer for presentational purposes.

3. Results

3.1. Greenspace noise levels across Greater London

Table 1 presents the summary statistics of annual average noise levels for each greenspace area by local authority district (i.e., borough). The average size of a London LAD was 48 km^2 (SD = 33 km^2) with an average number of residents is 266,667 persons (SD = 78,764), according to the 2011 UK Census. Average noise levels in greenspaces across Greater London ranged from 35 dB to 74 dB for L_{day} and 35 dB – 71 dB for L_{eve}. While there was a relatively small difference in mean greenspace noise levels between the 33 local authority districts (LAs), some individual areas showed relatively high noise levels compared to average levels. Highest mean noise levels were found in the Central London LADs of Westminster, Newham, Hammersmith and Fulham, Tower Hamlets, and Wandsworth, and the Outer London LAD of Hounslow. Highest greenspace noise levels for L_{day} and L_{eve} were in Westminster: 74 dB (L_{day}) and 71 dB (L_{eve}). Supplementary Table S3 presents the equivalent summary statistics by greenspace category.

Table 1
Summary statistics of the annual average noise levels in greenspaces across Greater London, categorised by local authority district. Table includes the percentage of greenspaces with spatially averaged noise levels that exceed the chosen noise guideline values for L_{day} and L_{eve}.

	L_{day} (dB)						L_{eve} (dB)				
	N	Min	Max	Median	Mean	≥51.2 dB (%)	Min	Max	Median	Mean	≥47.9 dB (%)
Barking and Dagenham	40	38	68	46	49	30	38	65	43	46	28
Barnet	165	37	71	45	48	32	37	68	43	46	32
Bexley	104	37	64	43	46	25	37	61	41	44	25
Brent	58	37	64	46	47	24	37	60	43	45	24
Bromley	213	37	66	43	45	19	36	63	41	43	19
Camden	25	38	63	49	49	40	37	61	41	43	40
Croydon	116	38	64	43	45	16	38	63	43	45	16
Ealing	132	38	67	46	47	25	36	68	42	46	25
Enfield	121	36	71	45	48	32	38	61	43	45	32
Greenwich	101	38	68	46	48	31	35	62	40	44	31
Hackney	24	39	62	48	49	38	37	63	42	44	38
Hammersmith and Fulham	31	41	71	51	52	48	37	66	43	45	52
Haringey	66	38	65	45	47	24	37	67	44	46	24
Harrow	92	35	66	42	45	25	38	61	42	44	25
Havering	112	38	66	44	46	24	37	65	41	44	24
Hillingdon	147	38	69	45	47	28	36	67	44	47	28
Hounslow	114	37	71	47	49	34	38	61	43	45	34
Islington	18	40	62	50	50	39	36	58	42	43	39
Kensington and Chelsea	10	39	66	48	49	30	38	64	42	45	30
Kingston upon Thames	65	38	65	45	46	19	38	60	46	46	19
Lambeth	32	38	66	47	49	44	38	65	43	46	44
Lewisham	72	37	69	44	46	19	38	59	45	47	19
Merton	91	38	68	44	46	23	40	67	48	49	23
Newham	56	38	70	49	52	45	39	58	47	47	43
Redbridge	89	37	70	47	49	33	38	62	45	47	33
Richmond upon Thames	109	38	65	45	47	28	38	63	44	47	28
Southwark	66	38	67	47	48	30	37	65	42	44	30
Sutton	83	37	62	44	45	19	37	67	46	49	19
Tower Hamlets	35	39	68	49	52	43	38	63	44	46	43
Waltham Forest	78	38	67	45	47	26	39	64	46	49	26
Wandsworth	49	40	69	48	50	37	39	65	45	47	37
Westminster	18	40	74	54	56	61	39	71	51	53	61

* The chosen L_{day} (51.2 dB) and L_{eve} (47.9 dB) noise thresholds were derived from the 53 dB L_{den} noise guideline (World Health Organisation, 2018), using empirical conversions published by Brink et al. (2018). L_{day} represents the 12-h daytime period of 07:00–19:00. L_{eve} represents the 4-h evening period of 19:00–23:00.

Fig. 3 shows the spatial distribution of greenspaces above and below the chosen noise thresholds for L_{day}. Across Greater London, 28 % of greenspaces exhibited annual average road traffic noise levels across the entire greenspace extent (individual area) that exceed the equivalent guideline value of 51.2 dB for L_{day} and 47.9 dB for L_{eve}. In Central London, Camden, Hammersmith, Lambeth, Newham, Tower Hamlets, and Westminster, had 40 % of greenspaces >51.2 dB L_{day} and >47.9 dB L_{eve} guideline values. Westminster showed the highest percentage (61 %) of entire (individual area) greenspace areas exceeding the recommended noise guideline values.

Fig. 4 shows the percentage of greenspaces with noise levels that exceed the chosen noise guideline values for L_{day} and L_{eve} for either across the entire space (100 %) or any part (>1 %) of that space by local authority district, with summary statistics presented in Supplementary Table S4. Supplementary Table S5 shows the equivalent by greenspace category. All greenspaces exhibit L_{day} or L_{eve} noise levels above the guideline for at least some of their area. Greenspaces in Central London are more likely to have noise levels that exceed the chosen threshold across either the entire area or in at least part of the space.

3.1.1. Noise levels at the nearest greenspace to residential locations

Fig. 5 shows the distribution of spatially averaged greenspace noise levels (L_{day}) within greenspace areas nearest to residential postcodes, categorised by LAD. The postcode centroid represents the central delivery point of each address. The average area of a publicly accessible greenspace land area is 4000 m^2 (SD = 200,000 m^2). Postcodes typically cover an area of 10,000 m^2 (SD = 30,000 m^2) and represent the lived environment of 58 residents (SD = 45) from 24 households (SD = 17), according to the 2011 UK Census. The average distance between each residential postcode and the nearest greenspace was 264 m. Associated summary statistics are presented in Supplementary Table S6.

Spatially averaged greenspace noise levels ranged from 35 dB to 74 dB for L_{day} and 35 dB – 71 dB for L_{eve}. The London LADs of Camden and Westminster exhibited the highest greenspace noise levels nearest to residential postcodes measuring 74 dB (L_{day}) and 71 dB (L_{eve}). Greenspaces with high noise levels nearest to residential locations were primarily concentrated in Central London, except for the local authority district of Lewisham. Supplementary Table S6 further presents the percentage of residential locations that were affected by greenspace noise levels above the guideline values, with highest percentages observed in Lambeth (57 %) and Wandsworth (56 %).

Fig. 6 shows the distribution of averaged greenspace noise levels (L_{day}) within greenspace areas nearest to residential postcodes, categorised by Index of Multiple Deprivation (IMD) quintile. Associate summary statistics are presented in Supplementary Table S7. Median noise levels in greenspace areas were 2 dB higher at residential locations in the most deprived areas (Q1) compared to those in the least deprived areas (Q5). While there is relatively little variation in median greenspace noise levels between quintile groups Q1 – Q4, noise levels for Q5 were ~2 dB lower measuring 45 dB. Summary results were supported by parametric and non-parametric tests (Supplementary Table S8) which showed significant differences in the logarithmic mean noise levels between all deprivation quintiles ($p < 0.05$), with the exception of Q2 and Q4. The percentage of residential locations with noise levels in greenspace areas that were above the chosen noise guideline values were not evenly distributed across the different deprivation groups. Greenspaces with noise levels above the L_{day} and L_{eve} guidelines were 5 % higher in most deprived communities (Q1) compared to the least deprived (Q5).

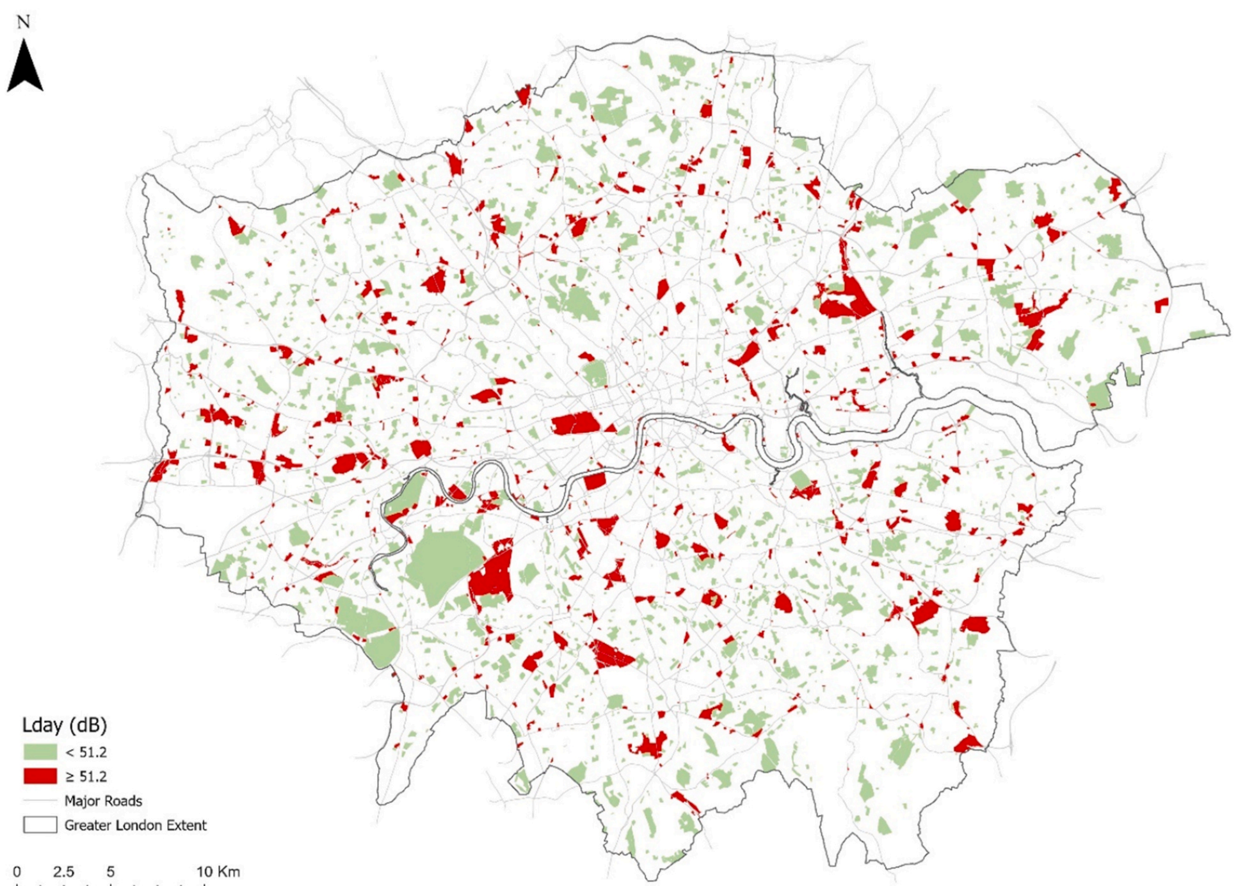

Fig. 3. Greenspaces in Greater London that are above and below the noise guideline value for Lday converted from the 53 dB L_{den} noise threshold guideline (World Health Organisation, 2018), using empirical conversions published by Brink et al. (2018). Contains OS data © Crown copyright and database right (2019).

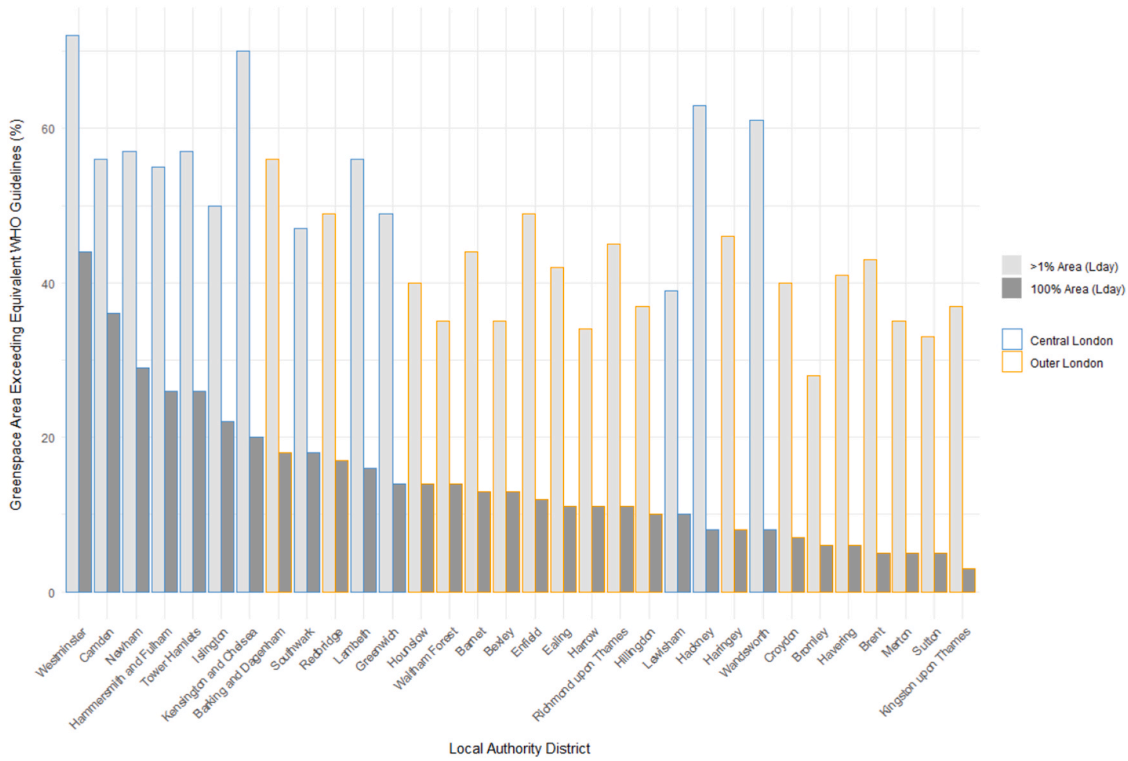

Fig. 4. – The percentage of greenspaces with annual average noise levels that exceed the chosen noise guideline values for L_{day} for either across the entire space (100 %) or any part (>1 %) of that space, categorised by local authority district. Local authority districts are ranked by descending 100 % Area.

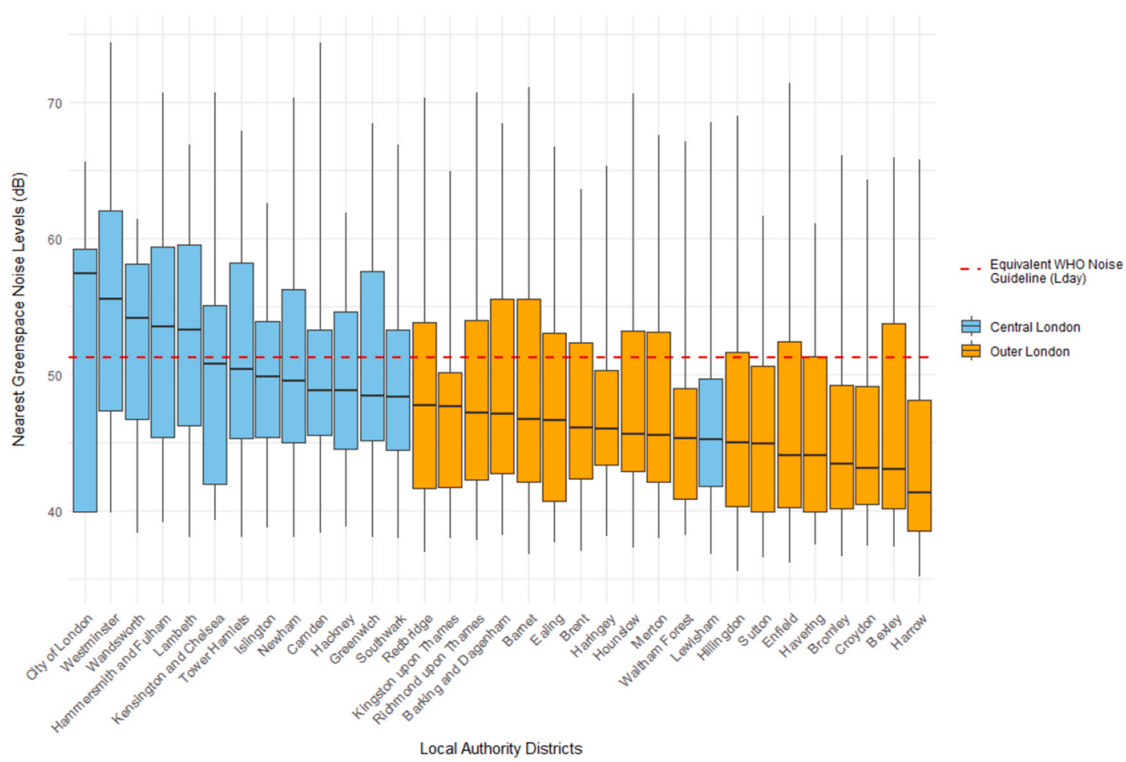

Fig. 5. – Descriptive statistics for average noise level (L_{day}) for the nearest residential location by LAD, ranked by descending LAD median noise level.

3.1.2. *Distance-based measures of noise levels in greenspaces*

Figs. 7–9 show the distribution of spatially averaged greenspace noise levels (L_{day}) within 300 m, 2 km, and 5 km of residential postcodes, categorised by LAD. Respective summary statistics are presented in Supplementary Table S9–S11. No greenspaces were found within 300 m of residential postcodes in the City of London district, but were present within both 2 km and 5 km radii. Greenspace areas within 300 m of residential locations in Central London exhibited higher average noise

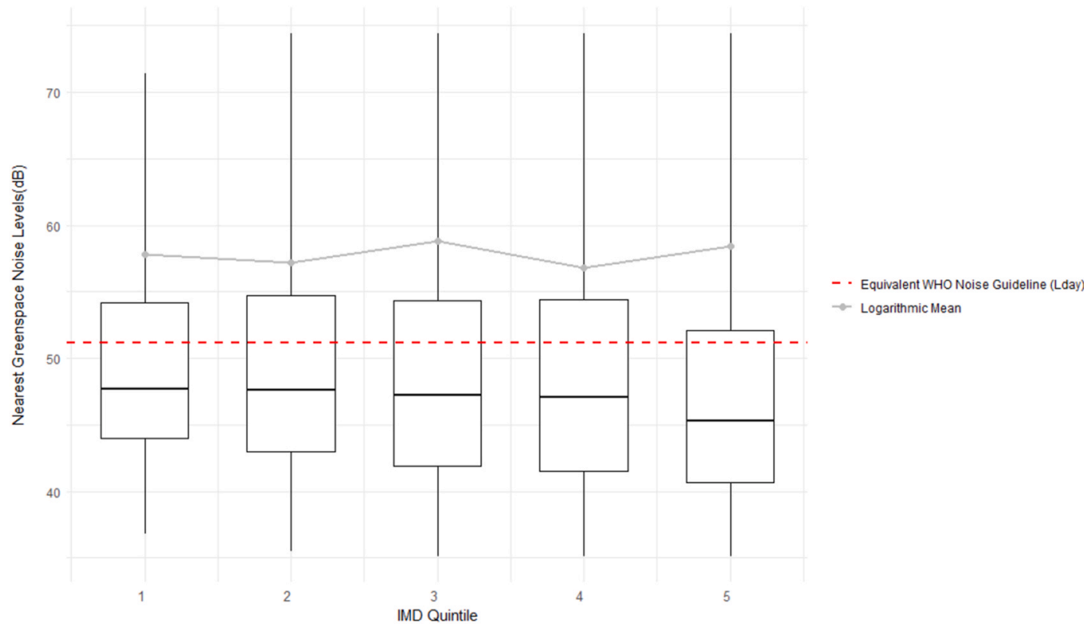

Fig. 6. Spatially averaged greenspace noise levels (L_{day}) within greenspace areas nearest to residential postcodes, categorised by Index of Multiple Deprivation quintile. IMD quintile 1 represents the 20 % most deprived areas, while quintile 5 represents areas that are the 20 % least deprived nationally. The logarithmic mean is displayed for reference in relation to parametric and non-parametric test results (Supplementary Table S8).

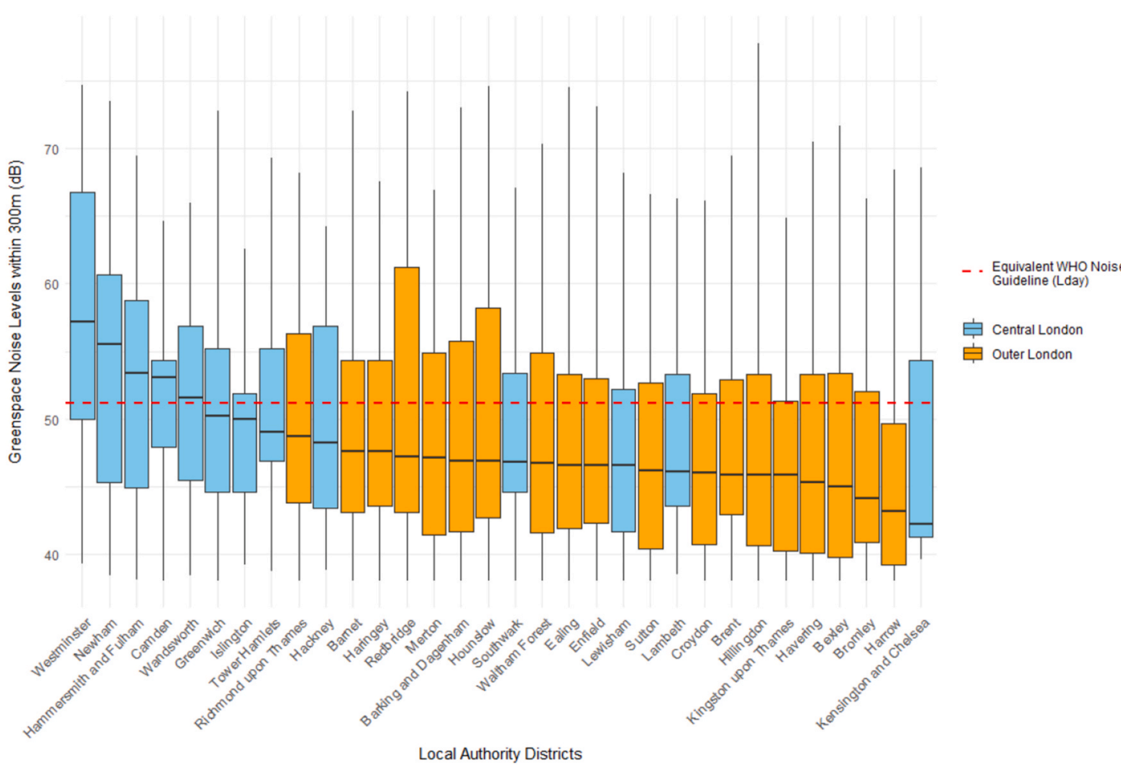

Fig. 7. Descriptive statistics for noise level (L_{day}) within 300m of residential location by LAD, ranked by descending LAD median noise level.

levels compared to greenspaces in Outer London. As distance from residential postcode increased from 300 m to 5 km, the distribution of high average noise levels became more dispersed across the London LADs, with higher greenspace noise levels observed in Outer London LADs. This pattern was also reflected in the percentage of residential locations that are affected by averaged noise levels above the chosen noise guideline values (S9 – S11). Additionally, as the geographical radius from a residential address increase, the variability in greenspace noise levels decreases. This is likely due to averaging effects.

Fig. 10 shows the distribution of population-weighted averaged greenspace noise levels (L_{day}) for OA community residents within travel distances of 300 m, 2 km, and 5 km, categorised by IMD Quintile. Respective summary statistics are presented in Supplementary Table S12. The figures show minimal variation in noise levels across the different deprivation groups, except for greenspaces within 5 km of the least deprived communities (Q5). For greenspaces within 5 km of

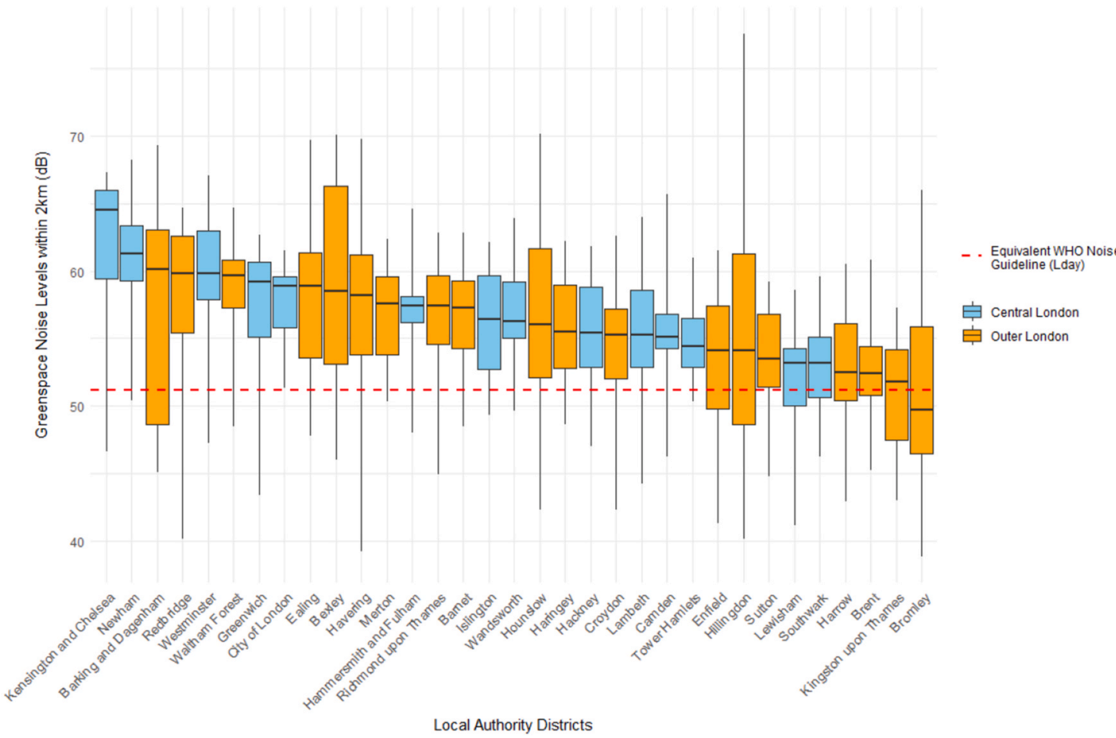

Fig. 8. Descriptive statistics for noise level (L_{day}) within 2 km of residential location by LAD, ranked by descending LAD median noise level.

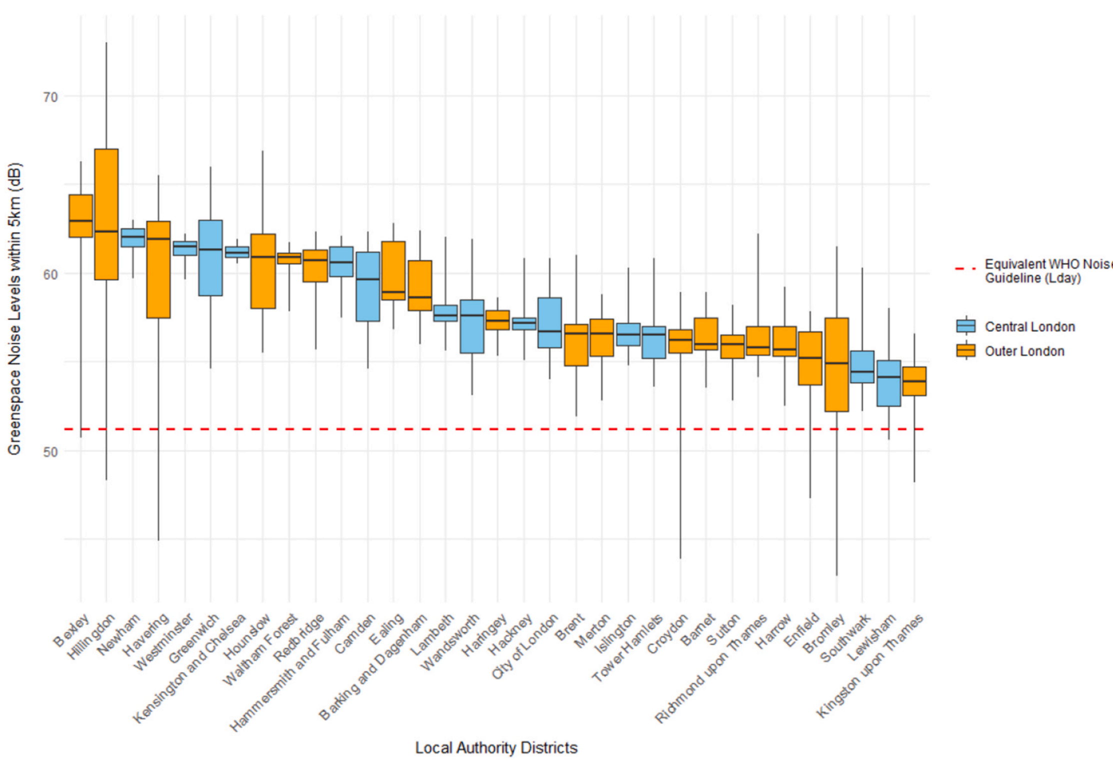

Fig. 9. Descriptive statistics for noise level (L_{day}) within 5 km of residential location by LAD, ranked by descending LAD median noise level.

residential postcodes, the results reveal a gradual decline in greenspace noise levels as deprivation decreases by 2 dB between the moderate (Q3) and least (Q5) deprived communities. Summary results are supported by parametric and non-parametric tests presented in Supplementary Table S13–S15 which show significant differences in the logarithmic mean noise levels between deprivation quintiles ($p < 0.05$).

Global Moran's I tests were conducted at the OA community level for each of the population-weighted average greenspace noise exposures (L_{day}) by travel distance, as well as, for IMD scores to assess spatial autocorrelation. It is important to note that higher IMD scores reflect higher levels of deprivation, and lower rank scores reflect lower levels of deprivation. The univariate test revealed strong spatial associations for

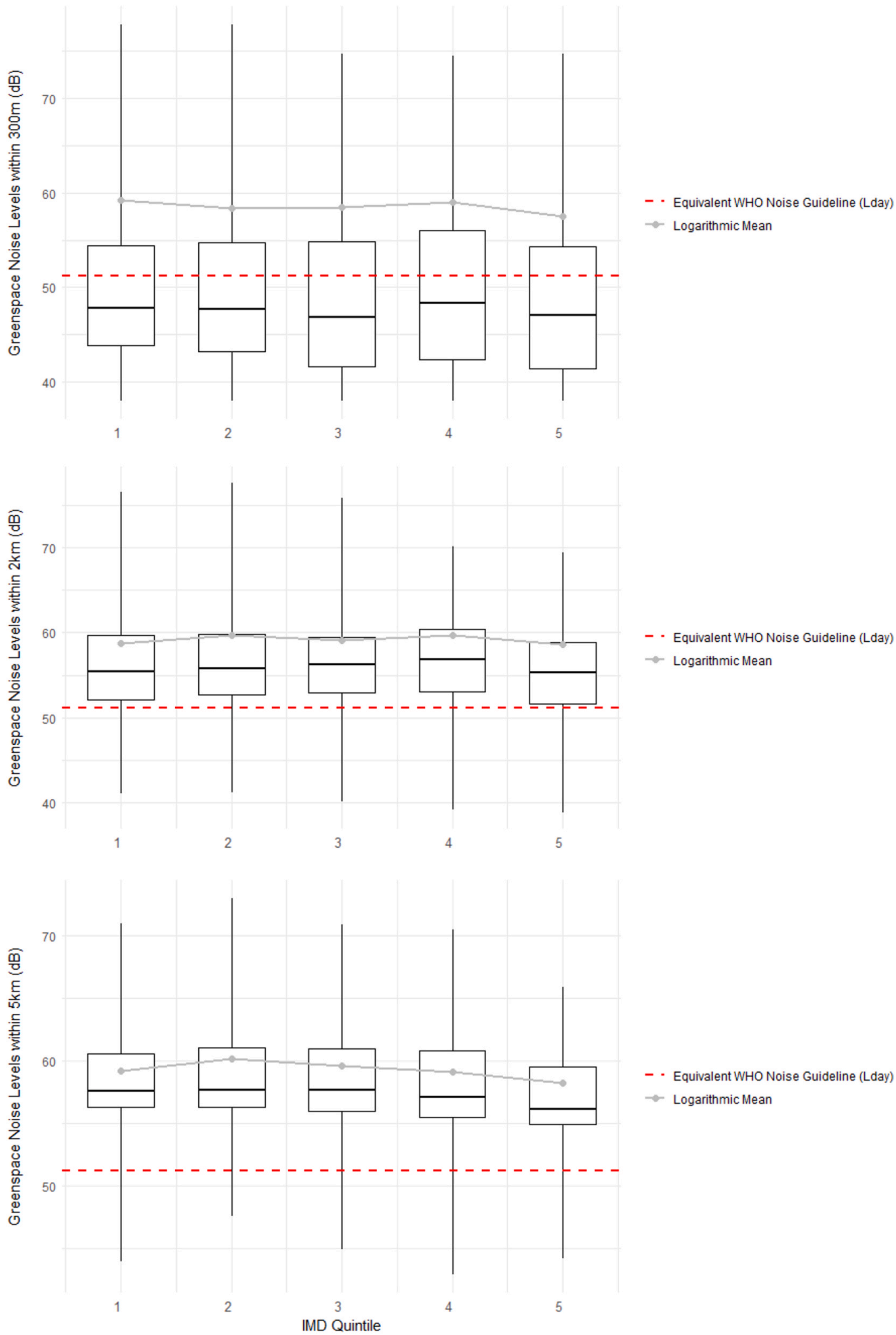

Fig. 10. Average noise levels (L_{day}) within 300m, 2 km and 5 km of residential location, summarised by Index of Multiple Deprivation quintile. IMD quintile 1 represents the 20 % most deprived areas, while, quintile 5 represents areas that are the 20 % least deprived nationally. The logarithmic mean is displayed for reference in relation to parametric and non-parametric test results (Supplementary Table S13–S15).

all distance-based proximities, 300 m (Moran's I = 0.56, $p < 0.05$), 2 km (Moran's I = 0.95, $p < 0.05$), and 5 km (Moran's I = 0.88, $p < 0.05$). These results demonstrate significant spatial clustering of greenspace noise levels at each distance, with the strongest association observed at 2 km. Similarly, IMD also showed strong spatial clustering (Moran's I = 0.8, $p < 0.05$), indicating that deprivation is highly concentrated across Greater London. The bivariate Global Moran's I found weak negative spatial associations between greenspace noise levels at the ego location (i) and IMD rank scores (j) at the neighbouring locations within 300 m (Moran's I = −0.01, $p < 0.05$), 2 km (Moran's I = −0.02, $p < 0.05$), and 5 km (Moran's I = −0.1, $p < 0.05$). These results suggest that a small number of the least deprived communities are more likely to encounter greenspaces with higher noise levels across Greater London.

4. Discussion

4.1. Summary

This study provides an assessment of greenspace exposures to road traffic noise in Greater London. This research adds to the body of literature by estimating exposures for locations where populations may spend their leisure time and represent potential restorative environments. Using modelled road traffic noise estimates, 28 % of greenspaces across Greater London exhibited road traffic noise levels that exceeded the equivalent WHO noise guideline values for the day-time and evening exposure period. Greenspaces in Central London were more likely to have noise levels that exceed the WHO noise guidelines compared to greenspaces in Outer London. Our study overall revealed no clear gradient in greenspace noise levels between deprivation groups. A 2 dB difference in average noise levels in greenspace areas was only observed in greenspace areas located within a 5 km radius of residential locations, particularly for the least deprived deprivation groups.

4.2. Comparison with other studies

Our study showed a greater number of greenspaces with high road traffic noise levels in Central London than reported elsewhere (CPRE London, 2018). Although research on road traffic noise levels within urban greenspaces is limited, the differences in noise levels among deprivation groups presented in this study were similar to those by Tonne et al. (2018). Their research of approx. 45,000 individuals taking part in a travel survey covering 2006–10, revealed little variation in average residential exposures to road traffic noise (i.e., ~55 dB LAeq24) across income deprivation quintiles in London. Similarly, no clear gradients were observed between day-time aircraft noise and deprivation, based on Carstairs Index data for approx. 155,000 postcodes around London Heathrow Airport (Gong et al., 2025). These findings indicate a limited association between noise levels and deprivation, contrasting with inequality gradients observed for other environmental exposome, such as air pollution (Fecht et al., 2015; Sheridan et al., 2019). Nevertheless, the distribution of greenspace noise levels across deprivation groups does not align with the environmental inequity presented in the Marmot Review, which identified residents of the most disadvantaged communities as being disproportionately affected by poor air quality, noise pollution, and lack of access to green spaces (Marmot, 2020). Greater London exhibits a unique spatial distribution of deprivation, a pattern often evident in a 'post-modern' city (Mendes, 2011). Area-level deprivation varies significantly across Greater London, with some of the most deprived districts historically located in the very centre of Central London (Travers et al., 2016). In recent years, processes of urban regeneration, particularly 'new-build' gentrification of social housing in Central London and along the London riverside, have attracted upper-middle-class professionals (Almeida, 2021). However, such redevelopments have contributed to a form of indirect displacement, known as 'exclusionary displacement' (Marcuse, 2013), where lower-income groups are unable to access property due to the gentrification of a neighbourhood (Davidson and Lees, 2005). In Greater London, this shift in class structure has led to the relocation of working-class populations to more affordable areas - often within the same district (Reades et al., 2023). Consequently, the associations between greenspace noise levels and deprivation presented in this study are unique to Greater London and may not necessarily reflect inequalities in other cities.

4.3. Wider theoretical and policy implications

The recent House of Lords Science and Technology Committee Report outlines environmental noise as a neglected pollutant that is poorly understood and regulated (UK Parliament, 2023). This study begins to address gaps in research evidence on environmental exposures in spaces where populations may seek respite during their leisure time. Urban greenspaces are known to provide positive effects on mental health and well-being, which include the reduction of anxiety and stress levels, alleviating depression, improving sleep, and improving overall life satisfaction (Lee et al., 2015; Kondo et al., 2018; Labib et al., 2021). This has been demonstrated in environmental psychology research, which has shown, through theories such as ART (Kaplan and Kaplan, 1989), that spending time in greenspaces can promote restorative processes by engaging involuntary attention through soft fascination (i.e., gentle, effortless attention), allowing directed attention mechanisms to recover (Moran, 2019; Von Lindern et al., 2016). However, the extent to which greenspaces exhibiting high noise levels provide a restorative environment can be questioned. Populations who regularly access greenspaces with high road traffic noise levels may experience constrained restoration, a process whereby the restorative benefits of greenspaces are reduced (Von Lindern et al., 2016; García-Martín et al., 2025). Overstimulating or distracting auditory disturbances produced by road traffic can mask pleasant soundscapes of 'winds, birds and water' which can contribute to the depletion of attentional resources and exacerbate directed attention fatigue in greenspace users – a phenomenon where sustained concentration on one task, while actively inhibiting other distractions, can lead to increased stress and psychological fatigue (Kaplan, 1995; Osborne, 2022). Moreover, it is important to acknowledge that the impact of audio-visual interactions within greenspaces can have on perceived noise levels. The presence of vegetation, biodiversity, and other specific audio-visual sources (i.e., fountains) has been shown to reduce the perceived loudness of road traffic noise, thereby providing some restorative benefit despite auditory disturbances (Axelsson et al., 2014; Van Renterghem, 2019; Wang and Kwan, 2025). Nonetheless, there is a substantial body of evidence that suggests road traffic noise can have acute and chronic effects on the human body, independent of any cognitive awareness or subjective perception of noise (Hansell et al., 2017). This underscores the importance of assessing the variability in objective noise levels within greenspaces, as undertaken in this study.

The urban morphology of a city may further compromise the restorative potential of greenspaces. Greenspaces in inner-city areas, often characterised by high population densities, dense or heavily built urban structures and extensive road network densities, are likely to experience elevated noise levels due to increased traffic congestion and sound propagation from surrounding buildings (Sakieh et al., 2017, Tong and Kang, 2021). Additionally, the increase in unwanted noise levels in these greenspace areas may have broader social implications for local residents by limiting opportunities for respite and disproportionately impacting those who depend on these spaces for relief from urban stressors. For example, noise-sensitive or recreational users seeking relaxation may be discouraged from visiting or spending extended periods of time in 'noisy' greenspaces. Not only does this limit their exposure to restorative environments, but it can negatively impact social interaction, social cohesion, and a sense of community, which can be valuable for marginalised groups (Dimitrova et al., 2017; Eadson et al., 2019).

Previous studies have also highlighted that the risk of avoidable health outcomes is greatest in populations characterised by low socioeconomic status. This is because the interconnections between high noise levels, poor health, and deprivation can exacerbate each other's effects, contributing to greater health inequalities – an interaction known as a 'triple jeopardy' effect (Hajat et al., 2015; Brunt et al., 2017; Verbeek, 2019). Therefore, it is of importance to consider the sonic environment when addressing the restorative potential of greenspaces. On the other hand, the recognition of quiet greenspaces in this study could help support the promotion of nature-based interventions. By designating 'quiet' greenspaces as part of 'green social prescribing' strategies, these spaces can be used to improve mental and physical health and, in turn, reduce health inequalities.

To the best of our knowledge, our study is the first UK study to assess noise levels within greenspace against specific daytime and evening thresholds derived from the WHO Regional Office for Europe published noise guidelines. There are currently no international health-based criteria for noise levels within greenspaces. In 2018, the WHO Regional Office for Europe published health-based guidelines for transport noise based on evidence consolidated from epidemiological studies, which were intended for Member States to enact policies that mitigate the impacts of noise on human health (Jarosińska et al., 2018). However, the guidelines are source-specific and not environment-specific, and were meant to cover all settings where people spend a significant portion of their time, such as residences, educational institutions, workplaces and public venues (EEA. 2018). In the absence of better information, the WHO noise guidelines were used as a point of reference to identify greenspaces with noise levels that may impair their restorative qualities. It is important to note that the analysis of sound pressure levels represents only one dimension of the greenspace soundscape. As previously highlighted, other non-acoustical factors also contribute to the overall restorative potential of a greenspace (Axelsson et al., 2014; Aletta et al., 2016). However, modelling or measuring psychoacoustic metrics was beyond the scope of the study due to the extensive data and computational requirements needed to do this across such a large geographical area. Similarly, to measure people's responses and experiences of these environments. The health effects attributable to the sound environment within a specific greenspace are better investigated using a soundscape approach at a microscale (e.g., Margaritis et al., 2018; Osborne, 2022), focusing on two or three greenspace areas to fully capture a greenspace's overall restorative potential. Additionally, further research is needed to better explore the local associations between traffic noise levels and the restorative potential of greenspace, particularly in areas identified in this study as exceeding health-based thresholds. A soundscape approach, which incorporates a mixed-methods approach, such as modelling, personal monitoring, and questionnaires within which lived experiences are captured, could offer valuable insights into how road traffic noise interacts with local socioeconomic conditions and greenspace functions, potentially revealing how noise may constrain restorative opportunities differently across deprivation groups.

5. Strengths and limitations

We conducted an examination of daytime and evening noise levels across 10 different types of greenspaces across Greater London. While studies, such as CPRE London (2018), have previously modelled road traffic noise levels within London greenspace, noise levels were only reported for public parks, leaving a significant proportion of greenspaces accessed by the public unaccounted for.

The cut-offs used to identify high greenspaces noise levels during the daytime and evening exposure period were established according to the current World Health Organisation's (WHO) Regional Office for Europe health-based guidelines on road traffic noise. However, it is important to acknowledge that the evidence used to determine these related to long-term average outdoor exposures estimated at place of residence rather than short-term exposures in greenspace or other locations. Furthermore, while we acknowledge that noise perception is subjective and will vary across a population according to different individual factors (e.g., noise-sensitivity), the aim of this study was to provide an objective description of the acoustic environment within greenspaces rather than to assess the perceptual response to noise. Nonetheless, categorising greenspaces based on whether they meet or exceed equivalent noise thresholds, derived from epidemiological studies measured at the population level, allowed us to identify greenspace areas where noise levels may have exceeded health-based thresholds.

While this study contributes to research evidence addressing socio-environmental inequalities related to noise in greenspaces, several factors must be considered when interpreting the results. Firstly, L_{day} and L_{eve} noise levels do not fully reflect the temporal variations in noise levels throughout the day. For example, noise levels will fluctuate due to higher traffic volumes during peak commuting time. As a result, these metrics do not accurately represent the soundscape equality of the greenspace by not accounting for periods of heightened noise disturbance. Similarly, while detailed high-resolution information on land-cover was utilised in the CNOSSOS-EU noise model, the dataset does not feature smaller structures such as hedgerows and fences, nor does it account for differences in vegetation or terrain that may affect sound attenuation and propagation. While fine details can have some impact sound attenuation and propagation (Margaritis et al., 2018), at the macro scale, their effects on overall statistical parameters are expected to average out, thereby ensuring consistency in the analysis. Future research should consider the influence of natural sound barriers like vegetation on greenspace noise levels. Secondly, this study specifically focuses on road traffic noise as a key contributor to greenspace noise levels. While other sources of anthropogenic noise (rail, aviation, industrial and commercial) may contribute to greenspace noise levels, these were not considered in this study to maintain a targeted analysis. Future research could explore the combined influence of different noise sources to provide a more comprehensive analysis of greenspace noise.

Part of this study assumes exposures occur at the nearest greenspace, which may not always reflect individuals' activities and preferences. Some types of greenspaces, e.g., golf courses, may not be easily accessible to all socioeconomic groups due to restrictions on access, or membership requirements. Other greenspaces may not be considered as the preferred choice for recreational or restorative activities, e.g., cemeteries. Moreover, it is important to recognise that the actual time individuals spend within greenspaces may vary. Individuals are unlikely to remain in greenspaces for the entire L_{day} or L_{eve} period, and evening visits maybe further reduced during winter months. While we acknowledge that these temporal and behavioural factors should be taken into consideration, the approaches provide insight into population exposures to greenspace noise levels.

One limitation of this study is the use of datasets, such as Annual Average Daily Traffic (AADT) counts and sociodemographic data, from different years. The temporal differences in datasets may introduce some variability in the results due to traffic patterns and population density changes. Additionally, more recent alterations to the road network, such as new speed restrictions and new cycling infrastructure, which also influence noise levels, should be considered in future research.

6. Conclusions

This study assessed the variability in noise levels within spaces where populations may seek respite during their leisure time. Our analysis found that 28 % of greenspaces in London exceed equivalent WHO road noise guideline levels during day-time and evening periods. Populations who regularly access greenspaces in Central London may experience reduced restorative benefits that these greenspaces may provide due to elevated noise levels. Furthermore, our analyses indicate a limited association between greenspace noise levels and deprivation in Greater London, especially when compared to other environmental exposures, such as air pollution.

CRediT authorship contribution statement

Kathryn Adams: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Formal analysis, Data curation. **Calvin Jephcote:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology. **Benjamin Fenech:** Writing – review & editing. **Anna Hansell:** Writing – review & editing. **Tess Osborne:** Writing – review & editing, Conceptualization. **John Gulliver:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Declaration of competing interest

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.

Acknowledgments

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We acknowledge support from the National Institute for Health and Care Research (NIHR) Leicester Biomedical Research Centre (BRC) and the NIHR Health Protection Research Unit (HPRU) in Chemical Threats and Hazards, a partnership between the UK Health Security Agency (UKHSA), the Health and Safety Executive (HSE) and the University of Leicester. The views expressed are those of the author(s) and not necessarily those of the NIHR, UKHSA, HSE or University of Leicester.

This research used the 'Alice-3 High Performance Computing Facility' at the University of Leicester. We acknowledge the use of information from OS Open Data © Crown copyright and database right 2019.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2025.103536.

Data availability

Data will be made available on request.

References

Alcock, I., White, M.P., Wheeler, B.W., Fleming, L.E., Depledge, M.H., 2014. Longitudinal effects on mental health of moving to greener and less green urban areas. Environ. Sci. Technol. 48, 1247–1255.

Aletta, F., Kang, J., Astolfi, A., Fuda, S., 2016. Differences in soundscape appreciation of walking sounds from different footpath materials in urban parks. Sustain. Cities Soc. 27, 367–376.

Almeida, A., 2021. Pushed to the margins: a quantitative analysis of gentrification in London in the 2010s. Runnymede and Centre for Labour and Social Studies (CLASS). https://www.runnymedetrust.org/publications/pushed-to-the-margins. (Accessed 30 March 2023).

Axelsson, Ö., Nilsson, M.E., Hellström, B., Lundén, P., 2014. A field experiment on the impact of sounds from a jet-and-basin fountain on soundscape quality in an urban park. Landsc. Urban Plann. 123, 49–60.

Babisch, W., 2006. Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased. Noise Health 8, 1–29.

Berman, M.G., Jonides, J., Kaplan, S., 2008. The cognitive benefits of interacting with nature. Psychol. Sci. 19, 1207–1212.

BOP Consulting, 2013. Green Spaces: the Benefits for London. London.

Bray, I., Reece, R., Sinnett, D., Martin, F., Hayward, R., 2022. Exploring the role of exposure to green and blue spaces in preventing anxiety and depression among young people aged 14–24 years living in urban settings: a systematic review and conceptual framework. Environ. Res. 214, 114081.

Brink, M., Schäffer, B., Pieren, R., Wunderli, J.M., 2018. Conversion between noise exposure indicators leq24h, lday, levening, lnight, ldn and lden: principles and practical guidance. Int. J. Hyg Environ. Health 221, 54–63.

Brunt, H., Barnes, J., Jones, S.J., Longhurst, J.W.S., Scally, G., Hayes, E., 2017. Air pollution, deprivation and health: understanding relationships to add value to local air quality management policy and practice in Wales, UK. J. Public Health 39, 485–497.

Carrier, M., Apparicio, P., Séguin, A.-M., 2016. Road traffic noise in montreal and environmental equity: what is the situation for the most vulnerable population groups? J. Transport Geogr. 51, 1–8.

Clark, S.N., Anenberg, S.C., Brauer, M., 2024. Global burden of disease from environmental factors. Annu. Rev. Publ. Health 46.

Comber, A., Brunsdon, C., Green, E., 2008. Using a gis-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. Landsc. Urban Plann. 86, 103–114.

CPRE London, 2018. Traffic Noise in London's Parks.

Dale, L.M., Goudreau, S., Perron, S., Ragettli, M.S., Hatzopoulou, M., Smargiassi, A., 2015. Socioeconomic status and environmental noise exposure in Montreal, Canada. BMC Public Health 15, 1–8.

Davidson, M., Lees, L., 2005. New-build 'gentrification'and London's riverside renaissance. Environ. Plann. 37, 1165–1190.

DEFRA, 2006. Environmental Noise (England) Regulations 2006.

Dimitrova, D., Tilov, B., Dzhambov, A., 2017. Social cohesion mediates the association between urban greenspace and mental health in youth: donka dimitrova. Eur. J. Publ. Health 27 ckx189-123.

DLUHC, 2022. Indices futures: updating the English indices of deprivation (IoD) consultation - government reponse [Online]. Gov.UK. Available: https://www.gov.uk/government/consultations/indices-futures-updating-the-english-indices-of-deprivation-iod-consultation/outcome/indices-futures-updating-the-english-indices-of-deprivation-iod-consultation-government-reponse. (Accessed 13 February 2025).

Dreger, S., Schüle, S.A., Hilz, L.K., Bolte, G., 2019. Social inequalities in environmental noise exposure: a review of evidence in the WHO European region. Int. J. Environ. Res. Publ. Health 16, 1011.

Eadson, W., Harris, C., Gore, A., Dobson, J., 2019. Space to Thrive: a Rapid Evidence Review of the Benefits of Parks and Green Spaces for People and Communities.

EEA, 2018. Environmental noise [Online]. Environmental report 2018. https://www.eea.europa.eu/airs/2018/environment-and-health/environmental-noise. Jan 2023.

EEA, 2020. Environmental Noise in Europe - 2020. Copenhagen.

Enoksson Wallas, A.K., 2019. Health Effects of Road Traffic Noise in Childhood and Adolescence.

Environmental Audit Committee, 2020. Levelling up: reducing regional inequalities [Online]. Available: https://committees.parliament.uk/writtenevidence/104219/html/. Nov 2024.

European Commission, 2002. Directive 2002/49/EC of 25 June 2002 relating to the assessment and management of environmental noise. Off. J. Eur. Communities - Legislation 189, 12–25.

Fecht, D., Fischer, P., Fortunato, L., Hoek, G., De Hoogh, K., Marra, M., Kruize, H., Vienneau, D., Beelen, R., Hansell, A., 2015. Associations between air pollution and socioeconomic characteristics, ethnicity and age profile of neighbourhoods in England and the Netherlands. Environ. Pollut. 198, 201–210.

Floud, S., Blangiardo, M., Clark, C., De Hoogh, K., Babisch, W., Houthuijs, D., Swart, W., Pershagen, G., Katsouyanni, K., Velonakis, M., 2013. Exposure to aircraft and road traffic noise and associations with heart disease and stroke in six european countries: a cross-sectional study. Environ. Health 12, 1–11.

García-Martín, M., Schaupp, J., Olafsson, A.S., Legarth, J.V., Beery, T.H., Tobias, S., 2025. Perceived constraints for psychological restoration in nearby greenspaces. An exploratory and multi-dimensional approach. Urban For. Urban Green. 107, 128746.

Gaudon, J.M., Mctavish, M.J., Hamberg, J., Cray, H.A., Murphy, S.D., 2022. Noise attenuation varies by interactions of land cover and season in an urban/peri-urban landscape. Urban Ecosyst. 1–8.

Gidlöf-Gunnarsson, A., Öhrström, E., 2007. Noise and well-being in urban residential environments: the potential role of perceived availability to nearby green areas. Landsc. Urban Plann. 83, 115–126.

Gong, X., Fenech, B., Blackmore, C., Chen, Y., Rodgers, G., Gulliver, J., Hansell, A.L., 2022. Association between noise annoyance and mental health outcomes: a systematic review and meta-analysis. Int. J. Environ. Res. Publ. Health 19, 2696.

Gong, X., Itzkowitz, N., Atilola, G.O., Adams, K., Jephcote, C., Blangiardo, M., Gulliver, J., Hansell, A., 2025. Inequality in exposure to daily aircraft noise near heathrow airport: an empirical study. Health Place 92, 103421.

Greater London Authority, 2020. Indices of deprivation: initial analysis [Online]. Available: https://data.london.gov.uk/blog/indices-of-deprivation-2019-initial-analysis/#:~:text=It%20is%20important%20to%20note,was%20the%20case%20in%20IMD2015. Nov 2024.

Greater London Authority, 2020. London Greenspaces Commission Report.Greater London Authority.

Greater London Authority, 2021. The London Plan: the Spatial Development Strategy for Greater London. https://www.london.gov.uk/programmes-strategies/planning/london-plan/the-london-plan-2021-online/annex-2-inner-and-outer-london-boroughs, 7 March 2025.

Hajat, A., Hsia, C., O'neill, M.S., 2015. Socioeconomic disparities and air pollution exposure: a global review. Curr. Environ. Health Rep. 2, 440–450.

Hansell, A.L., Cai, S.Y., Gulliver, J., 2017. Environmental impacts of road vehicles: past, present and future. Environmental Impacts of Road Vehicles: past, Present and Future. Royal Society of Chemistry.

Hansen, C.H., Hansen, K.L., 2021. Noise Control: from Concept to Application. CRC Press.

Jabbar, M., Yusoff, M.M., Shafie, A., 2022. Assessing the role of urban green spaces for human well-being: a systematic review. Geojournal 1–19.

Janta, H., Jephcote, C., Williams, A.M., Li, G., 2021. Returned migrants acquisition of competences: the contingencies of space and time. J. Ethnic Migrat. Stud. 47, 1740–1757.
Jarosińska, D., Héroux, M.-È., Wilkhu, P., Creswick, J., Verbeek, J., Wothge, J., Paunović, E., 2018. Development of the who environmental noise guidelines for the European region: an introduction. Int. J. Environ. Res. Publ. Health 15, 813.
Jiang, X., Fons, J., Sáinz De La Maza, M., Blanes, N., Peris, E., Röösli, M., Vienneau, D., 2025. Evaluation of the Benefits of Greenspace on noise-related Effects: a Health Impact Assessment on Annoyance (Eionet Report – Etc He 2024/10). European Topic Centre on Human Health and the Environment.
Kaplan, S., 1995. The restorative benefits of nature: toward an integrative framework. J. Environ. Psychol. 15, 169–182.
Kaplan, S., Berman, M.G., 2010. Directed attention as a common resource for executive functioning and self-regulation. Perspect. Psychol. Sci. 5, 43–57.
Kaplan, R., Kaplan, S., 1989. The Experience of Nature: a Psychological Perspective. Cambridge university press.
Kephalopoulos, S., Paviotti, M., Anfosso-Lédée, F., Van Maercke, D., Shilton, S., Jones, N., 2014. Advances in the development of common noise assessment methods in Europe: the CNOSSOS-EU framework for strategic environmental noise mapping. Sci. Total Environ. 482, 400–410.
Kondo, M.C., Fluehr, J.M., Mckeon, T., Branas, C.C., 2018. Urban green space and its impact on human health. Int. J. Environ. Res. Publ. Health 15, 445.
Labib, S.M., Lindley, S., Huck, J.J., 2021. Estimating multiple greenspace exposure types and their associations with neighbourhood premature mortality: a socioecological study. Sci. Total Environ. 789, 147919.
Lee, A.C., Jordan, H.C., Horsley, J., 2015. Value of Urban Green Spaces in Promoting Healthy Living and Wellbeing: Prospects for Planning.
Marcuse, P., 2013. Abandonment, gentrification, and displacement: the linkages in New york city. In: Gentrification of the City. Routledge.
Margaritis, E., Kang, J., Filipan, K., Botteldooren, D., 2018. The influence of vegetation and surrounding traffic noise parameters on the sound environment of urban parks. Appl. Geogr. 94, 199–212.
Marmot, M., 2005. Social determinants of health inequalities. Lancet 365, 1099–1104.
Marmot, M., 2020. Health equity in England: the marmot review 10 years on. Br. Med. J. 368.
Mendes, L.F., 2011. Postmodern city, gentrification and the social production of fragmented space. In: Cidades, Comunidades e Territórios.
Mensah, C.A., Andres, L., Perera, U., Roji, A., 2016. Enhancing quality of life through the lens of green spaces: a systematic review approach. International Journal of Wellbeing 6.
MHCLG, 2019. The English Indices of Deprivation. Ministry of Housing, Communities and Local Government, London, 2019.
Moran, D., 2019. Back to nature? Attention restoration theory and the restorative effects of nature contact in prison. Health Place 57, 35–43.
Morley, D.W., Gulliver, J., 2016. Methods to improve traffic flow and noise exposure estimation on minor roads. Environ. Pollut. 216, 746–754.
Morley, D.W., De Hoogh, K., Fecht, D., Fabbri, F., Bell, M., Goodman, P.S., Elliott, P., Hodgson, S., Hansell, A.L., Gulliver, J., 2015. International scale implementation of the cnossos-eu road traffic noise prediction model for epidemiological studies. Environ. Pollut. 206, 332–341.
Mueller, N., Rojas-Rueda, D., Khreis, H., Cirach, M., Milà, C., Espinosa, A., Foraster, M., Mceachan, R.R.C., Kelly, B., Wright, J., 2018. Socioeconomic inequalities in urban and transport planning related exposures and mortality: a health impact assessment study for bradford, UK. Environ. Int. 121, 931–941.
Münzel, T., Sørensen, M., Daiber, A., 2021. Transportation noise pollution and cardiovascular disease. Nat. Rev. Cardiol. 18, 619–636.
Osborne, T., 2022. Restorative and afflicting qualities of the microspace encounter: psychophysiological reactions to the spaces of the city. Ann. Assoc. Am. Geogr. 112, 1461–1483.
Paudel, S., States, S.L., 2023. Urban green spaces and sustainability: exploring the ecosystem services and disservices of grassy lawns versus floral meadows. Urban For. Urban Green. 84, 127932.
Ratcliffe, E., 2021. Sound and soundscape in restorative natural environments: A narrative literature review. Front. Psychol. 12, 570563.
Reades, J., Lees, L., Hubbard, P., Lansley, G., 2023. Quantifying state-led gentrification in London: using linked consumer and administrative records to trace displacement from council estates. Environ. Plan. A Econ. Space 55, 810–827.
Ridgley, H., Hands, A., Lovell, R., Petrokofsky, C., Stimpson, A., Feeley, A., Bedford, A., Fenech, B., Leeman, D., Skykes, E., 2020. Improving Access to Greenspace a New Review for 2020. Public Health England.
Riedel, N., Van Kamp, I., Dreger, S., Bolte, G., Andringa, T., Payne, S.R., Schreckenberg, D., Fenech, B., Lavia, L., Notley, H., Guski, R., Simon, D., Köckler, H., Bartels, S., Weber, M., Paviotti, M., 2021. Considering 'non-acoustic factors' as social and environmental determinants of health equity and environmental justice. Reflections on research and fields of action towards a vision for environmental noise policies. Transp. Res. Interdiscip. Perspect. 11, 100445.
Sakieh, Y., Jaafari, S., Ahmadi, M., Danekar, A., 2017. Green and calm: modeling the relationships between noise pollution propagation and spatial patterns of urban structures and green covers. Urban For. Urban Green. 24, 195–211.
Sheridan, C.E., Roscoe, C.J., Gulliver, J., De Preux, L., Fecht, D., 2019. Inequalities in exposure to nitrogen dioxide in parks and playgrounds in greater London. Int. J. Environ. Res. Publ. Health 16, 3194.
Sprague, N.L., Bancalari, P., Karim, W., Siddiq, S., 2022. Growing up green: a systematic review of the influence of greenspace on youth development and health outcomes. J. Expo. Sci. Environ. Epidemiol. 32, 660–681.
Taylor, L., Hochuli, D.F., 2017. Defining greenspace: multiple uses across multiple disciplines. Landsc. Urban Plann. 158, 25–38.
Tong, H., Kang, J., 2021. Relationship between urban development patterns and noise complaints in England. Environ. Plan. B Urban Anal. City Sci. 48, 1632–1649.
Tonne, C., Milà, C., Fecht, D., Alvarez, M., Gulliver, J., Smith, J., Beevers, S., Anderson, H.R., Kelly, F., 2018. Socioeconomic and ethnic inequalities in exposure to air and noise pollution in London. Environ. Int. 115, 170–179.
Travers, T., Sims, S., Bosetti, N., 2016. Housing and Inequality in London. Centre for London, London.
Trudeau, C., King, N., Guastavino, C., 2023. Investigating sonic injustice: a review of published research. Soc. Sci. Med. 326, 115919.
UK Parliament, 2023. The Neglected Pollutants: the Effects of Artificial Light and Noise on Human Health. Science and Technology Committee, London.
UK.Gov, 2011. Planning Policy Guidance 13: Transport.
Ulrich, R.S., 1983. Aesthetic and affective response to natural environment. In: Behavior and the Natural Environment. Springer.
Van Renterghem, T., 2019. Towards explaining the positive effect of vegetation on the perception of environmental noise. Urban For. Urban Green. 40, 133–144.
Verbeek, T., 2019. Unequal residential exposure to air pollution and noise: a geospatial environmental justice analysis for ghent, Belgium. SSM - Population Health 7, 100340.
Von Lindern, E., Hartig, T., Lercher, P., 2016. Traffic-related exposures, constrained restoration, and health in the residential context. Health Place 39, 92–100.
Wallner, P., Kundi, M., Arnberger, A., Eder, R., Allex, B., Weitensfelder, L., Hutter, H.P., 2018. Reloading pupils' batteries: impact of green spaces on cognition and wellbeing. Int. J. Environ. Res. Publ. Health 15, 1205.
Wang, L., Kwan, M.-P., 2025. How greenery exposure influences noise perception across geographic contexts. Landsc. Urban Plann. 263, 105444.
Wang'ombe, G., 2024. The impact of urban green spaces on community health and well-being. International Journal of Arts, Recreation and Sports 3, 14–25.
Waters, G., Wood, C., Mohith, D., Naumann, J., Piper, B., Murdock, A., Notley, H., Marazzi, L., 2023. Acoustic benefits of green infrastrcture in urban areas - a rapid evidence review. In: Proceedings of the Institute of Acoustics,Winchester, pp. 1–16.
Woo, J., Tang, N., Suen, E., Leung, J., Wong, M., 2009. Green space, psychological restoration, and telomere length. Lancet 373, 299–300.
World Health Organisation, 2011. Burden of Disease from Environmental Noise. World Health Organization, Bonn.
World Health Organisation, 2018. Environmental Noise Guidelines for the European Region. World Health Organisation, Regional Office for Europe.