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Spatial and socioeconomic inequalities of road-traffic noise and attributable burden of disease in London, England

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ABSTRACT

Noise pollution is one of the leading contributors to the environmental burden of disease in European cities, including London, England. However, a comprehensive city-wide assessment of the spatial disparities and the potential socioeconomic inequalities of road-traffic noise and the attributable health burdens is lacking. As such, we quantified, mapped, and compared the spatial disparities in noise exposures and attributable health burdens across the city, assessing inequalities within and between Boroughs (n=33). To do this, we used high-resolution noise exposures from all roads within the range of 35–80 dB (L_{den}, L_{night}) from a model complying with the CNOSSOS framework. We then combined the exposure distributions with epidemiological exposure-response relationships for annoyance, sleep disturbance, ischemic heart disease (IHD), stroke, and diabetes, and localized health burden data to quantify attributable Disability Adjusted Life Years (DALYs) lost at Borough-level (for the year 2018). Lastly, we assessed the linear and non-linear associations of noise attributable health burdens with Borough-level income deprivation and an index of multiple deprivation (IMD). The population within each Borough exposed above WHO guidelines varied substantially between Boroughs. At the upper end of the distribution, a quarter of Boroughs had 59% and 71% exposed above 53 L_{den} and 45 $L_{night,}$ respectively. The disparities in yearly attributable DALYs per 10,000 people between Boroughs ranged from 1-5 for diabetes to 14-43 for being highly sleep disturbed. Noise attributable DALYs were also significantly associated with some measures of income deprivation. This research will inform the discussion on environmental exposure disparities and associated health inequalities experienced by people across London.

Keywords: Road-traffic noise, burden of disease, inequalities, London, noise mapping

INTRODUCTION

Road-traffic noise affects millions of people in European cities and contributes to a significant disease burden (1, 2). While previous studies have highlighted disparities in noise attributable health burdens between countries and cities (1-4), analyses at smaller geographies are rare. In a separate publication, we quantified the transportation noise attributable burden in England from annoyance, sleep disturbance, ischemic heart disease (IHD), stroke, and diabetes, which varied significantly across the country (5). Notably, the largest regional burden from road, rail, and aircraft noise was concentrated in London (5, 6). For that analysis, exposures were derived from Environmental Noise Directive (END) strategic mapping, and so further inequalities in exposures from sources that did not meet the mapping threshold likely existed but were uncharacterized.

In this analysis we used a geographically flexible approach to quantify and compare inequalities in road-traffic noise exposures and attributable health burdens within and across the 33 Borough's in London, England. We also explored the potential associations with measures of Borough-level deprivation. This analysis is nested within a larger program of work to quantify the burden of disease from multiple sources of transportation noise across small geographical areas in England. As such, we kept the methods and approach consistent with that work (5, 6).

MATERIALS AND METHODS

We estimated the burden of disease attributable to road-traffic noise exposures within London Boroughs using established epidemiological methods which required the following information:

- Distributions of population exposure to road-traffic noise
- Epidemiological exposure-response relationships
- Local health data, including disease occurrence, mortality rates and life expectancy, and disability weights

We conducted the analysis for Greater London, which has a population of 8.8 million people and made estimates for each of the 33 Borough's (*Corporation of the City of London* is treated as a Borough for statistical purposes) within London. As most of the evidence of the health effects of noise is from cohort studies with adult subjects, we limited the analysis to the adult population normally resident in London. Furthermore, our target year of analysis was 2018.

Data

The road-traffic noise exposure estimates were created by the Centre for Environmental Health and Sustainability (CEHS) at the University of Leicester, using a transport noise model in accordance to the European Commissions 'Common framework for noise assessment (CNOSSOS) (7). The CNOSSOS noise propagation algorithms were implemented in PostgreSQL via the PostGIS v2.1 extension, following the protocol described by Morley et al. (8). Annual Average Daily Traffic (AADT) counts and traffic speeds were entered into the model, along with information relating to the surface roughness of land cover, building heights, wind profiles and annual average temperatures. Roads are divided into 10m segments and ray paths are drawn to the receptor locations accounting for the angle of view, source distance, and façade reflections. The AADT counts were available for the entire GB road-network in 2013 and were modelled by Morley and Gulliver (9). The estimated noise level at each receptor is the sum of sound propagation from every road in the network, including all public-accessible minor and local roads. The model was run for 140,793 address locations in London, which were selected by assigning population-weighted postcode centroids to the nearest building. The selected buildings represent the location where a majority of each postcode community population resides. Noise levels are modelled on the loudest façade at each of these receptor locations, identified by calculating the AADT count of the nearest road inverse to the roads distance. The 33 LADs in London typically contain 4,266 postcodes (SD = 1,355), which on average house 58 residents (SD = 44).

Postcode level population counts were taken from the 2011 Census, and the proportion of the population exposed to L_{den} and L_{night} noise levels, in 1 dB increments, between 40dB L_{den}/35dB L_{night} and 80 dB was then estimated in each LAD. We then estimated the number of people exposed within each Borough in 2018 by multiplying the proportion of people exposed in each 1dB band to the estimated Borough population size in 2018.

Following a systematic review of reviews (10), we selected health outcomes based on the strength of the epidemiological and mechanistic evidence (11). The health outcomes were annoyance (highly annoyed (HA)), sleep disturbance (highly sleep disturbed (HSD)), ischemic heart disease (IHD) (also can be referred to as coronary heart disease), stroke, and diabetes. We did not quantify cognitive impairment in children (12) as our study focused on the burden of disease among adults.

Exposure-response relationships (ERRs) for our main estimates were selected from our previous work done at the national level (5), and we retained these same ERRs for the London-level analysis for consistency and comparability. Specifically, in cases where there were more than one recent systematic review/meta-analysis proposing an ERR for an outcome-exposure pair, we considered the chronology of the publication and underpinning data (preference given to reviews with the most up-to-date evidence), whether the evidence came from a published peer-reviewed paper versus a conference paper (preference given to peer-reviewed publications), and where relevant, if the estimate came from one of the 2018 WHO commissioned reviews. We also only considered ERR estimates (e.g., relative risk (RR); odds ratio (OR); hazard ratio (HR)) that were statistically significant and were associated specifically to road-traffic as the source (as opposed to 'total noise' or using ERRs from other sources). We are also aware that there have been recent developments in the epidemiological evidence since our primary ERRs were selected, and so we conducted a series of sensitivity analyses with these alternative ERRs. The studies that we selected for the primary and sensitivity ERRs are given in Table 1.

Table 1. Health outcomes and exposure-response relationships (ERR) for road-traffic noise.

Health outcome	Noise metric	ERR source	ERR [95% confidence interval]	ERR lower	ERR upper
Primary ERRs					
Highly annoyed (HA)	L_{den}	(13) Guski et al 2017 *WHO commissioned meta-analysis*	%HA = 116.4304 – 4.7342 × L_{den} + 0.0497 × L_{den}^2 *Excluding Asian and Alpine studies*	40 dB	80 dB
Highly sleep disturbed (HSD)	L_{night}	(14) Smith et al 2022 *Meta-analysis (update to the WHO commissioned meta-analysis)**	%HSD = 31.18323 – 1.47351 × L_{night} + 0.01851 × L_{night}^2	40 dB	65 dB
Ischemic heart disease	L_{den}	(15) van Kempen et al 2018 *WHO commissioned meta-analysis*	1.08 [1.01-1.15] per 10 dB	53 dB	80 dB
Stroke	L_{den}	(15) van Kempen et al 2018 *WHO commissioned meta-analysis****	1.14 [1.03-1.25] per 10 dB	50 dB	70 dB

Diabetes mellitus	L_{den}	(16) Sahkvidi et al 2019 *Meta-analysis*	1.07 [1.02-1.12] per 5 dB	50 dB	80 dB
Alternative ERRs (sensitivity)					
Ischemic heart disease (1)	L_{den}	(17) Vienneau et al 2019 *Meta-analysis*	1.02 [1.00-1.04] per 10 dB	40 dB	80 dB
Ischemic heart disease (2)	L_{den}	(18) Pyko et al 2023 Pooled S*candinavian cohorts****	1.05 [1.02-1.08] per 10 dB	55 dB	75 dB
Stroke (1)	L_{den}	(19) Roswall et al 2022 *Pooled Scandinavian cohorts*	1.06 [1.03-1.08] per 10 dB	40 dB	70 dB
Diabetes (1)	L_{den}	(20) Liu et al 2023 *Meta-analysis*	1.06 [1.03-1.09] per 10 dB	40 dB	75 dB
Highly annoyed (1)	L_{den}	(21) Fenech et al 2022 ** *Update to WHO commissioned meta-analysis*	%HA = 57.256 – 2.5731 × L_{den} + 0.0312 × L_{den}^2	40 dB	80 dB

ERR: Exposure response relationship; ERR lower: Lowest noise level at which the ERR is valid; ERR upper: Upper threshold at which the ERR no longer linearly increases; RR: Relative risk ratio.
*Smith et al presented multiple curves for HSD. We used the 'combined estimate' where noise was explicitly mentioned in the question (14).
**ERR developed by updating the WHO ERR curve with new studies published between 2014-2022 (21)
*** Pyko et al 2023 reported a risk estimate of 1.03 [1.00-1.05] per 10 dB for the range between 40 to 75 dB L_{den}, however, due to a threshold effect observed at 55 dB, they estimated a risk estimate of 1.05 [1.02 – 1.08] for exposures at or above 55 dB L_{den}, which we use as our alternative ERR, as shown in Table 1.
**** The estimate for stroke incidence presented in van Kempen et al is from a single study, which is included in Roswall et al.

Our main measure of local disease burden was the Disability Adjusted Life Year (DALY). The DALY simultaneously considers the reduced health state due to disability before death (Years of Life Lived with Disability (YLD)) and the decline in life expectancy due to death (Years of Life Lost (YYL)). We estimated the underlying (irrespective of exposure) IHD, stroke, and diabetes DALYs for London and for each of the Boroughs using local (Borough-level) health data attributable to the year 2018, or as close to 2018 as possible. Prevalence-based YLD was calculated by combining annual disease prevalence estimates (22, 23) with disability weights, following the approach used by WHO (24, 25). The disability weights we used included: 0.405 for IHD (26), 0.552 for stroke (27), and 0.049 for diabetes (28). We estimated YLL by multiplying the disease-specific mortality rate by the standard life expectancy at the age at which death occurs (29), for each 5-year age band and for males and females separately. We estimated the disease-specific mortality rates for this calculation step by combing data on annual mortality counts for the year 2018 (30) and disease-specific mortality fractions (31). We defined the underlying cause of death using codes provided by the International Classification of Diseases Tenth Revision (ICD-10).

For annoyance and sleep disturbance, only the attributable morbidity component of the DALY was estimated (described below). We used the disability weights proposed in the 2018 WHO noise guidelines (0.02 (highly annoyed); 0.07 (highly sleep disturbed)) (26).

Attributable burden of disease calculation

For IHD, stroke, and diabetes, we estimated the population attributable fractions (PAF) for each Borough with equation 1:

$$\mathrm{PAF} = \frac{\sum_{i=1}^{n} p_i \times (RR_i - 1)}{\sum_{i=1}^{n} p_i \times (RR_i - 1) + 1} \qquad \text{Equation 1.}$$

where *i* represents a noise level in 1 dB increments; *n* is the total number of noise levels within the defined range; p_i represents the proportion of the population exposed to noise level *i*; and

RR_i is the relative risk increase in the health outcome at noise level *i*. As relative risks in the noise epidemiological literature are often represented as 10 dB or 5 dB increment increases, we scaled the literature RRs to 1 dB increases, assuming a linear relationship. In the absence of a consensus for the theoretical minimum risk exposure level associated with cardiometabolic diseases, for each exposure-outcome pair we assigned relative risk increases starting from a lower noise threshold level based on the noise ranges reported within each review/meta-analysis, or from the information contained in the individual studies within each review (Table 1). This ensured that we did not extrapolate relationships beyond the range of the data. For our primary IHD ERR, we set the lower threshold (53 dB L_{den}) to reflect the weighted average of the lowest noise levels measured in the included studies in the meta-analysis (26). It is also worth noting that a recent study by Pyko et al found that in their pooled cohorts, there was a threshold effect observed at 55 dB (L_{den}) above which the hazard ratio for incident IHD increased above 1 (18). For our primary stroke ERR, 50 dB L_{den} reflected the noise level at the bottom 5th percentile (rounded from 49 to 50 dB L_{den}) within the cohort study used in the meta-analysis (15, 32, 33); for our primary diabetes ERR, 50 dB L_{den} reflected the lower noise level at the bottom 5th percentile of the study with the majority weight in the meta-analysis (16, 34) (rounded from 49 to 50 dB L_{den}).

We multiplied the PAFs by the disease-specific DALYs to estimate the road-traffic noise attributable DALYs within each Borough for the year 2018 (adults only). This approach assumes that the PAF, based on ERRs of incident cases, applies equally to the morbidity and mortality component of the DALY.

The percentage of the population highly annoyed (HA) and highly sleep disturbed (HSD) within each Borough was estimated directly from the quadratic exposure-response functions in Table 1. We calculated the number of HA and HSD adults by multiplying the number of adults within each 1 dB noise band above 40 dB L_{den} (HA) and 40 L_{night} (HSD) by the percentage of the population HA and HSD at that corresponding noise level. We then multiplied the number of HA and HSD adults by the corresponding disability weight to estimate attributable DALYs (morbidity component only).

Associations between disease burden attributable to noise and markers of deprivation

Lastly, we explored the potential associations between Borough-level noise attributable health burdens (primary estimates) with income deprivation as well as a measure capturing multiple deprivation domains, called the Index of Multiple Deprivation (IMD) (data from (35, 36)). The IMD is a relative measure of deprivation in England based on seven domains of deprivation: income deprivation; employment deprivation; education, skills, and training deprivation; health deprivation and disability; crime; barriers to housing and services; and living environment deprivation. The IMD is derived by combining the deprivation scores across these 9 domain indices with pre-defined weights (more information can be found here (35)).

The deprivation measures at Borough-level were derived by aggregating estimates made at smaller geographical levels (Lower Layer Super Output Areas (LSOAs), n=4,835 in London) within each Borough. As such, we looked at multiple indicators reflecting both average deprivation and inequalities in deprivation within Boroughs:

Income deprivation measures at the Borough-level

- *Proportion income deprived*[1]: Population weighted average of the proportion of the population within each LSOA which is income deprived
- *Proportion most income deprived*: Proportion of LSOAs within each Borough that fall within the 10% most income deprived nationally

[1] This measure is sometimes referred to as the 'Income score (rate)' in ONS statistics documents [Mapping income deprivation at a local authority level - Office for National Statistics (ons.gov.uk)](#).

- *Deprivation income gap:* Difference between the highest and lowest LSOA score within Boroughs for the proportion which is income deprived

Index of Multiple Deprivation (IMD) measures at the Borough-level

- *Average IMD score:* Population weighted average of the combined IMD scores for the LSOAs within Boroughs. Higher scores reflect higher IMD deprivation.
- *Proportion with highest IMD:* Proportion of the LSOAs within each Borough that fall within the 10% most IMD deprived nationally.

We used deprivation indices attributable to the year 2019, as it was the closest year of data available to our target year of analysis (2018).

We explored potential linear associations between road-traffic noise attributable DALYs with the deprivation measures for each Borough visually (scatter plots; linear line plots) and statistically with Pearson correlation coefficients. We also explored the potential nonlinear associations visually with locally weighted smoothing (LOESS) line plots (k=3 knots) and statistically with Generalized Additive Models (GAMs) where splines (with 3-knots) were applied to the deprivation measures to allow for non-linear trends. In general, a linear association explained the relationship if one was present, and the splines were highly influenced by outliers due to the small sample size (n=33 boroughs). Therefore, we do not consider the non-linear associations further in the analysis.

RESULTS

Within and between borough disparities in road-traffic noise exposure

We found a large disparity in population noise exposures between Boroughs. Between 27% (lowest) and 72% (highest) of the populations within Boroughs were exposed to L_{den} road-traffic noise above the WHO guideline (53 dB). Similarly, between 40% (lowest) and 82% (highest) of the populations within Boroughs were exposed to L_{night} road-traffic noise above the WHO guideline (45 dB).

There were also noticeable within-Borough disparities as well (Figure 1). While the majority of the population within Boroughs was exposed between 50 – 55 dB L_{den}, on average 20% of the population was exposed below 50 dB L_{den}, and18% was exposed above 60 dB L_{den}. For night-time noise, the majority was exposed between 40-50 dB L_{night}, whereas on average 4.5% was exposed below 40 dB L_{night} and 9% above 60 dB L_{night}.

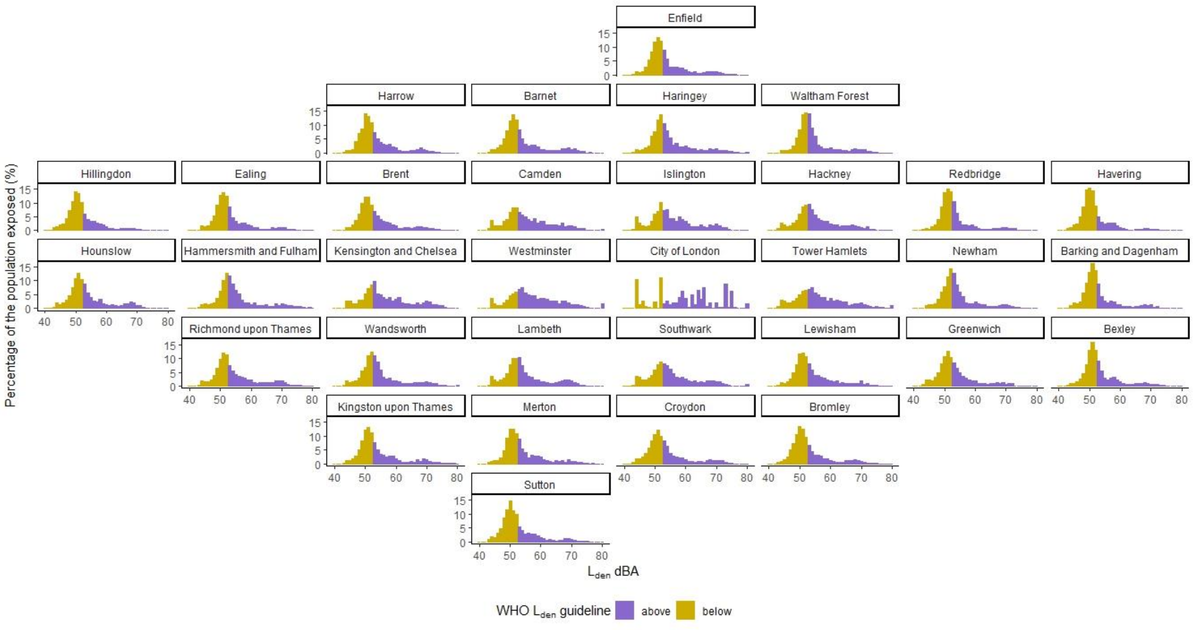

Figure 1. Distribution of the percentage of the population exposed to road-traffic noise levels and above the WHO guideline (L_{den} ≥ 53 dBA) within London Boroughs. The placement of each figure reflects the approximate geographical location of the Borough on a map of London.

Between borough inequalities in road-traffic attributable health burden

Overall, there were ~ 33,000 DALYs lost in 2018 due to road-traffic noise exposures in London, with the largest contribution from sleep disturbance (~15,000) and the least from diabetes (~1,700) (Table 2).

There was a large disparity in the road-traffic noise DALY rates (per 10,000 people) between Boroughs, ranging from 14 to 43 for sleep disturbance and 1 to 5 for diabetes (Figure 2). Boroughs in inner London had the highest attributable DALY rates from annoyance and sleep disturbance, which was also observed when comparing overall DALYs (allowing for the influence of population size), with the exception of the City of London. This is not surprising as inner London as a higher population density and more people living within close proximity to roads (and multiple roads). The spatial patterning was less consistent for attributable IHDs, strokes, and diabetes as the spatial distribution is further influenced by the underlying prevalence and mortality rates of those health outcomes within each Borough. The spatial patterning of attributable IHDs was relatively similar to attributable strokes, with City of London, Kensington and Chelsea, and Westminster Boroughs having the highest DALY rates. For diabetes the highest DALY rates were found in City of London, Brent, and Tower Hamlets Boroughs.

We conducted a series of sensitivity analyses by using alternative ERRs in the PAF calculations (and their corresponding thresholds). The estimated PAFs and DALYs for stroke and diabetes were relatively similar between the primary and alternative ERRs (Table 2). The estimated PAFs and DALYs were also similar between our primary ERR and the first alternative ERR for IHD (meta-analysis by Vienneau et al.), however higher in magnitude than the estimates produced with the second alternative ERR from the Scandinavian pooled cohort study. Lastly, our secondary ERR for annoyance (that takes into consideration more recent studies) estimated a higher number of DALYs compared with our primary ERR by a factor of about 1.35x. As a further sensitivity analysis, we estimated attributable IHD DALYs using our primary ERR but applying a higher threshold proposed by Pyko et al (55 dB L_{den}) and found that our estimated DALYs were reduced by approximately 500 (DALYs lost: ~1500) across London.

Table 2. Attributable Disability Adjusted Life Years lost in London (adults) in 2018 using the primary exposure response relationships (ERRs)* and alternative* ERRs as a sensitivity analysis.

Health outcome	Main analysis		Sensitivity analysis			
	Primary ERRs		**Alternative ERRs (1)**		**Alternative ERRs (2)**	
	Number adults	DALYs [95% CI]**	Number of adults	DALYs [95% CI]**	PAF% [95% CI]**	DALYs [95% CI]**
Highly annoyed	534,467	10,689	722,219	14,444	--	---
Highly sleep disturbed	213,723 [128,932-300,663]	14,961 [9,025-21,046]	--	--	--	--
	PAF% [95% CI]	DALYs [95% CI]	PAF% [95% CI]	DALYs [95% CI]	PAF% [95% CI]	DALYs [95% CI]
IHD	2.5% [0.3-4.7]	2,057 [255-3,899]	2.9% [0.0-5.7]	2,357 [0.0-4,733]	1.2% [0.5-1.9]	962 [377-1,573]
Stroke	6.9% [1-11.8]	3,330 [360-7,223]	8.4% [4.3-11.0]	4,028 [1,494-6,682]	--	--

Diabetes	7.3% [2.1-12.3]	1,704 [331-4,108]	8.4% [4.4% - 12.3%]	1,969 [678-4,105]	--	--

DALY: Disability Adjusted Life Year; 95% CI: 95% confidence interval; ERR: Exposure response relationship
*Primary and alternative ERRs and their lower and upper thresholds are listed in Table 1.
**The 95% confidence intervals (CI) around the central burden of disease estimates of IHD, stroke, and diabetes were based on the combined uncertainty reported for the ERR functions, disease prevalence, disability weights, and life expectancy. While the 95% CIs around the central estimate for sleep disturbance was based solely on the uncertainty estimate of the ERR function as the corresponding disability weight did not have a 95% CI. We did not have uncertainty estimates for the ERRs or disability weights to be able to construct a 95% confidence interval around the central estimate for annoyance.

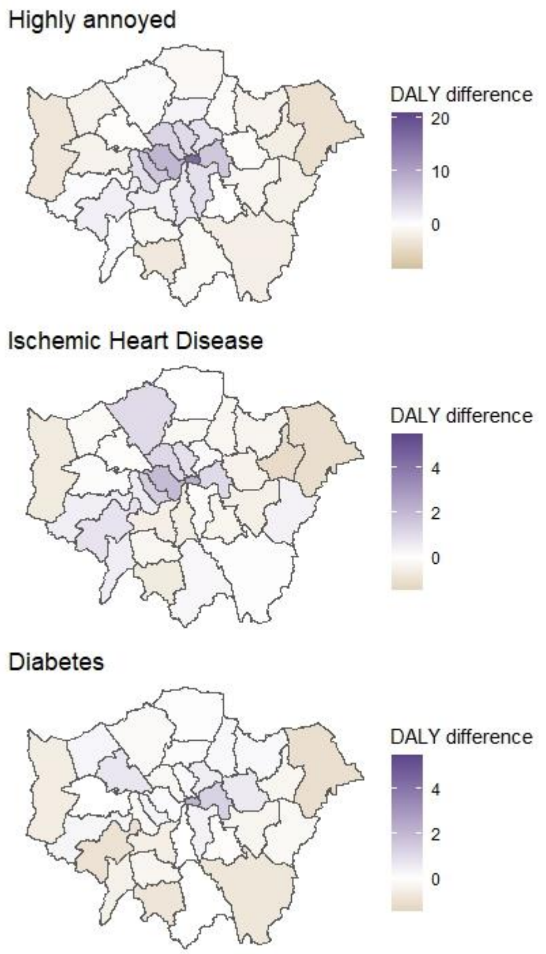

Figure 2. The difference in the rates between each Borough's Disability Adjusted Life Years (DALY) lost (per 10,000 people/yr) and the median rate across all London Boroughs (2018). Note that there is a difference in the colour scales between self-reported and physiological health outcomes. A value of 0 corresponds to the median DALY rate. Borough's with positive values have a higher DALY rate than the median and Borough's with negative values have a lower DALY rate than the median.

We observed consistent significant linear associations between noise attributable DALYs and the proportion most income deprived ('*Proportion of LSOAs within each Borough that fall within the 10% most income deprived nationally*') (Table 3) across Boroughs. Furthermore, we observed moderate positive, though not always statistically significant, associations between noise attributable DALYs and a measure representing inequalities in income within a Borough, which is the deprivation income gap ('*Difference between the highest and lowest LSOA score within Boroughs for the proportion which is income deprived*'). However, only three out of the five health outcomes had positive associations with the other measure of income deprivation, which reflected the average proportion of the population which is income deprived, and only the association with diabetes was statistically significant. Only diabetes DALYs were associated with the measures related to the Index of Multiple Deprivation.

Table 3 Pearson correlation coefficients and 95% confidence intervals* for the linear associations between measures of deprivation (income and the Index of Multiple Deprivation (IMD)) and noise attributable health DALYs (rate per 10,000 people) at the Borough level in London.**

	Highly annoyed DALY rate	Highly sleep disturbed DALY rate	Ischemic Heart Disease DALY rate	Stroke DALY rate	Diabetes DALY rate
Proportion income deprived	0.28 [-0.07, 0.58]	0.33 [-0.02, 0.61]	-0.08 [-0.42, 0.27]	-0.13 [-0.46, 0.23]	**0.68 [0.43, 0.83]**
Proportion most income deprived	**0.62 [0.34, 0.79]**	**0.62 [0.35, 0.80]**	**0.38 [0.03, 0.64]**	**0.37 [0.03, 0.64]**	**0.58 [0.30, 0.78]**
Deprivation income gap	**0.43 [0.10, 0.68]**	**0.41 [0.07, 0.66]**	0.32 [-0.03, 0.60]	**0.41 [0.08, 0.67]**	0.31 [-0.05, 0.60]
Average IMD score	0.26 [-0.10, 0.55]	0.31 [-0.04, 0.59]	-0.13 [-0.46, 0.23]	-0.14 [-0.47, 0.22]	**0.65 [0.39, 0.81]**
Proportion with highest IMD	0.31 [-0.04, 0.59]	0.34 [-0.01, 0.62]	0.12 [-0.24, 0.45]	0.25 [-0.11, 0.55]	**0.44 [0.11, 0.68]**

*Bolded estimates represent statistically significant associations at the 95% confidence level
**The City of London Borough (which is primarily a financial and business district) was removed from the analysis as it was a major outlier and skewed the underlying trends.

DISCUSSION

We found disparities in road-traffic noise exposures and attributable health burdens within and between Boroughs. In general, Boroughs in inner London (Camden, Greenwich, Hackney, Hammersmith and Fulham, Islington, Kensington and Chelsea, Lambeth, Lewisham, Southwark, Tower Hamlets, Wandsworth, Westminster (37), and the Corporation of the City of London for statistical purposes) had the highest population noise exposures and attributable DALYs from annoyance and sleep disturbance. This is because inner London Boroughs have a higher population density, with people living closer to the road network, including several major highways running through and around. As the road-traffic noise mapping was conducted in 2013, it does not take into account potential changes in traffic flows as a result of an Ultra-Low Emissions Zone (ULEZ) implemented in 2019 which applies a charge on vehicles based on emissions standards. There are also further plans to expand the ULEZ to all of Greater London by August 2023 (38). Therefore, an updated analysis in future years is recommended to reflect potential changes to the spatial distribution of exposure.

The spatial distribution of diabetes attributable DALYs was dissimilar to the other health outcomes, which is likely a reflection of the spatial distribution of the underlying prevalence and mortality of diabetes across London Boroughs. The diabetes attributable DALYs was also positively associated with measures of both income deprivation and the Index of Multiple Deprivation measures, possibly reflecting an underlying influence of both environmental (e.g., noise) and a broad spectrum of social determinants of health, that are spatially patterned across London (39-42).

Our analysis of noise attributable health burdens and measures of income deprivation and IMD was exploratory, as the geographical scale at which we conducted the ecological analysis (Borough level) was too large to examine potential associations at a localized level, given that noise exposures, income deprivation, and the health of residents in an area can vary significantly over small areas and neighborhoods in London (36, 43-46). However, we did find that two measures of income deprivation, which reflected income inequalities within Boroughs, had positive associations with noise attributable DALYs for all, or at least most, of the health outcomes. It is possible that inequalities in noise exposures and attributable health impacts compounded with inequalities in social determinants of health (such as income) can interact and further widen health inequalities. Associations between income deprivation and noise attributable health burdens could exist at smaller geographical levels (47) in London and further investigation is warranted with higher resolution data to investigate these complex relationships, as has been done for other urban areas in England (48).

Our calculations took into account spatial variations in noise exposures, population distributions, and underlying disease prevalence and mortality at Borough level across London. We made estimates for a range of health outcomes and utilized recent synthesized scientific evidence to derive our burden of disease estimates. However, our study is limited in the temporal misalignment of some of the available input data, including noise emission data from 2013, population distributions and local health data from around 2018, and socioeconomic measures from 2019. Our disease prevalence estimates were based on General Practice (i.e., Doctors clinic) reporting within the National Health Service (NHS) Quality and Outcomes Framework (QOF) (22). Prevalence estimates are based on the number of patients recorded as having disease on the practice register over the total practice list size. These data are limited however, as people who have not been formally diagnosed would not be included in the estimate and it is also possible that there are variations across practices in how conditions are diagnosed (though this is likely to be random).

CONCLUSION

We produced a geographical assessment of the burden of disease from road-traffic noise in Greater London and looked at associations with measures of area deprivation. Our study showed that road-traffic noise exposure is responsible for a significant disease burden, that varies unequally across Boroughs. Our work provides useful citywide information of potential associations between disease burden attributable to noise and indicators of deprivation, and can inform priorities in environmental health research, policies, and interventions. Further work is needed to identify relationships and associations at smaller geographical resolutions that are a more meaningful reflection of how noise pollution and population health varies across neighborhoods

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