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Working Paper

Modelling environmental equity: Exposure to environmental urban noise pollution in Birmingham, UK

CSERGE Working Paper EDM, No. 03-04

Provided in Cooperation with:

The Centre for Social and Economic Research on the Global Environment (CSERGE), University of East Anglia

Suggested Citation: Brainard, Julii S.; Jones, Andrew P.; Bateman, Ian J.; Lovett, Andrew A (2003) : Modelling environmental equity: Exposure to environmental urban noise pollution in Birmingham, UK, CSERGE Working Paper EDM, No. 03-04, University of East Anglia, The Centre for Social and Economic Research on the Global Environment (CSERGE), Norwich

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NOISE POLLUTION IN BIRMINGHAM, UK**

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Acknowledgements

The support of the Economic and Social Research Council (ESRC) is gratefully acknowledged. This work was part of the interdisciplinary research programme of the ESRC Centre for Social and Economic Research on the Global Environment (CSERGE).

We are indebted to staff Birmingham City Council (BCC), who were involved with the original noise pollution mapping, supplied us with the data used in this analysis, and commented on earlier versions of this paper. We also thank Dr. Iain Lake of UEA who helped coordinate our efforts and data acquisition. 1991 Census data are crown copyright, ESRC purchase.

ISSN 0967-8875

Abstract

This paper examines the extent to which inequalities in noise exposure are present in the city of Birmingham in the English midlands. Estimates of road and rail noise levels were made using established sound propagation models and were combined with data on noise generated from the city's airport. Demographic details from the 1991 UK Census provided information on population age, ethnic makeup, and deprivation. No relationship was established between noise exposure and population age, and there was only rather weak evidence of an association between noise exposure and ethnicity. However, greater disparities were observed in estimated noise exposures and levels of socio-economic deprivation. The implications of these findings with regard to possible efforts to reduce urban noise levels are discussed.

Key words: Noise Pollution, Environmental Equity, Population Exposure, Geographical Information Systems.

1. Introduction

Recent decades have seen increased recognition that biases within environmental policy making and regulatory processes, combined with discriminatory market forces, may lead to disproportionate exposures to environmental disamenities amongst certain population groups. In the context of examining such discrepancies, the terms *environmental equity* and *environmental justice* are sometimes used synonymously (Harding and Holdren, 1993), although distinctions can be made. Lavelle (1994) suggests that environmental equity implies an equal sharing of risk burdens, but not necessarily a reduction in the total burden of pollution. Cutter (1995) argues that environmental justice implies much more, including remedial action to correct an injustice imposed upon a specific subgroup of society. Perlin *et al.*, (1995) further advocate that environmental justice should achieve adequate protection from harmful hazardous agents for everyone, regardless of ethnicity, age or socio-economic status.

The hazardous environmental exposures often associated with environmental inequities include multiple sources of air pollution (Brajer and Hall 1992; Perlin *et al.*, 1995; Kim and Kim 2000; McLeod *et al.*, 2000; Morello-Frosch *et al.*, 2001, Brainard *et al.*, 2002), waste treatment and disposal facilities (Breen 1993; Graham *et al.*, 1999; Pastor *et al.*, 2001) and the cumulative impacts associated with living in urban and rural areas (Lavelle 1994; Laws 1997). In comparison, equity issues with regard to noise exposure are little-studied. The deleterious effect of noise pollution on the rural environment and on wildlife in particular is well-documented. Recent studies in this area include Croll *et al.*, (2001) and Stokes *et al.*, (1999). In urban areas the focus tends to be on the effects of pollution on human health rather than ecology. Potential effects of high noise on human welfare can include nuisance, disrupted sleep patterns, hearing loss, perceptions of poor well-being and loss of quality of life, impaired mental health, and stress-related health effects, which can be psychological, behavioral or physical in manifestation (Stansfield *et al.*, 2000, Passchier-Vermeer and Passchier, 2000).

Haines *et al.*, (2001) recently reported that children attending four schools located in high aircraft noise areas showed evidence of impaired reading comprehension and high levels of noise annoyance. Evans and Maxwell (1997) also found that 6-8 year olds exposed to chronic aircraft noise were more likely to suffer from deficits in language skills, whereas speech communication may be impaired for the elderly at ambient noise levels as low as 45 dB LAeq (Berglund 1996). Ng (2000) reported a direct correlation between exposure to building site noise and sleep disruption, inability to concentrate and difficulty in relaxation amongst adults. More seriously, the effect of traffic and other noise sources on cardiovascular risk factors in adults has been documented. A ten

year follow up to an earlier study (Babisch *et al.*, 1990), Babisch *et al.*, (1999) reported that long time male residents of homes exposed to high traffic noise had a relative risk of 1.6 for ischemic heart disease. Amongst a sample of 1542 young children, Regecova and Kellerova (1995) found that individuals attending nursery schools situated in areas with high traffic noise (> 60 dB(A)) had higher mean systolic and diastolic blood pressures and lower mean heart rate than children in quiet areas. In a study of exposure to local road and rail transport noise in Austrian villages, Evans *et al.*, (2001) also recently reported effects on infant cardiovascular health; children in the noisier areas had elevated resting systolic blood pressure and 8 hour, overnight urinary cortisol. The children from noisier neighbourhoods also showed elevated heart rate reactivity to a discrete stressor (reading test) in the laboratory and rated themselves higher in perceived stress symptoms on a standardised index.

Given the substantial evidence of the deleterious effects of environmental noise exposure on human health, any inequities in population exposure must be treated seriously. Indeed, Baum *et al.*, (1999) have argued that apparent health disadvantages of lower socio-economic groups may actually largely attributable to environmental stresses, including excess noise pollution. The research presented in the present article examines whether inequities in exposure to noise pollution are apparent amongst such population groups in a large English city. The work is grounded within the context of European developments and legislation on noise control. A Green paper from the European Commission published in the mid 1990s (CEC, 1996) claimed that about 20% (80 million) of the population in the European Union experience noise levels that are believed to have detrimental effects on human health. A further 42% of the EU population was believed to reside in so-called “grey areas”, where noise pollution, if not hazardous to human welfare, is severe enough to cause occasional serious nuisance.

The Commission Green Paper suggested that the mapping of noise levels should be undertaken within local contexts to serve as both a planning tool and input to further debate on public policy. Subsequent developments, including consultations with member countries (CEC, 1999), led to the issue of a Draft Framework Directive on the Assessment and Reduction of Environmental Noise by the EU in December 2000 (CEC, 2000). The Directive calls on member states to generate noise maps for all European conurbations with populations greater than 250,000 by 2005, with corresponding maps to be drawn up for urban areas with populations in excess of 100,000 by the end of 2009. The draft directive further stipulates that local authorities managing these conurbations should generate action plans that both analyse the noise maps and detail intended corrective measures.

In November 2000 the UK government issued a White Paper on Rural England (DETR & MAFF, 2000), announcing plans to consult on a national noise strategy in 2001 and map the main sources and areas of noise in England by 2004. The Council of the city of Birmingham, England, was also involved with European Union (EU) level discussions on noise reduction from an early stage, contributing to consultations on the 1996 Green paper and the subsequent development of noise mapping and abatement guidelines. Birmingham was subsequently chosen as the trial site for noise mapping in the United Kingdom. Hence the work undertaken in the city has been subject to a considerable amount of empirical effort and is of both national and European significance. Birmingham was consequently the obvious case study location for the work presented here.

Whilst we have a good understanding of the manner in which environmental noise pollution may affect the health of exposed populations, there is rather less evidence available on the degree of equity by which different populations are exposed to it. In particular, whilst the work of Baum *et al.*, (1999) suggests that lower socio-economic groups may be adversely exposed to noise, we have little evidence concerning the distribution of exposure amongst other disadvantaged groups such as ethnic minorities, and the very young or old. This is particularly pertinent given that previous work by the authors on equity of exposure to air pollutants found that urban ethnic populations tended to be concentrated in the most polluted areas (Brainard *et al.*, 2002).

The work presented in this article uses data from the Birmingham noise mapping project to make assessments of possible inequities in noise exposure between different population groups within Birmingham. Using a Geographical Information System (GIS), a methodology is developed whereby measures of noise exposure and population age, ethnicity, and socio-economic characteristics are calculated for neighbourhoods in the City. Using a combination of descriptive statistics, Kolmogorov-Smirnov tests, and mapping techniques the distributions of noise and population characteristics are then tested and compared. Finally, the implications of our findings for noise pollution legislation and future research into inequities in exposure are discussed.

2. Methods

2.1 The study area

The boundaries of the city of Birmingham were used to define the study region area (see inset map on Figure 1). Birmingham is the most urban of seven metropolitan local authorities that form the West Midlands region in England. The 1991 UK Census of Population recorded just under one million residents in the city.

2.2 Data sources

Information on the demographic structure of the study area population was extracted from the UK Census records held in the archive available on the Manchester Information & Associated Services (MIMAS) supercomputer service. The demographic details were compared to modelled levels of both day and night time noise values emitted from roads, rail, and air sources so that measures of exposure to noise could be calculated.

2.3 Population characteristics

Measures of spatial variations in the socio-economic characteristics of neighbourhood populations in Birmingham were extracted from the 1991 Census at enumeration district (ED) level (the most recent date and smallest area for which data were available). In total there were 1950 EDs within the study area. However, due to national confidentiality requirements, complete information was not available on the population of 10 EDs. Hence, 1940 EDs, with a median population of 496 residents and typical area of about 8.5 ha, were included in the final analysis.

A variety of socio-economic indicators were directly extracted or derived from the Census (Table 1). These focused on age, ethnicity, and indicators of poverty. There was no explicit income question in the 1991 Census, but a number of variables, such as levels of unemployment or car ownership, can be considered as proxy indicators of relative affluence or deprivation. As a general indicator of the level of socio-economic deprivation within each ED, census variables indicating the level of male unemployment (unemployed male residents over 16 as a proportion of all economically active male residents aged over 16), overcrowding (persons in households with 1 or more persons per room as a proportion of all residents in households), non-car ownership (residents in households with no car as a proportion of all residents in households) and low social class (residents in households with an economically active head of household in social class 4 or 5 as a proportion of all residents in households) were obtained from the Census. These were used to calculate Carstairs Deprivation Index (Carstairs and Morris, 1989) scores, a composite measure of social deprivation. The index is standardised using Z-scores such that the mean

value centres at zero. Within the index, negative scores indicate less deprived (and hence more affluent) areas, whilst positive scores denote neighbourhoods with higher levels of deprivation.

Table 1: Variables extracted or derived from the 1991 Census, for each ED

Variable name	Description	Range of observed values		
		Min.	Median	Max.
Ethnicity				
BANG	Bangladeshi population (%)	0	0	35.96
INDN	Indian population (%)	0	1.54	67.38
PAK	Pakistani population (%)	0	0.40	85.11
BLACK	Black population (%)	0	3.32	43.43
WHITE	White population (%)	4.95	92.10	100.0
Social Characteristics				
MUNEM	Male unemployment (%)	0	15.98	65.63
NOCAR	Households without a car (%)	0	47.87	93.75
OVERCR	Overcrowded households (>1.5 persons per room) (%)	0	6.42	55.57
LOWSC	Population of social class 4 and 5 (%)	0	23.08	100
RET	Pensioners (women >=60 years and men >=65 years old) (%)	0.92	17.71	84.51
U5	Infants under 5 years (%)	0	7.16	22.97
U15	Children aged 5-14 years (%)	0	21.80	60.17
Deprivation				
CARST	Carstairs deprivation index scores (value)	-5.50	-0.29	9.66

The use of secondary data sources, such as the UK Census, to determine the ethnic character of populations is not simple, as the dominant approach to the study of ethnic minority populations in the UK focuses on the relations between individuals within groups. Whereas the term 'race' may be treated as a distinct phenomenon which is linked to colour or racial categorisation (Rex, 1970), the analytical validity of the categorisation has been questioned (Miles, 1980). Ethnicity on the other hand is associated with a sense of belonging to a particular group (Anthais, 1992). As the categorisations in the UK Census are based on self-reported characteristics, we have chosen to use the term ethnicity rather than race here. White, Asian (including persons of Indian, Pakistani or Bangladeshi ancestry) and black (predominantly Caribbean but also African

ancestry) ethnic groups are particularly represented in Birmingham, and information on the population of each group was extracted for every ED from the census.

Age groups extracted for ED populations from the Census included the number of children under 5 years old, children under 15 years, and retired persons (aged over 60 years for women and 65 years for men).

2.4 Noise pollution

Information on modelled noise levels, based on values for 1998, was supplied by Birmingham City Council. Using the LIMA proprietary computer software package, maps of noise levels at reception points were derived by estimating noise levels from road, rail, and air sources at points regularly spaced at 10 metre intervals across the city. An overview of the methodology is presented below. More detail on the noise derivation process is given in Hinton (2000).

Noise estimates were utilised for both day and night time periods, and for road noise alone or road combined with that from the other sources. There were several reasons to assess the sources of noise independently. The amount of noise that a population is exposed to can vary substantially by source and throughout the day. For example, although noise levels will generally be lower at night, aircraft noise may be most disruptive in the late evening, whilst disturbance associated with road traffic noise may be highest in the late afternoon. Particular emphasis was placed on road noise in this research as road traffic is the overwhelming source of noise in the city. Moreover, the values for road noise emissions are the most reliable in the data used, as the estimates of rail and air noise levels had to be made at a considerably more generalised spatial resolution.

The main requirement for the estimation of road noise was a digital representation of the location of roads, and estimates of their associated traffic flows. For most of Birmingham, road centrelines, elevations, cuttings, and building locations were extracted from digital Ordnance Survey data. Some additional roads not included in that database were digitised manually. Separate estimates of vehicle movements for day (7am-11pm) and night-time periods (11pm-7am) were available for the 1900 individual road sections within the study area. However, as no details were available on temporal variations in vehicular speeds or the mix of road traffic vehicle types, it was necessary to treat these factors as constant throughout both time periods. It was also assumed that all road surfaces consisted of impervious bitumen.

The gradient of each road link was incorporated into the estimation of noise values. Aside from elevated road sections, the base height of roads was assumed

to be the same as ground height contours. The effect of road parapets, screens and embankments greater than 0.5 metres was also incorporated into the model. Calibration of the road noise generation was achieved by undertaking field measurements at two Birmingham sites (Walmley Golf Club and Sutton Park). The field measurements enabled an empirical formula to be derived which described sound/power relationships between the proportion of heavy goods vehicles on a road link, and measured noise levels at a distance of 25 metres from the road.

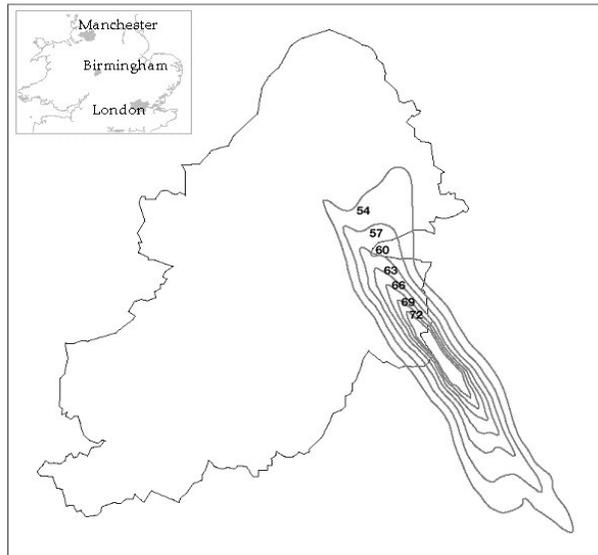
For the estimation of the contribution of rail noise to the overall noise profiles, details of passenger train services, including the number, type, length of units, and average speed between stations were used. Information on freight train movements was also utilised, although no specific data could be obtained on the length, type or average speed of these units. All sections of track in Birmingham were assumed to have insignificant gradients, and to be composed of identical materials. Furthermore, all trains of a particular type (e.g. electric or diesel passenger or freight) were assumed to have identical engines. No allowance was made for the effect of railway cuttings or embankments. Subsequent estimated noise levels were again calibrated using field assessments.

The mapping exercise undertook no independent modelling of aircraft noise. Rather, 3 decibel noise contours for a noise 'footprint' area affected by the city's airport in 1998 were supplied by Birmingham Airport for the time periods 7 am to 11 pm (Figure 1), and 11pm to 6am. No data were available for 6 am to 7 am, and so no estimates of aircraft noise were made for this period. Interpolation between contours was not attempted, but rather the areas between contours were categorised using estimates of noise levels according to the contour boundaries. It is important to note that the data for the airport footprint only refers to noise generation above 54 (day) or 48 (night) decibels. This cut off value was chosen because there is evidence from research undertaken elsewhere into annoyance from transportation noise that these values approximate to a cut off point below which there is a crossover between source-specific annoyance lines (Kurra *et al.*, 1999). However, the consequence of this decision is that there is some under-estimation of total noise levels just outside the designated airport footprint area.

All emissions sources were input to the LIMA package (produced by Stapelfeldt Ingenieurgesellschaft mbH) Germany for the estimation of sound propagation. The output estimates were generated on a 10 x 10 metre grid for reception points across Birmingham, in 5 dB bandwidths, for both day and night periods. The mapped values show continuous outdoor sound levels for the designated areas (Figure 2). The greatest single source of noise in Birmingham is the M6 motorway, with noise generation from air traffic also being quite significant

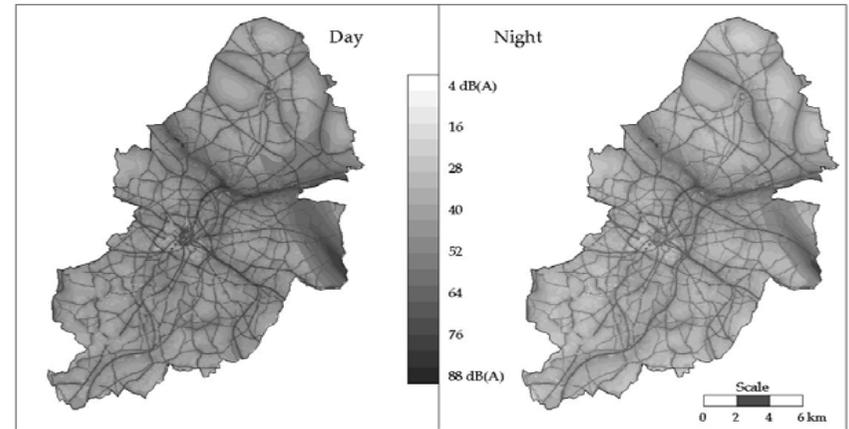
close to the airport. The measurements are denoted as dB L_{Aeq} . ‘A’-weighting refers to correction by factors that weight sound to correlate with the sensitivity of the human ear to sounds at different frequencies (Fidell *et al.*, 2002). Because values have been generalised so as to indicate an average sound level over the entire designated period (i.e. day or night), the noise estimates are assumed to be continuous and refer to modelled noise levels at a height of 4m above ground level. This height was chosen to comply with European standards for noise pollution modelling (European Commission, 1996). The combined noise source maps in Figure 2 were produced by logarithmic addition of the different noise sources.

Figure 1: Noise footprint (dB) around Birmingham airport



So that the noise data was consistent with the population dataset described below, the initial 10 metre resolution noise maps were resampled using the Arc/Info Geographical Information System package (ESRI, 1999) to derive levels for 20m x 20m cells. This conversion procedure required the generation of a surface in the form of a triangulated irregular network (TIN) from the 10x10m cell data. A new grid of 20 x 20m cells was overlain onto this map and interpolated estimates of noise levels at the centre of each new 20 x 20m cell were assigned as the average value for that entire cell.

Figure 2: Noise levels from combined (rail/road/airport) sources, for day and night-time, in A-weighted decibels (L_{Aeq})



2.4.1 Population-weighted average noise exposures for each ED

In order to use the noise exposure estimates to predict population dose, it was necessary to obtain a detailed estimate of the spatial distribution of the population of Birmingham. For this, a dataset that was derived from the 1991 UK Census of Population providing estimates of the number of persons residing in 200 x 200m grid cells across the study area was employed (Martin, 1996). Using Arc/Info, these data were subsequently resampled to a resolution of 20 x 20 m cells to allow for the irregular shape and small size of many of the Birmingham EDs, and to match the resolution of the noise estimates. The noise levels estimates were converted to ED level area averages by multiplying the noise value for each 20m x 20m grid cell by the population in that same cell. Summing these values for the entire ED, and dividing by the ED’s total population gave a population-weighted average exposure estimate.

2.4.2 Statistical analysis

The statistical analysis focused on the elucidation of possible differences in noise pollution exposures related to variations in population race, poverty and age. To examine these relationships, descriptive statistics including means, median, percentages, and quartiles were calculated. In order to determine how the estimates of exposure were distributed across the different population groups under study, Kolmogorov-Smirnov (KS) tests were also undertaken. The statistical analysis was undertaken using S-Plus 5 (MathSoft, 1998) and SPSS 10 (SPSS, 2000) software packages.

3. Results

3.1 The distribution of exposures based upon age profile

The analysis of noise exposure by age concentrated on the proportion of ED populations below the age of five years, between 5 and 14 years, and at pensionable age. To compare levels of noise exposure across these populations, the percentage of the total Birmingham population in each age group was determined for each ED. For example, the ED labelled CNFA10 had 56 children aged between 5 and 14 years. This equates to 0.012% of the total 45,140 persons within this age range residing in Birmingham in 1991. Calculating this percentage of the total for each ED allowed the proportion of each age group that was exposed to various noise levels to be determined. These proportions can be used to plot the cumulative frequency (proportion of population) against noise. Table 2 shows the median estimated noise exposures for various sources and times for each age cohort. Differences in apparent doses for each group are small, although pensioners appear to experience slightly higher noise levels than other population groups at night.

Table 2: Median estimated noise exposure for age cohorts in Birmingham (decibels)

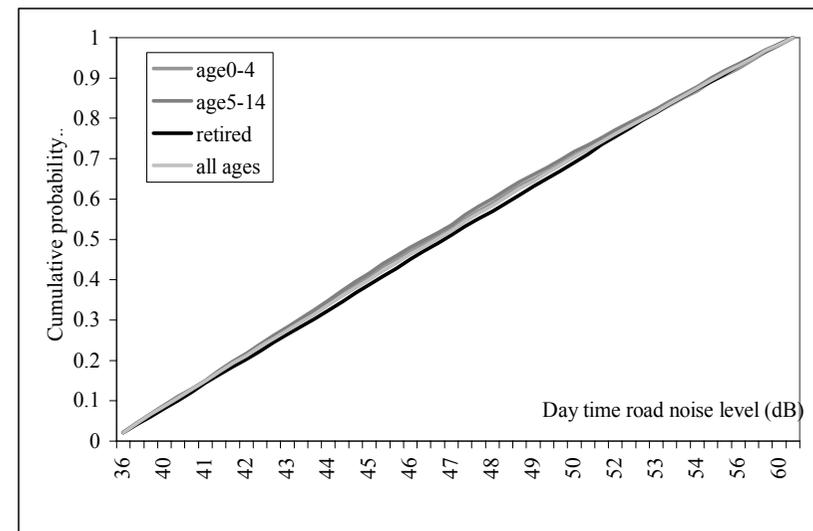
Age cohort:	0-4 yrs	5-14 yrs	Pensioners	City Average
<i>Source and period:</i>				
Road, day	46.6	46.4	46.8	46.7
Road, night	37.9	38.8	39.1	38.0
Combined, day	49.8	49.6	50.1	49.8
Combined, night	41.8	41.5	41.9	41.8

Figure 3 shows the cumulative frequency curves for daytime road noise. The ‘under 5’, ‘5 to 14’ and ‘pensioners’ lines are all virtually coincident, suggesting that there is no strong difference in estimated noise exposures experience between the different age cohorts. If the lines were divergent this would suggest that some populations were receiving disproportionate exposure. The equivalent plots of age against night-time road noise and combined source sound levels were extremely similar, and are not given here for the sake of brevity.

In order to confirm the apparent lack of differences in estimated noise exposure between groups, two-sample Kolmogorov-Smirnov (KS) tests were run to compare each of the age subgroups for each permutation of noise exposure. The KS test was used to determine the degree of difference in the shape of the

exposure lines in the figures. Here, the size of the KS statistic makes it possible to determine how strongly the pattern of exposure to noise differs between the various age groups considered in this analysis, whereby larger KS scores represent more strongly divergent exposure lines. This statistical measure is non-parametric and only requires that the data belong to a continuous distribution. More information on KS tests is given in Conover (1999). Critical values for the Kolmogorov-Smirnov statistic vary with sample intervals; in this case frequencies were broken down into 2% quantiles, giving 50 intervals. None of the KS scores reached statistical significance at a $p=0.1$ level, confirming that there is little evidence of age related disparities in noise exposure in Birmingham.

Figure 3: Cumulative probability distributions for specified age cohorts against exposure to daytime road noise in Birmingham



3.1.1 The distribution of noise exposure based upon ethnic profile

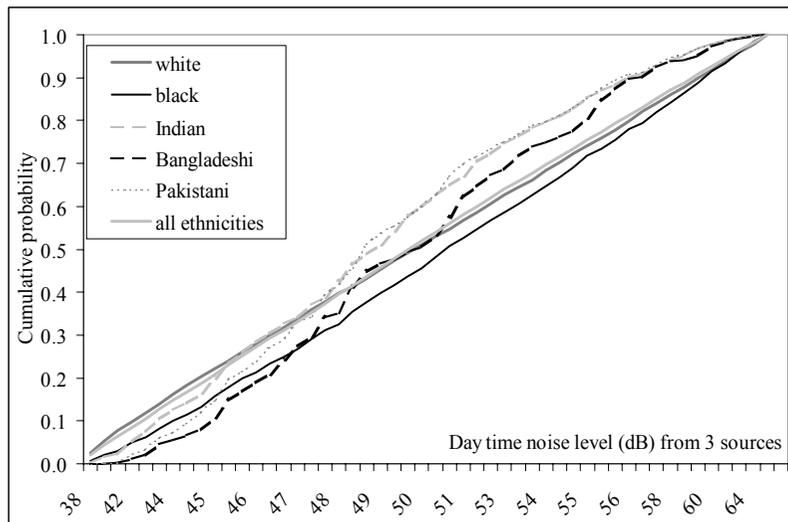
In the 1991 Census, the population of Birmingham was reported as being 78.49% white, 14.13% Asian and 5.85% black. The percentage of each ethnic group in each ED was determined so that comparisons between these groups could be made. Table 3 shows the median estimated noise exposure for various sources and times for each ethnic group. The table suggests that greater ethnicity associated disparities in median noise exposure are apparent than was

the case for age, with the Asian subgroups tending to experience somewhat lower exposure than the city average, and blacks somewhat higher levels. These differences are plotted as a cumulative frequency graph in Figure 4.

Table 3: Median estimated noise exposure for ethnic groups in Birmingham (decibels)

Ethnic group:	Indian	Pakistani	White	Bangladeshi	Black	City Average
<i>Source and period:</i>						
Road, day	45.9	45.8	46.6	47.1	47.6	46.7
Road, night	37.2	37.0	37.9	38.5	38.5	37.9
Combined, day	48.1	48.9	50.0	50.4	51.0	50.8
Combined, night	41.3	41.8	41.8	42.3	43.3	41.8

Figure 4: Cumulative probability distributions for specified racial groups and modelled daytime noise emissions from combined road/rail/airport sources



Two-sample Kolmogorov-Smirnov (KS) tests were again run to compare each of the racial subgroups for each permutation of noise exposure and the results of these are given in Table 4. For road noise alone, during the day or at night, Table 4 shows no statistically significant difference in modelled exposure between racial groups at a $p=0.05$ level. However, there is some weak evidence of disparate experiences with regard to emissions from combined sources. In particular a comparison of the significance values in Table 4 with the median exposure estimates for different ethnic groups in Table 3 suggests that the Indian and Pakistani communities would appear to have significantly less daytime noise exposure than black populations at a confidence level of 90% ($p=0.10$). The discrepancy is repeated between Indian and black populations for night time noise, but is less strong between Pakistani and black communities. Neither the white nor the Bangladeshi populations are significantly advantaged over the other ethnic groups with regard to day or night time noise from the combined sources.

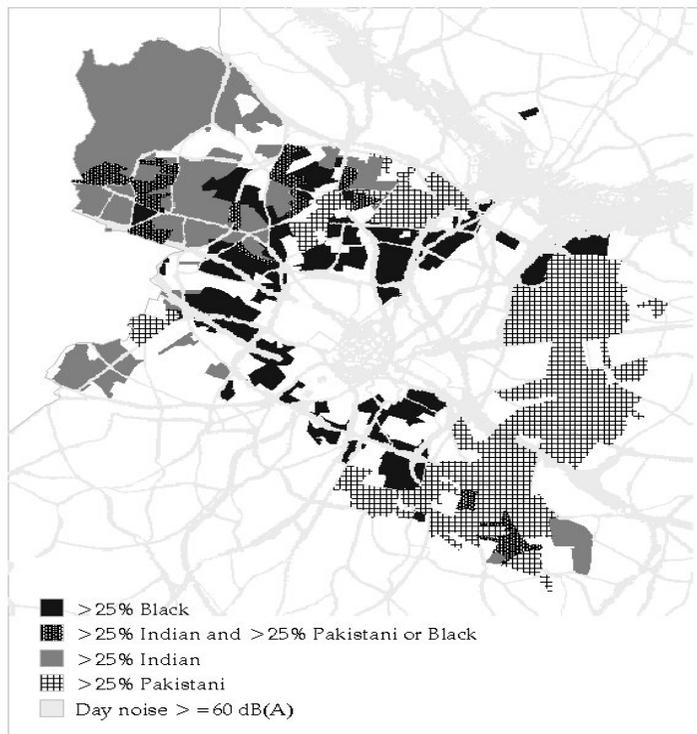
Table 4: Kolmogorov-Smirnov statistics for two-sample tests comparing cumulative probability distributions for ethnic groups and noise from combined sources

<i>Day</i>				
	Indian	Pakistani	Black	Bangladeshi
White	0.1214	0.1327	0.0731	0.1227
Indian		0.0521	0.1611	0.0974
Pakistani			0.1734	0.0962
Black				0.1173
<i>Night</i>				
	Indian	Pakistani	Black	Bangladeshi
White	0.0973	0.0892	0.0957	0.1094
Indian	--	0.0893	0.1608	0.1344
Pakistani		--	0.1270	0.0546
Black			--	0.1013
Critical values:	$p=.1$ 0.1513	$p=.05$ 0.1923	$p=.01$ 0.2305	

Note: Values exceeding the critical $p=0.1$ threshold are highlighted in bold

Further explanations for the above findings of disparities in exposure between ethnic groups were sought by examining geographical distribution of ethnic minority populations in the city. Figure 5 maps enumeration districts in the city centre (where the ethnic minority populations are heavily concentrated) with specified proportions of various ethnic groups. The population of twenty EDs were at least 25% Indian and 25% black or Pakistani, whereas 71 were at least 25% black, but less than 25% Indian or Pakistani. The remainder were predominantly Indian, Pakistani, or white. Grid cells that were receiving at least an estimated value of 60 dB (LAeq) noise are also shown on the figure.

Figure 5: Location of highly ethnic neighbourhoods (concentrations of these groups is negligible outside the city centre) and high noise areas



The city centre is marked by the presence of high noise in the middle of the map, as it is apparent that roads become more closely congested in this area. Although the centre itself is a predominantly white area, with more than 80% of residents being reported as white in the Census, it is relatively unpopulated with approximately just 3500 residents and hence high city centre exposures contribute little to the overall residential noise exposure profile for white Birmingham residents. Figure 5 shows a ring of EDs around the centre with relatively large concentrations of black populations. To the northwest are mixed and Indian areas, whilst southeast of the city centre are the neighbourhoods with the highest concentrations of Pakistani residents. It is apparent that the closer proximity of black populations to the city centre and the associated traffic noise may explain their higher estimated noise exposures compared to other ethnic groups. Although still rather central, both the Indian and Pakistani communities are far enough away from the high density roads, the M6 motorway, and the airport to be less affected.

3.1.2 The distribution of noise exposure based upon deprivation

The Carstairs index of deprivation was used as an indicator of poverty in this analysis. To compare the measures of noise exposure for different levels of deprivation, EDs were categorised into quartile groups. The lowest group refers to the least deprived (and hence most affluent) 25% of EDs according to their Carstairs score. The fourth quartile is the most deprived 25% of EDs.

Ethnicity was found to be closely associated with Carstairs index scores; the percentage of each ED population classified as black has a correlation coefficient of 0.541 ($p < 0.001$) with the Carstairs index. The equivalent correlation for the Asian community is 0.528 ($p < 0.001$). The strong association between poverty and ethnicity is illustrated by Table 5, which shows the proportion of every ethnic group population in each Carstairs quartile. The final column of the table gives the proportion of each ethnic group in the 10% most deprived EDs. A clear gradient is apparent whereby the proportion of the population reported as white declines with increasing deprivation, whilst the proportion of the other ethnic groups increases. Although only 4.8% of white populations reside within the top 10% of deprived EDs, 34.2% of Asians, and 23.0% of blacks live in these areas.

Cumulative proportions of populations in different deprivation categories were compared to estimated noise exposures, and Kolmogorov-Smirnov (KS) statistics were calculated to assess the magnitude of any disparities in exposure between these groups. These statistics showed no statistically significant disparities for the road-only noise map data, either at day or night time levels. Furthermore, no significant differences in exposure were apparent between the deprivation groups for daytime noise from the combined source map. However,

some discrepancies were evident in estimated exposure to night time noise from the combined sources. Table 6 shows median estimated exposure levels for night noise from rail/road and airport sources, while Figure 6 depicts cumulative proportions of populations in different deprivation categories against estimated night time noise levels.

Table 5: Percentage of each ethnic group in each Carstairs deprivation index quartile. Top decile also included

	1 st quartile	2 nd quartile	3 rd quartile	4 th quartile	10 th decile
Ethnicity:					
White	30.2	27.5	26.0	16.2	4.8
All Asian	8.6	10.7	16.7	64.0	34.2
Bangladeshi	1.9	2.7	7.5	87.8	55.3
Indian	17.2	19.6	22.3	40.9	17.0
Pakistani	2.7	5.3	13.8	78.3	44.1
Black	7.2	15.4	25.8	51.7	23.0

Table 6: Median estimated night time noise (decibels) from combined road/rail/airport emissions for Carstairs index deprivation cohorts

Cohort	1 st quartile	2 nd quartile	3 rd quartile	4 th quartile	10 th decile	City Average
	41.25	42.1	41.8	42.5	42.7	41.83

Table 7 shows the KS statistics for each cumulative frequency exposure curve in Figure 6. A comparison of the exposure levels in Table 6 with the corresponding KS statistics for each cumulative frequency curve in Table 7 shows that, at night, the 25% least deprived (most affluent) areas experience estimated noise levels that are lower than those in the most deprived 10% of enumeration districts at a p=0.1 level. However Table 6 shows that the lowest estimated noise levels are found in third quartile EDs, and the second and fourth Carstairs quartiles fair no worse than the city average, being statistically indiscernible from the other two groups. These observations suggest that there are some disparities for the most deprived EDs, but provide no clear evidence of an overall trend in the relationship between deprivation and night time noise levels.

Figure 6: Cumulative probability distributions for specified deprivation groups and modelled daytime noise emissions from combined road/rail/ airport sources

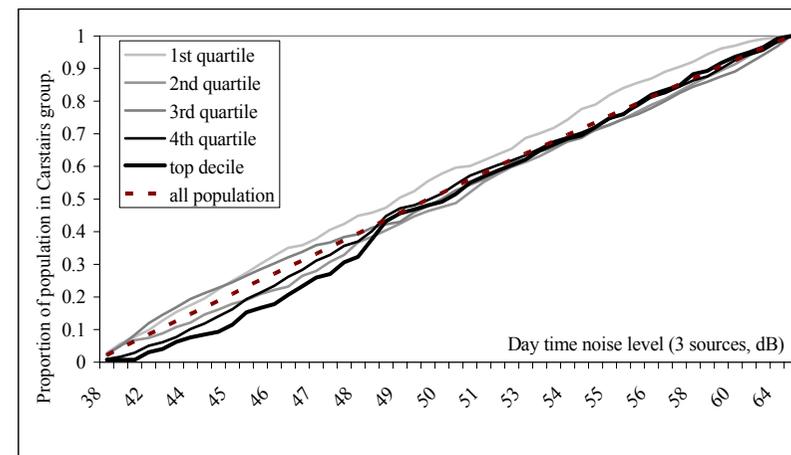


Table 7: Kolmogorov-Smirnov statistics for two-sample tests comparing cumulative probability distributions for night time noise exposure between deprivation groups.

	2 nd quartile	3 rd quartile	4 th quartile	10 th decile	City average
1 st quartile	0.0920	0.1052	0.1011	0.1664	0.0706
2 nd quartile		0.0783	0.0439	0.1003	0.0320
3 rd quartile			0.1186	0.1583	0.0575
4 th quartile				0.0745	0.0635
10 th decile					0.1235
Critical values:	p=.1 0.1513	p=.05 0.1923	p=.01 0.2305		

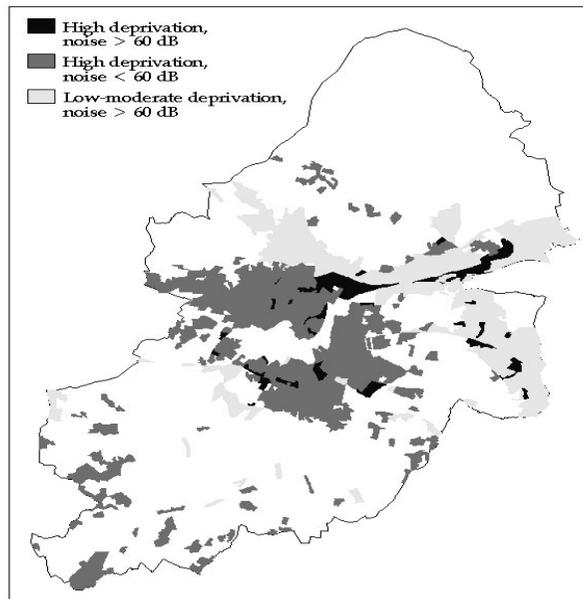
Note: Values exceeding the critical p=0.1 threshold are highlighted in bold.

To investigate the association between deprivation and noise exposure further, Figure 7 was produced which maps the top (most deprived) Carstairs quartile EDs with the noise data. For cartographic purposes, sixty dB(A) was again

chosen as threshold to differentiate lower and higher noise areas. The most deprived areas with high noise levels are shaded in the darkest tones. Deprived areas with noise levels below 60 dB(A) are presented in lighter tones.

Figure 7 shows many EDs with high levels of deprivation outside the city centre. Most of these do not appear to experience particularly high noise exposure, however. Indeed, as was found for different ethnic groups, the map suggests that levels of noise pollution are quite variable between high deprivation areas. Moreover, there are sizeable areas of land near the M6 motorway and city airport that do not have significantly deprived populations according to the Carstairs index, but do experience high noise levels. It hence it seems likely that, in the absence of the motorway and the airport, inner city exposures would predominate and the deprivation related disparities in noise exposure would be much greater than those observed here.

Figure 7: Location of deprived neighbourhoods (as noted by Carstairs score) and high noise areas. Figure key denotes noise level and which quartile or decile group a shaded area falls into



5. Discussion

Little previous research has addressed the question of the differential impact of noise pollution upon the diverse communities residing in urban areas. Using a case study of the city of Birmingham England, this study has sought to go some way to rectify this deficiency by assessing the distribution of exposure to noise from road traffic, rail, and aircraft sources amongst a diverse urban population.

Our findings suggest illustrate the considerable diversity in both the sources and magnitude of noise exposure in Birmingham. For example, we found that spatial patterns of A-weighted environmental noise from road, rail, and aircraft sources ranged from under 20 to over 80 decibels in the study area. Whilst, our results suggest that, in Birmingham at least, that there are not strong disparities in noise exposure associated with the population characteristics of age, ethnicity, and deprivation, some inequalities in exposure were apparent. We found that black ethnic groups tended to live in neighbourhoods with higher than average exposure to noise, particularly that generated during the daytime. Conversely, Indian and Pakistani communities appear to experience relatively low noise levels. We also found some inequalities in noise exposure associated with deprivation. In particular, estimated exposure to night time noise from the combined sources was significantly elevated amongst the populations of the most deprived EDs.

A strong association does exist between deprivation and ethnicity, making it difficult to discern the independent effects of the two factors. Similarly, there are many deprived areas without especially high noise levels, and many non-deprived areas with apparently high noise problems. To some communities, the benefits of living near modern transport links can compensate for high noise pollution. Indeed, we found evidence of comparatively affluent populations receiving high levels of aircraft and motorway noise. Amongst these groups, the improved mobility offered by these facilities may outweigh any disamenity associated with higher noise exposures. However the fact that some ethnic groups and more deprived communities appear to be exposed to higher noise levels than the rest of the population is a cause for concern.

There are some caveats to note regarding the data underlying our analysis. We used a detailed and rigorous methodology to produce maps of geographical variations in noise exposure across Birmingham. However our estimates are based on modelled rather than measured noise levels. They refer to values averaged over the entire day or night period, and hence give no indication of areas where noise may be especially elevated for relatively brief periods. Such sporadic but loud noise may be perceived as more annoying than constant low level emissions (NPL 1998). We were also unable to examine individual

exposures to noise. Such exposures can be highly dependent on lifestyle factors such as occupation, or amount of time spent outdoors. Furthermore, whilst indoor and outdoor noise levels may be partially associated, some residents may receive differential indoor and outdoor exposures due to the presence of significant indoor sources and the standard of noise insulation features in residential buildings.

Our analysis assumed that noise levels across the place of residence of populations was the sole contributor to the dose they received. This is, of course, a simplification as individual daily commuting patterns may mean that work, recreational, and domestic activities take place in different areas. Hence, the daytime and night time populations of central Birmingham may be rather different. Although we were able to differentiate between day and night time noise levels, data on individual activity patterns was not available at a high enough spatial resolution to allow us to assess how the population composition changed during these periods. Furthermore inequities in the housing market leading to differential residential environmental exposures amongst population groups are arguably the most important consideration from an environmental equity perspective. Nevertheless, an assessment of equity based upon more detailed day and night time exposures would be an innovation in the environmental equity literature and a worthy future extension to this analysis.

Unfortunately, although it the most recent information source available, it is some time since 1991 Census was undertaken. It may be that the effects of migration, coupled with an ageing population cohort, mean that the geographical distribution of some groups for the period for which the noise modelling was undertaken will not match that at the time of the census. However there is no reason to believe that these characteristics have changed strongly over the relatively short between the Census being undertaken and the period for which the noise estimates were made.

The population groups we considered were chosen to represent those containing particularly vulnerable individuals. Of course, individual and cultural factors, as well as influencing noise exposures, may also affect noise tolerance. To assess disturbance, it is ultimately necessary to survey residents in areas with apparently elevated exposure to determine the perceived disturbance from ambient noise levels. This perspective has been formally echoed in a recent review commissioned by the DETR (NPL 1998), that discusses inconsistencies and controversy with regard to research on noise nuisance levels and the setting of public guidelines (NPL 1998). The report cites the work of Fidell *et al.*, (1991), who derived a dose-effect relationship between noise levels and nuisance response. The research highlighted considerable disparities in individual tolerances to exposure to loud noise; whilst only 50% of the studied

population were 'highly annoyed' by levels above 80 dB, almost all reported noise levels above 90 dB to be highly annoying. Similar relationships have been derived for specific types of effect, such as sleep and activity disruption (Miedema and Vos, 1998). However, whilst these person-specific findings can be helpful in identifying threshold values for particular effects from specific sources, they less useful for the definition broad-based standards from all noise sources (NPL, 1998).

It was not our aim to develop a policy framework of remediation measures of environmental inequities. However it is useful to consider the policy implications of our findings. The NPL report did not issue specific guidelines on exceedence thresholds. Instead it called for work to develop an agreed method to consider multiple source noises, cumulative noise exposure, and other risk factors or modifiers in order to assess overall health impacts. The report notes that this is not a simple problem but a solution is required that will provide a framework for the practitioner or decision maker to consistently and effectively assess the impact of noise, and may be used to inform effective noise control decisions. We would argue that one aspect of this framework should be the possible disparate effects of any mitigation measures on the different segments of the community, as distinguished by racial or socio-economic character.

As noted previously, vehicle traffic (especially the M6 motorway) and aircraft noise, are the main sources of differentials in population noise exposure in Birmingham. Ongoing technical improvements in the aviation industry may help to considerably reduce noise from the airport in the future. Similar advances should be possible with regard to both automobile design and road surface construction. However, increasing levels of car ownership and transport of freight by road can easily act to erode gains made from the introduction of technical innovations. Hence we suggest that, at a local scale at least, any policies to redress inequities in exposure to noise pollution should place a particular emphasis on the mechanisms driving changes in land use patterns, urbanisation, and the development of transportation corridors.

From a policy standpoint, consideration also needs to be made of the social factors that have led to the disparities in noise exposure observed here. Recent research elsewhere has suggested that the process may due linked to lower housing costs in less environmentally desirable areas (Oakes *et al.*, 1996). However, other findings propose that disproportionate siting of pollution sources matters far more than post-siting minority move-in (Pastor *et al.*, 2001). At the heart of this, factors such as economic restructuring across cities undoubtedly hold important social consequences for immigrant and impoverished populations. Such people, induced to migrate by changing economic

circumstances, find growing ghettoisation, isolation, cultural antipathies, and environmental degradation in their new settings (Laws, 1997).

In Birmingham the situation is complex, and the present day geography of ethnicity and poverty within the city is a result of the interplay between personal preferences and external forces operating in the public and private housing markets. Undoubtedly, discriminatory housing practices have been important. (Henderson and Karn, 1987). As a result of forces in the housing arena, there has been a distinct pattern of the redistribution of more vulnerable populations in Birmingham in the years leading up to this study. In particular, there has been a picture of white movement from the middle to outer rings of the city, West Indian movement from the middle to inner rings, and Asian movement within the middle ring. These trends, coupled with the fact that many ethnic families in Birmingham live in much higher levels of poverty than their white counterparts (Rex, 1979), have contributed to the distributions of exposure observed here. It will be a challenge for legislators to address many of these fundamental issues.

The aim of this paper was to investigate environmental equity the distribution of exposure to environmental noise in city of Birmingham, England. We were unable to detect any differences in exposure between population age groups, although we did find some evidence of disparities associated with ethnicity. In particular, we observed that black populations appeared to experience the highest noise levels of all ethnic groups in Birmingham. With respect to socio-economic deprivation, we found that the highest estimated noise levels were coincident with the most deprived neighbourhoods. Our results suggest that, whilst the disparities are not large, a problem of multiple inequities in noise exposure in Birmingham does exist, and we propose that policy makers need to give careful thought to the development of innovative solutions to address them.

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