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Population-Level Exposure to $PM_{2.5}$, NO_2, Greenness (NDVI), Accessible Greenspace, Road Noise, and Rail Noise in England

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Abstract: Air pollution, greenspace and noise are interrelated environmental factors with the potential to influence human health outcomes. Research has measured these exposures in diverse ways across the globe, but no study has yet performed a country-wide analysis of air pollution, greenspace, and noise in England. This study examined cross-sectional $PM_{2.5}$, NO_2, greenness, accessible greenspace, road noise, and rail noise exposure data at all residential postcodes in England (n = 1,227,681). Restricted cubic spline models were fitted between each environmental exposure and a measure of socioeconomic status, the Index of Multiple Deprivation (IMD) rank. Population-weighted exposures by IMD deciles, urbanicity, and region were subsequently estimated. Restricted cubic spline models were also fitted between greenness and each other environmental exposure in the study. The results show some evidence of inequalities in exposure to air pollutants, greenspace, and noise across England. Notably, there is a socioeconomic gradient in greenness, NO_2, $PM_{2.5}$, and road noise in London. In addition, NO_2, $PM_{2.5}$, and road noise exposure decrease as greenness increases in urban areas. Concerningly, almost all air pollution estimates in our study exceed international health guidelines. Further research is needed to elucidate the socioeconomic patterns and health impacts of air pollution, greenspace, and noise over time.

Keywords: air pollution; greenspace; noise; environmental exposure; environmental inequality

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1. Introduction

Air pollution, greenspace, and noise are interlinked environmental factors that exist at spatially and temporally varying levels in the human sphere. Evidence suggests that all three exposures have the potential to affect human health [1–3]. Road transport is a common source of both air pollution and noise, whereas the presence of greenspace in the area has the potential to reduce the level of these harmful environmental factors [4–6]. In this paper, air pollution signifies solid particles and gases in the air, specifically nitrogen dioxide (NO_2) and fine particulate matter with a diameter of less than or equal to 2.5 µm ($PM_{2.5}$) [7]. There is increasing evidence that even at relatively low concentrations, $PM_{2.5}$ and NO_2 can be harmful to human health [8]. The World Health Organisation (WHO) guidelines indicate that $PM_{2.5}$ and NO_2 should not exceed 5 and 10 micrograms per cubic metre (µg/m^3) annually or 15 and 25 µg/m^3 daily, accordingly [9]. Attempts to mitigate air pollutant emissions and subsequent human exposure face challenging trade-offs of controlling other environmental factors and protecting distinct health outcomes [10–12].

Research supports a relationship between long-term $PM_{2.5}$ and NO_2 exposures and deteriorated health. Although $PM_{2.5}$ and NO_2 exist at distinct spatial and temporal resolutions, both air pollutants enter the lungs and may cross the oxygen–blood barrier, causing inflammation and oxidative stress, and leading to negative effects throughout the body [13].

$PM_{2.5}$ may be particularly harmful due to its small size, enabling it to travel deep into the lungs and penetrate tissue [14]. In the United Kingdom (UK), between 28 and 36 thousand deaths each year are attributable to air pollution, according to estimates by the Committee on the Medical Effects of Air Pollutants [15]. There is also evidence of links between $PM_{2.5}$ and NO_2 and other specific diseases and health outcomes, namely, lung cancers, cardiovascular and respiratory diseases, and cognitive impairments [16].

The relationship between greenspace and human health has not been investigated as thoroughly compared to air pollution. Research suggests that greenspace may cause direct and indirect health benefits by facilitating physical activity, stress reduction, and social contact and limiting exposure to air pollution, noise, flooding, and heat [1,17]. Greenspace can be quantified in numerous ways according to its type, size, quality, availability, accessibility, and usage [18]. Evidence suggests that the health benefits of greenspace exist across urban and rural contexts, although urban residents may present greater improvements in cardiovascular, birth, and mortality outcomes compared to their rural counterparts, particularly with closer access to urban greenspaces [19]. In the present study, greenspace is defined by a measure of the proportion of live, green vegetation, namely the Normalised Difference Vegetation Index (NDVI) and proximity to the nearest publicly accessible greenspace from residential postcodes.

Due to the heterogeneity among the definitions of greenspace and the complex interplay of mechanisms by which it influences health, it is difficult to measure and compare its health benefits [20]. A systematic review associated characteristics of greenspaces, their locations, their usage for recreational activities, and their increasing availability with lower mortality and other indicators of improved physical and mental health [21]. Some research suggests greenspace may also positively impact the developing brain; for example, a one decile increase in the percentage of neighbourhood greenery was consistently related to 0.8 fewer errors on a spatial working memory task across deprivation levels in a cohort of 4700 British 11-year-olds [22,23]. Further studies among children and adolescents demonstrated reduced rates of obesity and improved lung function and circulatory health with increased greenspace exposure [24]. The WHO recommends every household have a greenspace of at least 0.5 hectares within 300 m to achieve universal greenspace access [25].

Noise from human sources may refer to sounds from industrial, transport, and leisure activities, although this paper focuses specifically on road and rail transport noise. Research implicates long-term noise exposure in detrimental auditory and non-auditory health effects, such as annoyance, sleep disturbances, cognitive impairments, and cardiometabolic problems [26,27]. In Europe, an estimated 12,000 premature deaths per year are caused by prolonged noise exposure [28]. Evidence in the area suggests these health effects may arise from chronic psychological and physiological stress and the disruption of self-regulatory processes [26]. The health impacts of noise exposure may also share similar mechanisms to that of air pollution, namely inflammation and oxidative stress, particularly in its effects on the central nervous system and mental health [29]. The WHO recommends that average noise levels should be reduced below 53 decibels (dB) for road noise and 54 dB for rail noise in order to mitigate adverse health effects [27].

Due to the parallels in exposure and health effects among air pollution, greenspace and noise, it is important to examine these factors simultaneously [30]. Multiple studies have found synergistic effects of air pollution and greenspace, where greenspace exposure protects human health against air pollution; the evidence for the effects of noise is less clear [31–35]. A few UK-based studies have explored the effects of air pollution, greenspace, and noise on health in conjunction. A health impact assessment in London estimated 71.5 attributable deaths over one year due to NO_2 and 8 to road noise, and 6.8 deaths prevented due to greenspace exposure [36]. Research using the UK Biobank, a large long-term study, indicates that NO_2 and PM_{10} were related to 10% and 8% higher risk of developing Parkinson's disease, while greenspace reduced the risk mediated by air pollution [37]. The UK Biobank has also demonstrated sustained negative noise impacts and protective greenspace effects on stroke and type 2 diabetes while accounting for exposure to numerous air pollutants [38,39].

There is growing national interest in air pollution, greenspace, noise, and health outcome research in the UK. A recent report from the Department for Environment, Food and Rural Affairs (Defra) emphasises the economic, social, and health benefits of greenspace, including its potential to reduce air pollution and noise exposure, and calls for action to improve access [40]. The latest Marmot Review, another key British publication, describes widening inequities, where areas of higher deprivation have less access to greenspace, poorer health, and higher levels of air pollution and noise, but the potential to experience the greatest health benefits of greenspace exposure [41]. Despite available evidence, research examining air pollution, greenspace, noise, and related health impacts in the UK remains small-scale, presenting the need to further examine these factors using a large, nation-wide study population.

Given the current regard in the UK for air pollution, greenspace, and noise, it is essential to understand the general population's exposure to these interlinked environmental factors. The aim of this paper is to provide and compare national estimates in England of air pollution, greenspace, and noise exposures around residential postcodes in relation to socioeconomic characteristics. Comprehensive data from diverse sources are used to provide a description of the variations in these environmental exposures across the country. This paper seeks to inform on this salient topic and provoke further research to investigate the relationships among air pollution, greenspace, noise, and their health effects.

2. Materials and Methods

2.1. Residential Postcodes in England

All residential postcodes in England from the Office for National Statistics (ONS) Postcode Directory (May 2021) with more than one usual resident at the time of the 2011 Census were extracted, after excluding those with limited geographical information or precision (n = 1,227,681) [42]. Air pollution, greenspace, and noise were evaluated using each exposure measure stated below at the centroid of the full postcode boundaries, each of which contains on average 15 properties. Every postcode has information on the income sub-domain of the Index of Multiple Deprivation (IMD 2019), measured by the Lower Super Output Area (LSOA), encompassing approximately 1500 residents per LSOA on average, and Rural–Urban Classification (2011 Census) [43].

2.2. Environmental Exposure Measures

2.2.1. Air Pollution

Maps of the 2019 annual mean $PM_{2.5}$ and NO_2 levels across the UK, measured in micrograms per cubic metre ($\mu g/m^3$) at a 1 × 1 km resolution, were obtained from Defra's Modelling of Ambient Air Quality [44]. Thorough monitoring and modelling methodology is defined elsewhere [45]. Briefly, for both NO_x and $PM_{2.5}$, the background concentrations were quantified by combining contributions from various point and areal emission sources detailed in NAEI (National Atmospheric Emissions Inventory) in industry, domestic, road traffic, rural areas, and others. For $PM_{2.5}$, additional contributions to the background concentration were added, such as secondary (in)organic aerosol, regional primary particles, regional calcium/iron-rich dusts from re-suspension, iron-rich dusts from re-suspension due to vehicle activity, sea salt, and residuals. In addition to such background concentrations, the roadside increment concentrations were formulated for the urban major road census points (A-roads and motorways). This offers more robust roadside assessments while preserving the link with AURN (Automatic Urban and Rural Network) measurement data to calibrate this portion of the model. For NO_2, background and roadside concentration maps were calculated by applying a calibrated version of the updated oxidant-partitioning model that reflects the complex interrelationships among NO, NO_2, and O_3 as a set of chemically coupled species. In this paper, respective $PM_{2.5}$

and NO_2 averages in a 1 km radius from each postcode centroid were calculated using from the Defra air pollution maps.

2.2.2. Greenspace

Two indicators, the greenness of the biomes and publicly accessible greenspace, were assembled in order to examine the quality and accessibility of neighbourhood greenspace. For greenness, we used Normalised Difference Vegetation Index (NDVI) products generated by Copernicus Global Land Monitoring Service, the Earth Observation programme of the European Commission [46]. The NDVI is calculated using the Red and Nir reflectance values from the 10-daily Top of the Canopy reflectance values measured by the PROBA-VEGETATION sensor at a 333 m resolution (copyright BELSPO, and distribution by VITO NV) [47]. NDVI values range from -0.08, indicating the least green, to 0.92, indicating the most green; any values outside of this range represent missing values where data were not able to be collected. To represent the general greenness of the area, we generated the average of 12 NDVI images observed from 1 May to 31 August in 2019 across the UK. We then allocated the nearest averaged NDVI values at each postcode centroid.

To measure accessible greenspace, the extent and location of publicly accessible greenspaces across England were obtained from a subset of Natural England's Green and Blue Infrastructure, Accessible Greenspaces (map three) [48]. This dataset includes greenspaces recorded in the Ordnance Survey's Greenspace database, namely play spaces, playing fields, public parks and gardens, and religious grounds and cemeteries, as well as greenspaces in the Local Nature Reserve, Natural England open-access data, Millennium Greens, Country Parks, Doorstep Greens, and Parks and Gardens databases [49]. The distance in metres from postcode centroids to the closest boundary of the accessible greenspace was calculated to represent the accessible greenspace.

2.2.3. Noise

Maps of 24 h annual average road and rail noise, with separate weightings for evening and night periods (L_{den}), were obtained from Defra's Noise Team. Details on the strategic road and rail noise mapping calculation methodology conducted by Defra is described elsewhere [50]. In short, according to the Environmental Noise Directive (round 3), noise was measured in decibels at 4 m above the local ground level on a 10 m grid across 26,000 km of major roads, 5200 km of major railways, and 65 agglomerations. Approximately 59% of England (77,000 km^2 for roads and 20,000 km^2 for railways) was considered, with 3 km buffers around the roads and 1 km buffers around the railways and agglomerations added in order to include all noise sources affecting the noise levels within the calculation area. Major roads were defined as motorways and A-roads within agglomerations and those with more than 3 million vehicle movements per year. Major railways included railway corridors containing Network Rail (NR) and/or Channel Tunnel Rail Link (HS1) lines within agglomerations and those with more than 30,000 train movements per year in 2011. In this paper, the estimated average noise levels from road and rail sources were assigned separately at the postcode centroid. Among all target residential postcodes in this study, 13% and 83% of the postcodes contained missing values for road and rail noise, respectively. This is because these postcodes are not located near major roads and railways where the noise mapping was carried out, or where values are below 35 dB and, therefore, deemed unreliable by the Defra Noise Team.

2.3. Analyses

First, we investigated the associations between each environmental exposure measurement, namely $PM_{2.5}$, NO_2, NDVI, accessible greenspace, road noise, and rail noise, and the measure of socioeconomic status (income sub-domain of IMD rank) by fitting restricted cubic spline models with four knots. Restricted cubic splines, or natural splines, place knots based on Harrell's recommendation of equally spaced percentiles from the original variable's marginal distribution [51]. Restricted cubic splines are useful for very curved functions and create a continuous, smooth linear function up to the first knot, followed by piecewise cubic polynomials between the middle knots, becoming linear after the final knot. The spline models using all available data were fitted against a scatterplot of a 0.01% sample of all residential postcodes in England, separately for urban and rural areas and London and non-London regions, in order to explore these contrasts. Using the same methodology, we examined the associations between each environmental exposure measure and the NDVI and accessible greenspace, respectively. For the accessible greenspace measure, a natural log transformation was applied to account for its positively skewed distribution. Statistical distributions of air pollution, greenspace, and noise exposure across urban and rural areas in this study are presented in Appendix A Figure A1.

Next, we estimated the population-weighted exposure to air pollution ($PM_{2.5}$ and NO_2), greenspace (greenness and accessibility), and noise (road and rail) by socioeconomic status (IMD income sub-domain deciles), urbanicity, and region using the postcode headcount (ONS, May 2021).

All environmental data were prepared in Geographic Information System (GIS) software, Quantum GIS (QGIS) version 3.22.7, and statistical analyses were performed in STATA software version 17.

3. Results

3.1. Environmental Exposures and Deprivation

3.1.1. Air Pollution

Generally, people live with higher $PM_{2.5}$ and NO_2 levels in urban areas than in rural areas (Figure 1A). Although socioeconomic gradients in NO_2 are seen in urban areas (Table 1), London, other regions and nationally (Table 2), with 2–6 μg/m^3 higher exposure observed in the most deprived group than the least deprived group, this pattern is not evident in rural areas. For $PM_{2.5}$, socioeconomic gradients are not clear or may suggest the opposite direction at rural postcodes (i.e., in Table 1 affluent areas are exposed to higher $PM_{2.5}$ than deprived areas, with 1.2 g/m^3 lower $PM_{2.5}$ in the most deprived area compared to the least deprived area). A lack of clear a pattern in $PM_{2.5}$ exposure is consistent across the subgroups examined in this study, except in London (Table 2), where there is a 1.4 μg/m^3 reduction in the population-weighted average in $PM_{2.5}$ in the least deprived group compared to the most deprived group.

Table 1. Population-weighted air pollution, greenspace (GS), and noise exposure in England summarised by deprivation and urbanicity. Mean (SD), unless stated otherwise.

Urbanicity	IMD ƚ	Population, Person	NDVI	Accessible GS, m	$PM_{2.5}$, μg/m^3	NO_2, μg/m^3	Road Noise, dB	Rail Noise, dB
Urban	1 (most)	5,166,713	0.51 (0.12)	171 (118)	9.4 (1.4)	16.6 (4.5)	48.9 (6.2)	41.9 (6)
	2	5,096,797	0.51 (0.11)	166 (119)	10 (1.8)	17.9 (6.2)	49.3 (6.2)	42.5 (6.5)
	3	4,982,796	0.51 (0.11)	172 (122)	10.1 (1.8)	18.0 (6.5)	49.0 (6.3)	42.7 (6.6)
	4	4,550,705	0.51 (0.11)	183 (129)	10 (1.7)	17.4 (6.4)	49.0 (6.5)	43.0 (6.6)
	5	4,125,862	0.53 (0.11)	192 (133)	10 (1.6)	16.7 (6)	48.8 (6.6)	43.0 (6.7)
	6	3,887,552	0.54 (0.11)	196 (137)	9.9 (1.6)	16.2 (6)	48.6 (6.6)	42.9 (6.7)
	7	3,797,953	0.56 (0.10)	206 (149)	9.7 (1.5)	15.4 (5.4)	48.4 (6.5)	42.8 (6.7)
	8	3,945,417	0.57 (0.10)	216 (153)	9.5 (1.5)	14.9 (5.4)	48.4 (6.6)	43.3 (6.9)
	9	3,930,888	0.59 (0.09)	220 (157)	9.5 (1.4)	14.4 (4.7)	48.0 (6.6)	43.1 (6.8)
	10 (least)	4,184,786	0.61 (0.08)	239 (168)	9.4 (1.2)	13.4 (3.6)	47.7 (6.4)	42.9 (6.7)

Table 1. *Cont.*

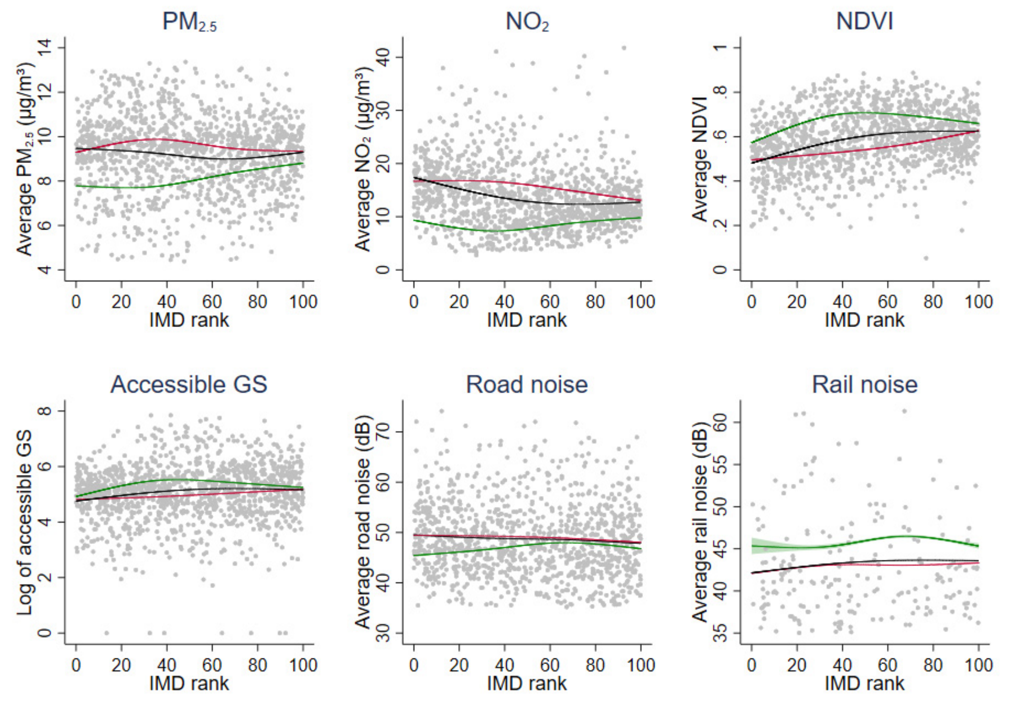
Urbanicity	IMD [ⱡ]	Population, Person	NDVI	Accessible GS, m	$PM_{2.5}$, μg/m^3	NO_2, μg/m^3	Road Noise, dB	Rail Noise, dB
Rural	1 (most)	90,489	0.58 (0.10)	204 (189)	7.76 (1.58)	8.91 (2.54)	43.8 (6.34)	43.3 (5.78)
	2	225,121	0.62 (0.10)	246 (322)	7.64 (1.66)	8.43 (2.86)	45.7 (7.38)	45.8 (8.10)
	3	403,205	0.63 (0.10)	319 (421)	8.03 (1.78)	8.43 (3.37)	45.8 (7.47)	44.3 (6.99)
	4	827,534	0.67 (0.10)	362 (441)	7.75 (1.67)	7.59 (3.23)	46.0 (7.44)	44.0 (7.01)
	5	1,208,256	0.68 (0.10)	368 (446)	8.11 (1.51)	7.98 (2.98)	46.7 (7.82)	44.5 (7.02)
	6	1,480,382	0.68 (0.09)	359 (425)	8.28 (1.48)	8.32 (2.92)	46.8 (7.60)	45.5 (7.60)
	7	1,446,161	0.68 (0.09)	341 (388)	8.34 (1.46)	8.77 (2.94)	47.2 (7.67)	45.7 (7.59)
	8	1,342,656	0.67 (0.09)	324 (363)	8.65 (1.30)	9.26 (2.82)	47.6 (7.70)	45.2 (7.26)
	9	1,304,460	0.66 (0.08)	288 (306)	8.63 (1.30)	9.39 (2.54)	47.0 (7.16)	44.7 (7.51)
	10 (least)	1,014,536	0.65 (0.08)	270 (252)	8.95 (1.15)	10.0 (2.30)	46.5 (6.67)	44.9 (7.29)

[ⱡ] Index of Multiple Deprivation (1—most deprived decile group; 10—least deprived decile group).

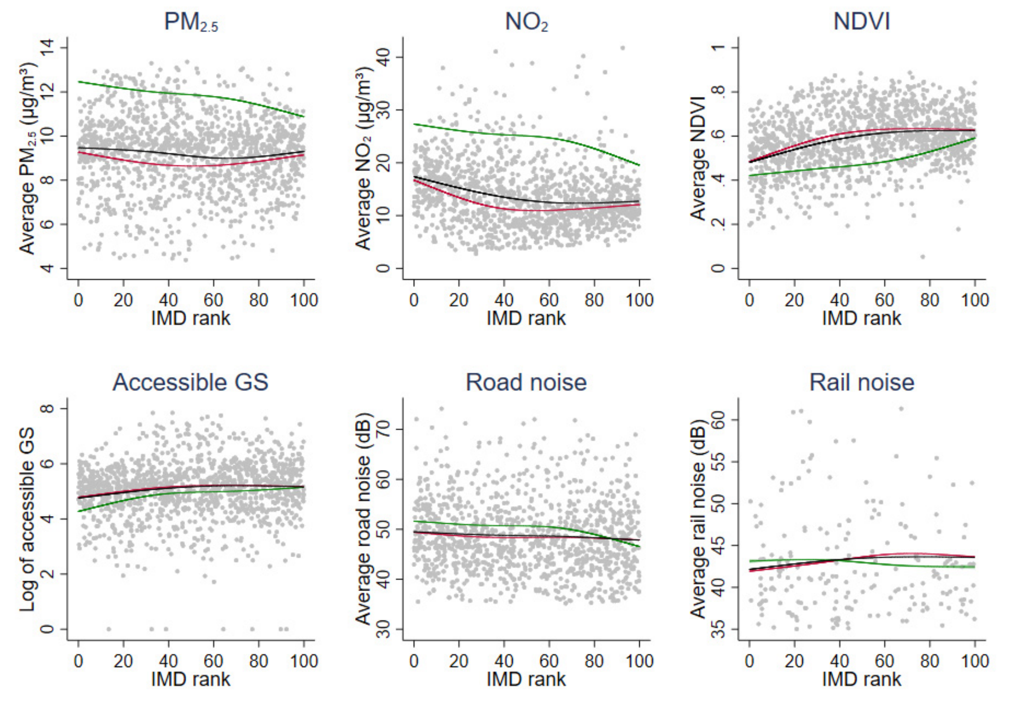
Table 2. Population-weighted average air pollution, greenspace (GS), and noise exposure in England summarised by deprivation and regionality. Mean (SD), unless stated otherwise.

Region	IMD [ⱡ]	Population, Person	NDVI	Accessible GS, m	$PM_{2.5}$, μg/m^3	NO_2, μg/m^3	Road Noise, dB	Rail Noise, dB
England overall	1 (most)	5,257,202	0.51 (0.12)	172 (120)	9.4 (1.5)	16.4 (4.6)	48.9 (6.3)	41.9 (6)
	2	5,321,918	0.51 (0.12)	169 (135)	9.9 (1.8)	17.5 (6.4)	49.2 (6.3)	42.6 (6.5)
	3	5,386,001	0.52 (0.12)	183 (169)	10 (1.9)	17.3 (6.8)	48.8 (6.4)	42.8 (6.6)
	4	5,378,239	0.54 (0.12)	211 (219)	9.7 (1.9)	15.9 (7.0)	48.8 (6.6)	43.0 (6.6)
	5	5,334,118	0.56 (0.12)	232 (253)	9.5 (1.8)	14.7 (6.6)	48.5 (6.8)	43.0 (6.7)
	6	5,367,934	0.58 (0.12)	241 (262)	9.4 (1.7)	14.0 (6.4)	48.2 (6.8)	43.1 (6.8)
	7	5,244,114	0.59 (0.11)	243 (247)	9.3 (1.6)	13.6 (5.7)	48.2 (6.8)	43.1 (6.9)
	8	5,288,073	0.60 (0.11)	243 (231)	9.3 (1.5)	13.5 (5.4)	48.3 (6.8)	43.5 (7)
	9	5,235,348	0.60 (0.10)	237 (207)	9.3 (1.5)	13.1 (4.8)	47.8 (6.7)	43.3 (6.9)
	10 (least)	5,199,322	0.62 (0.08)	245 (188)	9.3 (1.2)	12.7 (3.6)	47.5 (6.5)	43.1 (7)
London	1 (most)	178,395	0.44 (0.09)	102 (77.0)	12.4 (0.6)	26.7 (4.5)	51.0 (5.5)	43.3 (6.6)
	2	1,172,634	0.44 (0.10)	131 (105)	12.3 (0.7)	26.3 (5)	50.6 (6)	43.1 (6.8)
	3	1,422,971	0.44 (0.10)	151 (110)	12.2 (0.6)	25.9 (4.5)	50.4 (5.9)	43.1 (6.8)
	4	1,157,592	0.45 (0.10)	172 (118)	12.1 (0.7)	25.5 (4.6)	50.3 (6)	43.6 (6.8)
	5	958,673	0.47 (0.11)	191 (125)	11.9 (0.7)	24.5 (4.9)	49.7 (6.1)	43.1 (6.8)
	6	895,653	0.48 (0.11)	197 (125)	11.8 (0.6)	24.1 (5)	49.6 (6.1)	42.6 (6.6)
	7	727,226	0.51 (0.11)	190 (126)	11.6 (0.7)	23.1 (5.2)	49.0 (6.1)	42.7 (6.7)
	8	672,747	0.52 (0.11)	203 (132)	11.6 (0.7)	23.2 (5.5)	49.2 (6.3)	42.8 (6.6)
	9	646,530	0.54 (0.11)	215 (136)	11.3 (0.7)	21.4 (4.8)	47.9 (6)	42.7 (6.5)
	10 (least)	341,235	0.57 (0.09)	226 (134)	11.0 (0.7)	20.1 (4.2)	46.4 (5.3)	42.0 (6.3)
Other regions	1 (most)	5,078,807	0.51 (0.12)	174 (120)	9.28 (1.36)	16.1 (4.2)	48.8 (6.3)	41.7 (5.9)
	2	4,149,284	0.53 (0.11)	180 (140)	9.28 (1.46)	15.0 (4.2)	48.8 (6.4)	42.1 (6.2)
	3	3,963,030	0.54 (0.11)	195 (184)	9.16 (1.49)	14.2 (4.5)	48.2 (6.5)	42.4 (6.3)
	4	4,220,647	0.56 (0.12)	221 (239)	9.02 (1.60)	13.3 (4.9)	48.3 (6.8)	42.6 (6.5)
	5	4,375,445	0.58 (0.12)	241 (273)	9.02 (1.50)	12.6 (4.6)	48.2 (7)	43.0 (6.7)
	6	4,472,281	0.60 (0.11)	250 (281)	8.97 (1.44)	12.0 (4.4)	47.9 (6.9)	43.4 (6.9)
	7	4,516,888	0.61 (0.11)	252 (260)	8.92 (1.41)	12.1 (4.1)	48.0 (6.9)	43.3 (6.9)
	8	4,615,326	0.61 (0.11)	249 (241)	8.97 (1.31)	12.0 (3.7)	48.1 (6.9)	43.7 (7.1)
	9	4,588,818	0.61 (0.09)	240 (215)	9.00 (1.29)	12.0 (3.4)	47.7 (6.8)	43.5 (7.1)
	10 (least)	4,858,087	0.62 (0.08)	246 (191)	9.16 (1.18)	12.2 (3)	47.6 (6.6)	43.3 (6.8)

[ⱡ] Index of Multiple Deprivation (1—most deprived decile group; 10—least deprived decile group).



(**A**)



(**B**)

Figure 1. Associations among air pollution, greenspace (GS), noise, and deprivation. IMD rank percentile varies from 0 (most deprived) to 100 (least deprived). Restricted cubic splines were predicted using all available data. Grey dots represent a 0.01% random sample of all residential postcodes. Shading around the fitted splines indicates the 95% confidence intervals. (**A**) Red (urban), green (rural), and black (national); (**B**) red (London), green (other regions), and black (national).

3.1.2. Greenspace

Although people live with higher greenness in rural areas than in urban areas, people live closer to accessible greenspaces (as defined in this study) in urban areas compared to rural areas (Figure 1A). Similar observations apply in the comparison between London and other regions (Figure 1B).

There is approximately a 10% increase in greenness from the most deprived to the least deprived residential postcodes in urban areas, in London and other regions, whereas such a socioeconomic gradient in greenness is not as pronounced in rural areas (Figure 1A,B). In addition, closer proximity to accessible greenspace was not observed with improved socioeconomic status in either urban, rural, London, or other regions. The socioeconomic gradient in proximity to accessible greenspace was generally flat or close to marginally negative associations (i.e., decreased distance with greater deprivation). This effect is particularly prevalent in London, where the most affluent postcodes are located, on average, over 100 m further from accessible greenspaces than the most deprived postcodes (Table 2).

3.1.3. Noise

Overall, the socioeconomic gradient was weak for both road and rail noise, with most noise-level differences between 1 and 2 dB (Tables 1 and 2). Generally, residential postcodes in rural areas experienced lower road noise and higher rail noise compared to urban areas and nationally (Figure 1A). There was a marginal decrease in road noise and increase in rail noise with increasing affluence nationally and in urban areas; however, no discernible socioeconomic gradient was observed in rural areas.

For road and rail noise in London, the most deprived group experiences higher exposure and the least deprived group lower exposure when compared to postcodes in other regions of the same deprivation level. In addition, the most deprived postcodes are exposed to 4.6 dB higher road noise than the most affluent postcodes in London (Table 2).

Figure 1B further demonstrates that up until the 40th percentile of deprivation, London residents experience more rail noise, after which more affluent postcodes in other regions have higher rail noise than those in London. This effect, where other regions experience more noise than London, is only evident in the least deprived decile for road noise.

3.2. Environmental Exposures and NDVI

3.2.1. Air Pollution

Nationally, in London and in urban areas, people experience lower $PM_{2.5}$ and NO_2 at postcodes with higher greenness (Figure 2A,B). In addition, according to Figure 2A, $PM_{2.5}$ levels increase as rural areas become greener, until an NDVI of 0.6, where it begins to rapidly decrease. Similarly, as greenness increases, people living in regions other than London experience slightly higher $PM_{2.5}$, and rural areas experience slightly higher NO_2, until an NDVI of 0.6, from which it begins to decrease.

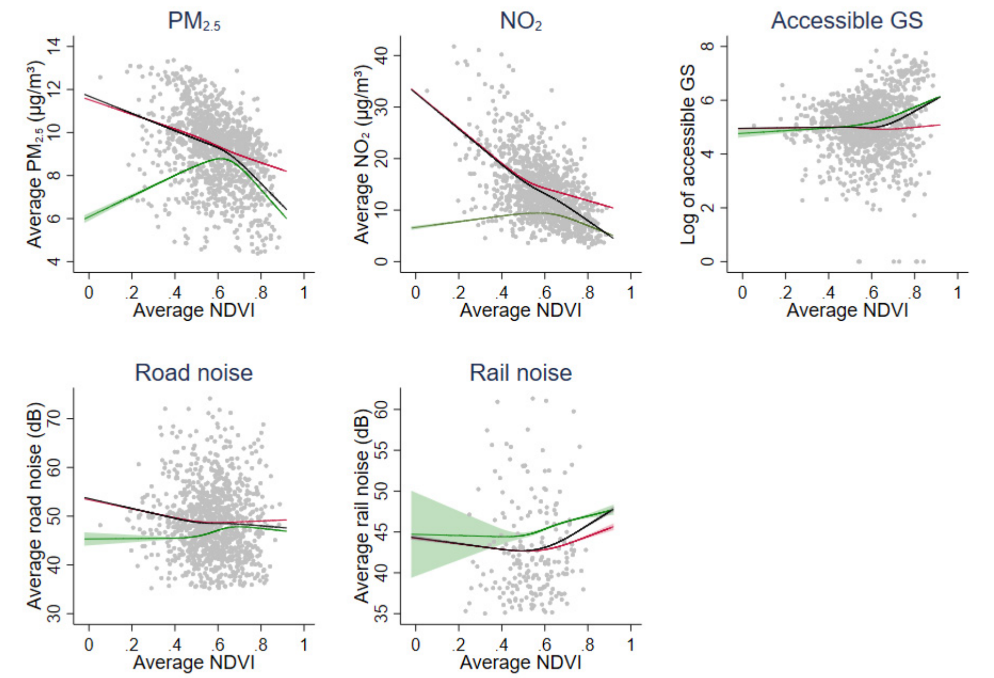
3.2.2. Greenspace

As seen in Figure 2A, the distance to accessible greenspaces increases with higher greenness levels for postcodes with an NDVI above 0.5 in rural areas and 0.6 nationally. In London, the greener the area the closer people live to accessible greenspaces, whereas accessible greenspaces becomes further away as greenness increases above an NDVI of 0.6 for people living in other regions (Figure 2B).

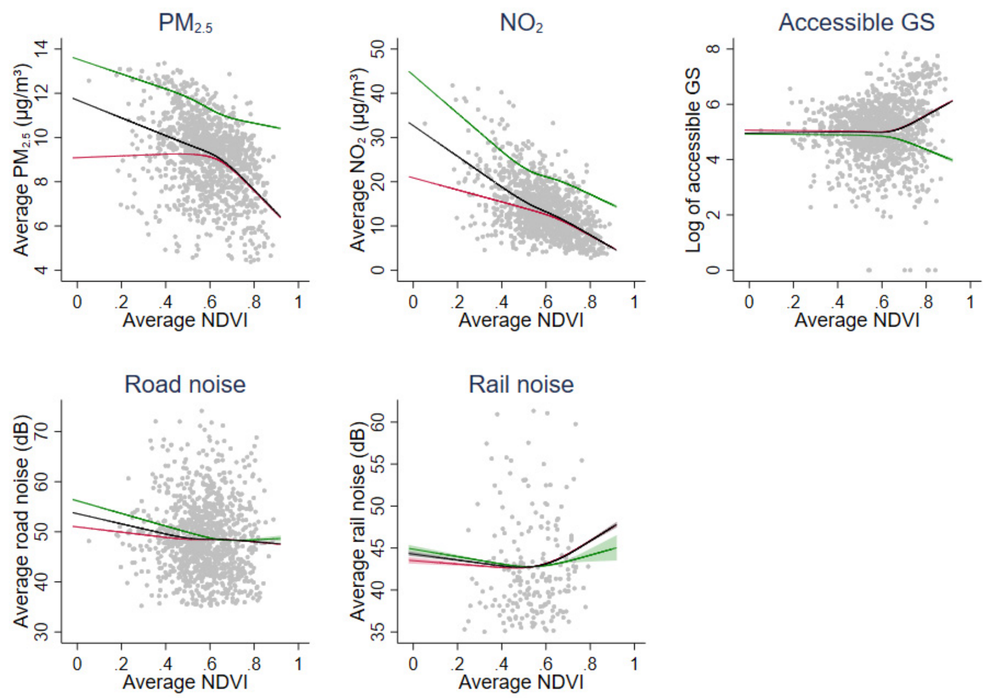
3.2.3. Noise

As seen in Figure 2A,B, postcodes with increasing greenness experience less road noise, except in rural areas where there is a slight increase in road noise until NDVI reaches 0.6, from which road noise begins to decrease. In contrast, people living in areas with higher greenness experience lower rail noise until an NDVI of between 0.5 and 0.6, where rail noise begins to increase.

Patterns of air pollution, NDVI and noise summarised by accessible greenspace are presented in the Appendix B Figure A2(1,2).



(**A**)



(**B**)

Figure 2. Associations between air pollution, accessible greenspace (GS), and noise and greenness (NDVI). NDVI varies from −0.08 (low greenness) to 0.92 (high greenness). Restricted cubic splines were predicted using all available data. Grey dots represent a 0.01% random sample of all residential postcodes. Shading around fitted splines indicates 95% confidence intervals. (**A**) Red (urban), green (rural), and black (national); (**B**) red (London), green (other regions), and black (national).

4. Discussion

Our results provide evidence of urban–rural, regional, and socioeconomic patterns in air pollution, greenspace, and noise around all residential postcodes across England. We found that urban areas and London postcodes are less green and experience more $PM_{2.5}$ and NO_2 than rural areas and postcodes in other regions. On average, most groups examined in this study live within 300 m of accessible greenspace, and therefore, meet the WHO universal greenspace recommendations; however, over half of the socioeconomic groups in rural areas do not meet this requirement, despite overall being exposed to higher greenness levels, representing contrary findings between accessible greenspace and the greenness measure in rural areas in this study [25]. Average 24 h road and rail noise estimates in our analyses also remain below the WHO limits of 53 dB for road and 54 dB for rail in all stratified groups [27]. In every setting except for NO_2 in rural areas, air pollution estimates observed in this study all exceed the WHO recommended annual maximum levels of 5 $\mu g/m^3$ for $PM_{2.5}$ and 10 $\mu g/m^3$ for NO_2 [9]. This is concerning given the comprehensive evidence suggesting exposure to air pollution above these limits is related to a range of health conditions affecting the whole body [8,16].

Our analyses also yielded socioeconomic patterns in environmental exposures. The results show a clear socioeconomic gradient in London, where wealthier areas are greener and experience less NO_2, $PM_{2.5}$, and road noise than poorer areas. In addition, there is a parallel socioeconomic gradient in urban areas and other regions for greenness. We further found that the most deprived group experiences less greenness in rural areas, and more $PM_{2.5}$, NO_2, and road noise in urban areas and other regions than the least deprived group. These findings are in keeping with the environmental inequity evidence presented in the Marmot review, where areas of higher deprivation have fewer greenspaces and are more polluted than areas of lower deprivation [41]. However, the studies included in the Marmot review investigated socio-environmental patterns in individual cities in England, rendering the observations from our country-wide analyses more pertinent to understanding the general population's exposure.

Some findings in our study provide unexpected patterns. To begin with, while rural areas are greener, they are also further from accessible greenspace compared to urban areas. This may be explained by the nature of the measurements used in this study; greenspace indicates areas officially designated for recreational activity, with varying levels of greenery. Therefore, this measure may be limited in its ability to accurately represent available greenspaces in rural areas relative to urban areas. In addition, our results suggest that the most deprived group lives closer to accessible greenspace in urban, rural, London, and other regions than the least deprived group. The majority of affluent postcodes may be generally located in residential neighbourhoods, with private gardens and leafy streets, making them greener but slightly further from publicly accessible greenspace than residences located in deprived areas. The diverging findings between the greenspace measures in this study highlight the challenges of defining greenspace and the importance of considering the different roles that it plays in promoting human health. Previous research examining health outcome differences in greenspace between urban and rural areas suggests urban populations may experience more health benefits from greenspace proximity [19]; future studies could seek to examine evidence of this pattern in the UK context.

There were also some surprising results for the air pollution and noise measures included in our study. Firstly, the least deprived group is exposed to more $PM_{2.5}$, NO_2, and road noise than the most deprived group in rural areas. However, it may be more desirable to live in areas that are closer to transport links in rural areas, thus creating this noisier, more polluted effect at the most affluent postcodes. Importantly, the type of $PM_{2.5}$ typically found in rural areas from dust and pollen may be less harmful than the $PM_{2.5}$ present in urban areas, which is more likely to be highly contaminated with dangerous particles from combustion [52]. Our study additionally shows that the poorest postcodes experience less rail noise than the wealthiest group in all settings except for London. Nevertheless, the residential postcodes with estimated rail and road noise were clustered along major roads and railways in England, naturally limiting study targets and leading to missing data for a range of residences. Therefore, it is difficult to widely generalise conclusions from the noise data in our study. In addition, the results for $PM_{2.5}$, road noise, and rail noise generally should be interpreted with caution, as the differences amongst the groups are primarily of only 1–2 $\mu g/m^3$ or dB.

Our findings further highlight patterns among the environmental factors in this sample. Lower $PM_{2.5}$ and NO_2 exposure is observed as spaces become more green in urban areas, London, and nationally, in line with the evidence base that greenspace has the potential to reduce levels of harmful pollutants [1,17]. Recent studies in Hong Kong and Sweden have produced similar findings, with dense urban areas experiencing more air pollution and noise with decreasing greenspace [53,54]. A parallel trend is noted in rural areas and other regions at greenness levels above an NDVI of 0.6, and for road and rail noise, below this margin of NDVI, from which the linear trends appear less clear. Higher greenness is indicated with closer proximity to accessible greenspaces only in London, suggesting that these greenspace variables are measuring distinct facets of greenspace in other areas. This result supports research in the area demonstrating diverse relationships depending on the type of greenspace measure [20].

A strength of this study is its inclusion of the two greenspace measures, road and rail noise data, and distinct air pollutant measures to provide a comprehensive representation of the general population's exposure in England. Research has investigated air pollution, greenspace, and noise in relation to mortality using similar measures to our study in Belgium, Switzerland, China, the Netherlands, and Spain [31–35]. Although the exposure measures included in these studies are, at times, more extensive and at a higher resolution than those used in the present analyses, they are limited to their countries in geographic scope. In two studies in England, NO_2 was measured at 100 m resolution in London, and $PM_{2.5}$ and NO_2 were modelled at the LSOA level in Bradford [36,55]. Both studies examined the 24 h average road noise and the percentage of greenspace surface area around the selected cities. Although our study is novel in its measurement of air pollution, greenspace, and noise across all of England, the large-scale nature of the study yields trade-offs on details of the exposure measurements.

Despite its contributions to research in the area, the current study has several other limitations. To begin with, the cross-sectional design provides only a snapshot of exposure to air pollution, greenspace, and noise in England. A longitudinal analysis examining changes in environmental exposure in relation to relevant health-related outcomes would provide insight into an exposure–response function. Additionally, it is important to acknowledge that the presentation of exposure patterns are affected by the choice of cubic spline function; diverse analysis methods could be used to further investigate the relationships among environmental factors. Moreover, the availability of noise data limited to areas along major roads and railways, and challenges in defining greenspaces in both urban and rural area in relation to accessibility, make it difficult to draw generalisable interpretations of our results. It would be interesting to explore the contribution of other air pollutants and types of noise, such as from air traffic, and to use an accessible greenspace indicator that is more inclusive of wilder, unofficial greenspaces.

Our study has numerous implications for future research and policy. The findings indicate that there is a dangerous excess of air pollutants in urban–rural, regional, and socioeconomic groups according to WHO standards [9,56]. This is concerning given the possible mental and physical health risks across bodily systems if these standards are not met [16]. Greenspace and noise also remain unevenly distributed across the country, posing further threats to health inequality [21,26]. Thus, our study affirms the importance of calls for action to improve environmental conditions, as well as the underlying mortality rate, in order to narrow socioeconomic differences in health outcomes in the UK [40,41]. The present research project also exemplifies the complexity of measuring environmental exposures, in particular greenspace and noise [17,18,20]. This places emphasis on the value of environmental monitoring, and the use and development of universal indicators for air pollution, greenspace, and noise. It is the ambition of this study to inspire and inform further investigations of air pollution, greenspace, and noise patterns and their relation to diverse health outcomes in England.

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Institutional Review Board Statement: This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the London School of Hygiene & Tropical Medicine, protocol code #26559 granted on 30 November 2022.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The dataset can be made available upon request from the authors. The raw data supporting the conclusions of this article will be made available by the authors upon request.

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Appendix A

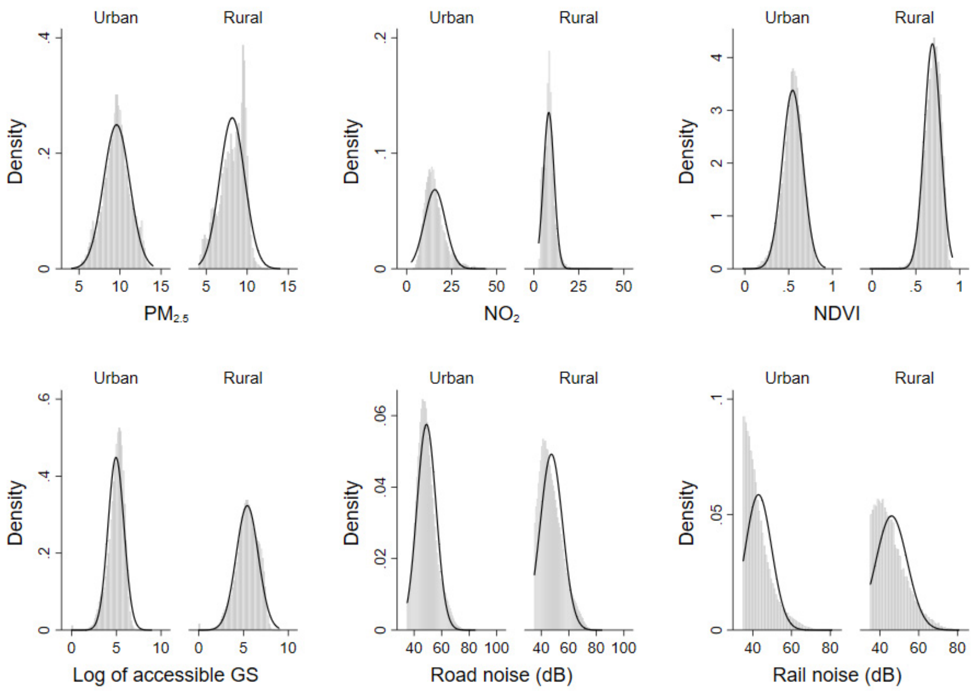
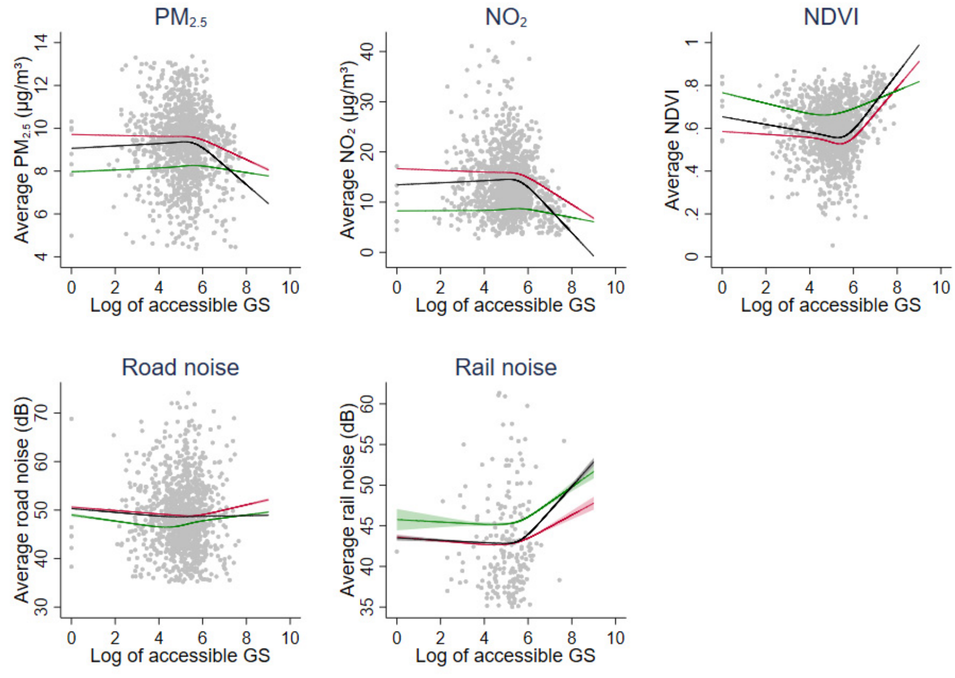
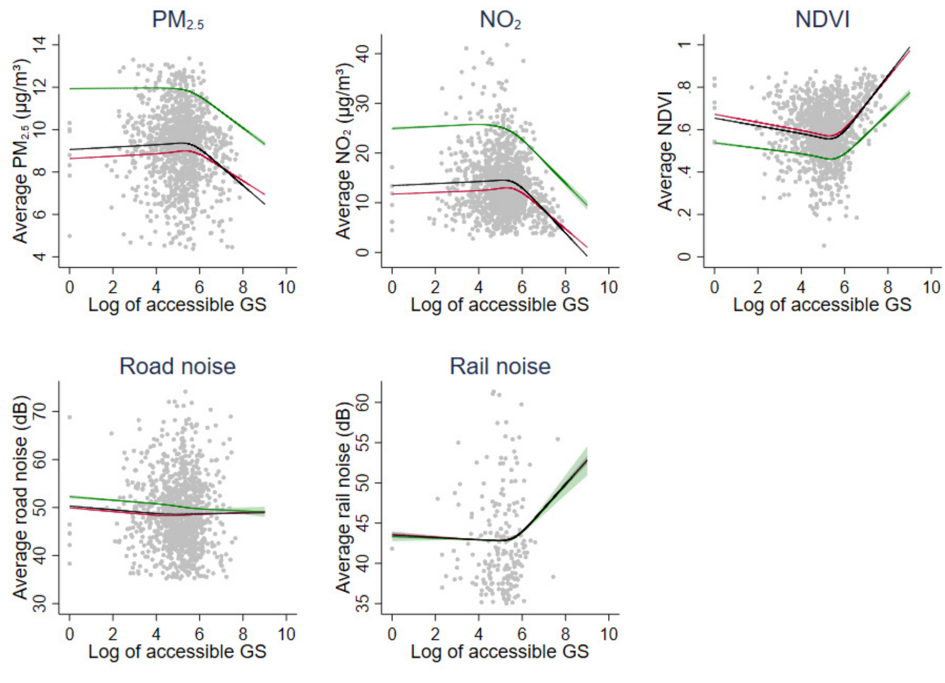


Figure A1. Distribution of air pollution, greenspace (GS), and noise exposure at all residential postcodes with measurements by urbanicity. Shaded areas indicate density with a normal distribution fitted in solid lines. $PM_{2.5}$ (n = 1,227,681), NO_2 (n = 1,227,681), NDVI (n = 1,218,956), accessible GS (n = 1,227,681), road noise (n = 1,071,970), and rail noise (n = 209,040).

Appendix B



(**1**)



(**2**)

Figure A2. Associations between air pollution, greenness (NDVI), and noise and accessible greenspace (GS, log-transformed). Log of accessible GS varied from 0 (close proximity) to 9.01 (further). Restricted cubic splines were predicted using all available data. Grey dots represent a 0.01% random sample of all residential postcodes. Shading around the fitted splines indicates the 95% confidence intervals. (**1**) Red (urban), green (rural), and black (national); (**2**) red (London), green (other regions), and black (national).

References

1. Hankey, S.; Marshall, J.D. Urban Form, Air Pollution, and Health. *Curr. Environ. Health Rep.* **2017**, *4*, 491–503. [CrossRef] [PubMed]
2. van Kempen, E.; Fischer, P.; Janssen, N.; Houthuijs, D.; van Kamp, I.; Stansfeld, S.; Cassee, F. Neurobehavioral effects of exposure to traffic-related air pollution and transportation noise in primary schoolchildren. *Environ. Res.* **2012**, *115*, 18–25. [CrossRef]
3. Asta, F.; Michelozzi, P.; Cesaroni, G.; De Sario, M.; Davoli, M.; Porta, D. Green spaces and cognitive development at age 7 years in a rome birth cohort: The mediating role of nitrogen dioxide. *Environ. Res.* **2021**, *196*, 110358. [CrossRef]
4. Son, J.-Y.; Choi, H.M.; Fong, K.C.; Heo, S.; Lim, C.C.; Bell, M.L. The roles of residential greenness in the association between air pollution and health: A systematic review. *Environ. Res. Lett.* **2021**, *16*, 093001. [CrossRef]
5. Margaritis, E.; Kang, J. Relationship between green space-related morphology and noise pollution. *Ecol. Indic.* **2017**, *72*, 921–933. [CrossRef]
6. Montes-González, D.; Vílchez-Gómez, R.; Barrigón-Morillas, J.M.; Atanasio-Moraga, P.; Rey-Gozalo, G.; Trujillo-Carmona, J. Noise and Air Pollution Related to Health in Urban Environments. *Proceedings* **2018**, *2*, 1311. [CrossRef]
7. Zawar-Reza, P.; Spronken-Smith, R. Air Pollution Climatology. In *Encyclopedia of World Climatology Encyclopedia of Earth Sciences Series*; Oliver, J.E., Ed.; Springer: Dordrecht, The Netherlands, 2005; pp. 21–32.
8. Landrigan, P.J.; Fuller, R.; Acosta, N.J.R.; Adeyi, O.; Arnold, R.; Basu, N.; Baldé, A.B.; Bertollini, R.; Bose-O'Reilly, S.; Boufford, J.I.; et al. The Lancet Commission on pollution and health. *Lancet* **2018**, *391*, 462–512. [CrossRef]
9. World Health Organisation. *WHO Global Air Quality Guidelines: Particulate Matter ($PM_{2.5}$ and PM_{10}), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide*; World Health Organisation: Geneva, Switzerland, 2021.
10. Liu, H.; Yu, J.; Zhang, S.; Ding, B. Air-Conditioned Masks Using Nanofibrous Networks for Daytime Radiative Cooling. *Nano Lett.* **2022**, *22*, 9485–9492. [CrossRef]
11. Zhang, Y.; Zhu, M.; Wei, Q.; Wang, M. Removing Chlorobenzene via the Synergistic Effects of Adsorption and Catalytic Oxidation over Activated Carbon Fiber Loaded with Transition Metal Oxides. *Atmosphere* **2022**, *13*, 2074. [CrossRef]
12. Wu, L.; Zhu, Y.; Yuan, J.; Guo, X.; Zhang, Q. Advances in Adsorption, Absorption, and Catalytic Materials for VOCs Generated in Typical Industries. *Energies* **2024**, *17*, 1861. [CrossRef]
13. Thangavel, P.; Park, D.; Lee, Y.C. Recent Insights into Particulate Matter (PM(2.5))-Mediated Toxicity in Humans: An Overview. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7511. [CrossRef] [PubMed]
14. Han, M.; Yang, F.; Sun, H. A bibliometric and visualized analysis of research progress and frontiers on health effects caused by PM(2.5). *Environ. Sci. Pollut. Res. Int.* **2021**, *28*, 30595–30612. [CrossRef] [PubMed]
15. COMEAP. *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom*; Health Protection Agency: London, UK, 2018. Available online: https://www.gov.uk/government/publications/comeap-mortality-effects-of-long-term-exposure-to-particulate-air-pollution-in-the-uk (accessed on 2 October 2024).
16. Schraufnagel, D.E.; Balmes, J.R.; Cowl, C.T.; De Matteis, S.; Jung, S.-H.; Mortimer, K.; Perez-Padilla, R.; Rice, M.B.; Riojas-Rodriguez, H.; Sood, A.; et al. Air Pollution and Noncommunicable Diseases: A Review by the Forum of International Respiratory Societies' Environmental Committee, Part 2: Air Pollution and Organ Systems. *Chest* **2019**, *155*, 417–426. (In English) [CrossRef]
17. Hartig, T.; Mitchell, R.; de Vries, S.; Frumkin, H. Nature and health. *Annu. Rev. Public Health* **2014**, *35*, 207–228. [CrossRef]
18. *Urban Greenspaces and Health*; WHO Regional Office for Europe, World Health Organisation: Copenhagen, Denmark, 2016.
19. Browning, M.H.E.M.; Rigolon, A.; McAnirlin, O.; Yoon, H. Where greenspace matters most: A systematic review of urbanicity, greenspace, and physical health. *Landsc. Urban Plan.* **2022**, *217*, 104233. [CrossRef]
20. Zhang, J.; Yu, Z.; Zhao, B.; Sun, R.; Vejre, H. Links between green space and public health: A bibliometric review of global research trends and future prospects from 1901 to 2019. *Environ. Res. Lett.* **2020**, *15*, 063001. [CrossRef]
21. Kondo, M.C.; Fluehr, J.M.; McKeon, T.; Branas, C.C. Urban Green Space and Its Impact on Human Health. *Int. J. Environ. Res. Public Health* **2018**, *15*, 445. [CrossRef] [PubMed]
22. de Keijzer, C.; Gascon, M.; Nieuwenhuijsen, M.J.; Dadvand, P. Long-Term Green Space Exposure and Cognition Across the Life Course: A Systematic Review. *Curr. Environ. Health Rep.* **2016**, *3*, 468–477. (In English) [CrossRef]
23. Flouri, E.; Papachristou, E.; Midouhas, E. The role of neighbourhood greenspace in children's spatial working memory. *Br. J. Educ. Psychol.* **2019**, *89*, 359–373. (In English) [CrossRef]
24. Ye, T.; Yu, P.; Wen, B.; Yang, Z.; Huang, W.; Guo, Y.; Abramson, M.J.; Li, S. Greenspace and health outcomes in children and adolescents: A systematic review. *Environ. Pollut.* **2022**, *314*, 120193. [CrossRef]
25. *Urban Green Spaces: A Brief for Action*; WHO Regional Office for Europe, World Health Organisation: Copenhagen, Denmark, 2017.
26. Basner, M.; Babisch, W.; Davis, A.; Brink, M.; Clark, C.; Janssen, S.; Stansfeld, S. Auditory and non-auditory effects of noise on health. *Lancet* **2014**, *383*, 1325–1332. [CrossRef] [PubMed]
27. *Environmental Noise Guidelines for the European Region*; WHO Regional Office for Europe, World Health Organisation: Copenhagen, Denmark, 2018.
28. *Environmental Noise in Europe*; European Environmental Agency, Publications Office of the European Union: Luxembourg, 2020.
29. Hahad, O.; Kuntic, M.; Al-Kindi, S.; Kuntic, I.; Gilan, D.; Petrowski, K.; Daiber, A.; Münzel, T. Noise and mental health: Evidence, mechanisms, and consequences. *J. Expo. Sci. Environ. Epidemiol.* **2024**. [CrossRef]
30. Oudin, A. Short review: Air pollution, noise and lack of greenness as risk factors for Alzheimer's disease-epidemiologic and experimental evidence. *Neurochem. Int.* **2020**, *134*, 104646. [CrossRef] [PubMed]

31. Bauwelinck, M.; Casas, L.; Nawrot, T.S.; Nemery, B.; Trabelsi, S.; Thomas, I.; Aerts, R.; Lefebvre, W.; Vanpoucke, C.; Van Nieuwenhuyse, A.; et al. Residing in urban areas with higher green space is associated with lower mortality risk: A census-based cohort study with ten years of follow-up. *Environ. Int.* **2021**, *148*, 106365. [CrossRef] [PubMed]
32. Vienneau, D.; de Hoogh, K.; Faeh, D.; Kaufmann, M.; Wunderli, J.M.; Röösli, M.; SNC Study Group. More than clean air and tranquillity: Residential green is independently associated with decreasing mortality. *Environ. Int.* **2017**, *108*, 176–184. [CrossRef] [PubMed]
33. Ji, J.S.; Zhu, A.; Lv, Y.; Shi, X. Interaction between residential greenness and air pollution mortality: Analysis of the Chinese Longitudinal Healthy Longevity Survey. *Lancet Planet. Health* **2020**, *4*, e107–e115. [CrossRef]
34. Klompmaker, J.O.; Janssen, N.A.H.; Bloemsma, L.D.; Marra, M.; Lebret, E.; Gehring, U.; Hoek, G. Effects of exposure to surrounding green, air pollution and traffic noise with non-accidental and cause-specific mortality in the Dutch national cohort. *Environ. Health* **2021**, *20*, 82. [CrossRef]
35. Nieuwenhuijsen, M.J.; Gascon, M.; Martinez, D.; Ponjoan, A.; Blanch, J.; Garcia-Gil, M.d.M.; Ramos, R.; Foraster, M.; Mueller, N.; Espinosa, A.; et al. Air Pollution, Noise, Blue Space, and Green Space and Premature Mortality in Barcelona: A Mega Cohort. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2405. [CrossRef]
36. Mitsakou, C.; Dimitroulopoulou, S.; Heaviside, C.; Katsouyanni, K.; Samoli, E.; Rodopoulou, S.; Costa, C.; Almendra, R.; Santana, P.; Dell'Olmo, M.M.; et al. Environmental public health risks in European metropolitan areas within the EURO-HEALTHY project. *Sci. Total Environ.* **2019**, *658*, 1630–1639. [CrossRef]
37. Feng, Y.; Li, M.; Hao, X.; Ma, D.; Guo, M.; Zuo, C.; Li, S.; Liang, Y.; Hao, C.; Wang, Z.; et al. Air pollution, greenspace exposure and risk of Parkinson's disease: A prospective study of 441,462 participants. *J. Neurol.* **2024**, *271*, 5233–5245. [CrossRef]
38. Gu, T.; Yang, T.; Wang, J.; Hu, X.; Xu, Z.; Wang, Y.; Jin, J.; Zhang, J.; He, T.; Li, G.; et al. Modification of green space on the associations between long-term road traffic noise exposure and incident intracerebral hemorrhage: A prospective cohort study. *Environ. Res.* **2023**, *231*, 116189. [CrossRef] [PubMed]
39. Yang, T.; Gu, T.; Xu, Z.; He, T.; Li, G.; Huang, J. Associations of residential green space with incident type 2 diabetes and the role of air pollution: A prospective analysis in UK Biobank. *Sci. Total Environ.* **2023**, *866*, 161396. [CrossRef] [PubMed]
40. Public Health England. Improving Access to Greenspace: A New Review for 2020. 2020. Available online: https://assets.publishing.service.gov.uk/media/5f202e0de90e071a5a924316/Improving_access_to_greenspace_2020_review.pdf (accessed on 28 November 2023).
41. Marmot, M.; Allen, J.; Boyce, T.; Goldblatt, P.; Morrison, J. *Health Equity in England: The Marmot Review 10 Years on*; Institute of Health Equity: London, UK, 2020.
42. ONS Geography. ONS Postcode Directory (May 2021) for the UK. Available online: https://geoportal.statistics.gov.uk/datasets/92a9ad71b8534a8889a59565e96e4df1/about (accessed on 10 January 2022).
43. Ministry of Housing Communities and Local Government. English Indices of Deprivation 2019. Available online: https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019 (accessed on 20 September 2022).
44. Department for Environment Food and Rural Affairs. Modelled Background Pollution Data. Available online: https://uk-air.defra.gov.uk/data/pcm-data (accessed on 1 August 2022).
45. Ricardo, Energy and Environment. *Technical Report on UK Supplementary Assessment under the Air Quality Directive (2008/50/EC), the Air Quality Framework Directive (96/62/EC) and Fourth Daughter Directive (2004/107/EC) for 2019*; Report for The Department for Environment, Food and Rural Affairs, The Welsh Government, The Scottish Government and The Department of the Environment for Northern Ireland; Ricardo, Energy and Environment: Didcot, UK, 2021; Issue 1. Available online: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2102111100_2019_PCM_technical_report.pdf (accessed on 20 September 2022).
46. Normalized Difference Vegetation Index. Copernicus Global Land Monitoring Service. Available online: https://land.copernicus.eu/global/products/ndvi (accessed on 5 August 2022).
47. Smets, B.; Jacobs, T.; Swinnen, E.; Toté, C.; Claes, P. *Product User Manual Normalised Difference Vegetation Index, Collection 300 m Verion 1*; VITO Copernicus Global Land Operations: Copenhagen, Denmark, 2016.
48. Natural England. Green and Blue Infrastructure (England). Available online: https://www.data.gov.uk/dataset/f335ab3a-f670-467f-bedd-80bdd8f1ace6/green-and-blue-infrastructure-england (accessed on 6 August 2022).
49. Moss, M. England Green Infrastructure Mapping Database Beta Version 1.1 User Guide. In *Natural England Research Report NERR105*; Natural England: York, UK, 2021.
50. Shilton, S. *Calculations of Noise Levels from Road and Rail Sources*; Hepworth Acoustics: Manchester, UK, 2013.
51. Frank, J.; Harrell, E. *Regression Modeling Strategies*, 2nd ed.; Springer Series in Statistics: Nashville, TN, USA, 2015.
52. Harrison, R.M.; Yin, J. Chemical speciation of $PM_{2.5}$ particles at urban background and rural sites in the UK atmosphere. *J. Environ. Monit.* **2010**, *12*, 1404–1414. [CrossRef] [PubMed]
53. Stucki, L.; Betner, S.; Selander, J.; Lohmus, M.; Akesson, A.; Eriksson, C. Sociodemographic inequalities in long-term exposure to air pollution, road traffic noise, and greenness: A population-based cohort study of women. *Environ. Epidemiol.* **2023**, *7*, e279. [CrossRef]
54. Liu, D.; Kwan, M.P.; Kan, Z.; Liu, Y. Examining individual-level tri-exposure to greenspace and air/noise pollution using individual-level GPS-based real-time sensing data. *Soc. Sci. Med.* **2023**, *329*, 116040. [CrossRef]

55. Mueller, N.; Rojas-Rueda, D.; Khreis, H.; Cirach, M.; Milà, C.; Espinosa, A.; Foraster, M.; McEachan, R.R.; Kelly, B.; Wright, J.; et al. Socioeconomic inequalities in urban and transport planning related exposures and mortality: A health impact assessment study for Bradford, UK. *Environ. Int.* **2018**, *121*, 931–941. [CrossRef]
56. Wei, Y.; Schwartz, J. The updated WHO air quality guidelines are a big step forward but not a complete solution. *Bmj* **2024**, *384*, q542. [CrossRef]