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Environmental justice and health: the implications of the socio-spatial distribution of multiple environmental deprivation for health inequalities in the United Kingdom

Jamie R Pearce*, Elizabeth A. Richardson, Richard J. Mitchell and Niamh K Shortt

*Corresponding Author

Prof. Jamie Pearce
School of Geosciences
University of Edinburgh
Drummond Street
Edinburgh, UK
EH8 9XP

Tel: 0131 650 2294

Email: Jamie.Pearce@ed.ac.uk

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Abstract

Understanding persistent and increasing spatial inequalities in health continues to be an important field of academic enquiry for geographers, epidemiologists and public health researchers. Delivering robust explanations for the growing spatial divide in health offers potential for improving health outcomes across the social spectrum, but particularly among disadvantaged groups. One potential driver for the increasing geographical differences in health is the disparity in exposure to key characteristics of the physical environment that are either health promoting or health damaging. Whilst the framework of 'environmental justice' has long been used to consider whether disadvantaged groups bear a disproportionate burden of environmental disamenities perhaps surprisingly, the research fields of environmental justice and health inequalities have remained largely separate realms. In this paper we examine the confluence of environmental characteristics that potentially function as key mechanisms to account for the socioeconomic gradient in health outcomes in the UK. We developed the Multiple Environmental Deprivation Index (MEDIX), an area-based measure that represented the multiple dimensions of health-related environmental disamenities for census wards across the UK. By comparing the index to an area measure of income deprivation, we found that at the national-level multiple environmental deprivation increased as the degree of income deprivation rose. Using mortality records we also found that MEDIX had an effect on health that remained after taking into account the age, sex and socioeconomic profile of each area. Area-level health progressively worsened as the multiple environmental deprivation

increased. However, this effect was most pronounced in the least income deprived areas. Our findings emphasise the importance of the physical environment in shaping health, and the need to consider the social and political processes that lead to income deprived populations bearing a disproportionate burden of multiple environmental deprivation. Future research should simultaneously consider the ‘triple jeopardy’ of social, health and environmental inequalities.

Key words: Environmental justice; health inequalities; environmental deprivation; GIS; binomial regression; United Kingdom.

Background

Recent research in numerous countries has firmly established steadfast geographical inequalities in health status across sub-national geographical areas (Davey Smith et al., 2002 ; Pearce et al., 2008a ; Singh & Siahpush, 2006). The evidence demonstrates that health outcomes tend to be substantially poorer in areas characterised by high levels of social and economic disadvantage, relative to areas characterised by social and economic advantage. This socio-spatial distribution is apparent for most measures of mortality, morbidity and for many health-related behaviours such as smoking (Curtis, 2004). Further, spatial differences in health have tended to rise in many countries over the past decades. In the UK for example, health has improved at a substantially faster pace in the most advantaged areas of the country compared to the least advantaged places since the early 1980s (Shaw et al., 2005). Similar findings have been noted in other countries including the United States, Australia and New Zealand (Hayes et al., 2002 ; Pearce & Dorling, 2006 ; Singh & Siahpush, 2006). Many commentators regard such health inequalities as unfair and a

matter for policy action, which suggests that inequalities may be ameliorable and ultimately avoidable (Woodward & Kawachi, 2000). However, even those critics who do not regard the inequalities as unjust do tend to recognise that spillover effects such as crime, violence, spread of infectious disease, and concentrations of alcohol and drug use, affect all of society (Woodward & Kawachi, 2000). Whilst most governments have noted their aspiration to reduce health inequalities, it has been argued that policy approaches to narrow this health divide have lacked potency (Shaw et al., 2005).

The recent report from the World Health Organisation (*Closing the Gap in a Generation: Health Equity Through Action on the Social Determinants of Health*) recognises that the social distribution in health status is underlain by the unequal distribution of resources and opportunities that are fundamental to a healthful life, such as wealth, education, employment, access to health care and the environment in which people live (WHO Commission on Social Determinants of Health, 2008). This notion is important, because it recognises that unequal access to good quality physical environments is likely to partially account for social disparities in health status. In simple terms, low income populations are at greater risk of ill health, and a proportion of that inflated risk may arise because being poorer brings greater exposure to an adverse physical environment (Lee, 2002). Further, there is also a suggestion that those who are already faced with socio-economic adversity may also be more susceptible to the health effects of an unfavourable physical environment (O'Neill et al., 2003).

The framework of 'environmental justice' has often been used to investigate disparities in exposure to key aspects of the physical environment that are either beneficial or harmful to health. Environment justice can be defined as the "equal access to a clean environment and equal protection of issues of environmental harm irrespective of race, income, class or any other differentiating feature of socioeconomic status" (Cutter, 1995). Many researchers have fixed their attention on considering whether there are disparities in exposure to environmental or occupational 'goods' and 'bads' between socially contrasting communities (Lee, 2002). The distinction has been made between 'environmental inequality' and 'environmental justice'. Whether an environmental inequality represents an environmental injustice will depend upon whether the processes that created the distribution were inequitable (Richardson et al., 2010b ; Schlosberg, 2007 ; Walker et al., 2005).

Whilst in recent years there has been an exponential increase in the international literature considering issues of distributional justice of environmental characteristics, five key criticisms can be made. First, most studies have considered only a single environmental attribute (e.g. ambient particulate pollution) with few empirical investigations considering a *range* of environmental features. This issue is pertinent because a variety of environmental factors are likely to simultaneously (and potentially multiplicatively) shape health outcomes. As Evans and Kantrowitz (2002) argue:

"We suspect that the potential of environmental exposure to account for the link between SES [socioeconomic status] and health derives from the multiple exposures to a plethora of suboptimal environmental

conditions. That is, we would argue that a particularly important and salient aspect of reduced income is exposure to a confluence of multiple, suboptimal environmental conditions”

Evans and Kantrowitz (2002, p304)

Hence it is possible that residents of socially disadvantaged areas are exposed to a wide array of low quality environmental features. It is likely that investigations into the multiple dimensions of environmental disadvantage will provide fertile insights into the ubiquitous socioeconomic gradient in health. Second, there is also a lack of research in the international literature that has explicitly investigated the implications of differential socioeconomic exposure to environmental characteristics for inequalities in health status. As Brulle and Pellow (2006) note, studies of environmental justice and health inequalities “remain largely separate realms” (p104). Third, whilst many researchers have considered the distributional fairness of environmental toxins in North America, most aspects of the environmental justice research agenda are less well developed in the UK. Fourth, with few exceptions (e.g. Mitchell & Dorling, 2003 ; Pearce & Kingham, 2008), most previous work has been restricted to a confined locality such as a single urban area and few studies have considered environmental justice issues at a national scale. Finally, most environment justice research has focused exclusively on the presence or absence of pathogenic components of the environment. The presence or absence of salutogenic aspects (i.e. those that are beneficial) has received scant attention. These omissions are an important impediment to the field of research and have prevented the establishment of a knowledge base on which public policy decisions might be grounded.

This paper responds to recent calls in the literature for research which considers the social dimensions of multiple environmental risk factors (Evans & Kantrowitz, 2002), that integrates this work into a health inequalities research framework (Brulle & Pellow, 2006), and that considers the potential for the environment to promote good health, as well as harm health. We extend previous environmental justice analyses that have tended to consider a single environmental feature, by assessing the socio-spatial distribution of *multiple* dimensions of the physical environment. In order to gauge whether the capture of multiple components of the physical environment leads to conclusions that are consistent with the previous environmental justice work in the UK, we firstly evaluate the socio-spatial distribution of a range of environmental characteristics which have significance for health and well being in a UK context. Second, in order to capture a variety of the important health-related dimensions of environmental disamenities we develop a novel measure of multiple environmental deprivation for small areas (n = 10,654) across the country. We then utilise the index to evaluate the social distribution of multiple environmental deprivation across the UK. Finally, we assess the implications of exposure to multiple environmental deprivation for health and health inequalities. Before outlining the methods used to address the research aims, an overview of the health-related environmental justice literature is provided.

Environmental disparities

The earliest studies of environmental justice originated in the United States, and principally focused upon the positioning of hazardous waste and noxious facilities that were predominantly located in the vicinity of ethnic minority communities (Anand, 2004 ; Bullard, 1983 ; United Church of Christ, 1987 ; US General

Accounting Office, 1983). More recently the focus of environmental justice research has broadened beyond 'environmental racism' to examine settings outside of the United States, a wider range of vulnerable populations, and to consider a more extensive range of environmental concerns. For instance, whilst continuing to recognise the importance of race within an environmental justice framework, an increasing number of studies have also considered the environmental justice concerns of other vulnerable social and demographic groups such as low income, socially deprived, elderly, or young populations. The expansion of the scope of environmental justice concerns into additional environmental realms is producing a burgeoning literature considering the social and economic dimensions of environmental issues including climate change (Woodward et al., 2000), water quality (Hales et al., 2003), heat waves (Harlan et al., 2006), and environmental disasters such as Hurricane Katrina (Atkins & Moy, 2005).

Within an environmental justice framework, the element of the physical environment that has probably received the most attention is air pollution. Research in North America has overwhelmingly demonstrated that low income and predominantly ethnic minority neighbourhoods are exposed to higher levels of a range of air pollutants within many urban areas (Ito & Thurston, 1996 ; Jerrett et al., 2001 ; Korc, 1996 ; Perlin et al., 2001). A recent review of the environmental disparities literature covering a wide range of environmental concerns concluded that "the poor and especially the non-white poor bear a disproportionate burden of exposure to suboptimal, unhealthy environmental conditions in the United States" (Evans & Kantrowitz, 2002, p 323). Although studies outside of North America are less common, the available evidence is generally consistent with these findings. For

example, research in New Zealand found that particulate pollution levels tended to be higher in more socially deprived and low income neighbourhoods (although not areas with a high ethnic minority population) across the country (Kingham et al., 2007 ; Pearce & Kingham, 2008 ; Pearce et al., 2006). Similar findings have been noted in the United Kingdom where a study of exposure to nitrogen dioxide among different population groups established that pollution was most concentrated in the poorest communities and where the young tended to live (Mitchell & Dorling, 2003). Similarly, Brainard et al. (2002) found that in the city of Birmingham exposure to carbon monoxide and nitrogen dioxide was strongly related to indicators of ethnicity and poverty.

Comparable findings have been noted for other environmental characteristics that are potentially detrimental to health. There is mounting evidence that socially deprived and ethnic minority communities often experience disproportionate exposure to hazardous substance sites (Higgs & Langford, 2009 ; Salmond et al., 1999 ; Walker et al., 2005), industrial accidents (Elliott et al., 2004), noise (Sobotta, 2007), the risks and direct effects of flooding (Fielding, 2007 ; Johnson et al., 2007), heat waves (Harlan et al., 2006 ; Klinenberg, 2002) and other environmental disasters (Bullard, 2007). For instance, the uneven impacts in the immediate aftermath of Hurricane Katrina, as well as the subsequent institutional responses during the post-disaster recovery period, are well documented (Pastor et al., 2006).

While research into the uneven socio-spatial distribution of environmental pathogens has a long history, in recent years health geographers and public health researchers have become increasingly interested in the potentially therapeutic, or salutogenic,

properties of places, and the latent health enhancing impacts of key facets of natural environments (Williams, 2007). Researchers with interests in inequalities in health status and other indicators of well-being have examined whether there are consistent disparities in access to health promoting environments. For instance, it has been postulated that physical access to green or open spaces may enhance health through encouraging physical activity (Humpel et al., 2002). Potentially, there are further health benefits of physical and visual access to greenspaces through psychosocial mechanisms that may lower levels of stress and blood pressure (Pretty et al., 2005), as well as acting to hasten recovery from surgical procedures (Ulrich, 1984). Socially disadvantaged communities often have poorer availability of neighbourhood greenspaces (Combera et al., 2008 ; Estabrooks et al., 2003), although this is not always the case (Barbosa et al., 2007 ; Pearce et al., 2007 ; Pearce et al., 2008b ; Timperio et al., 2007). Similarly, the social distribution of the local availability of other environmental ‘goods’ including beaches (Pearce et al., 2007) and the ecology of urban environments such as urban forestry (Perkins et al., 2004 ; Heynen et al., 2006) have also received consideration.

Environmental Justice and Health

Whilst there is evidence for social and geographical disparities in exposure to various environmental features which potentially harm or promote health and well-being, few researchers have directly considered the implications of unequal environmental exposure for inequalities in health status. In other words, it is widely assumed but largely untested that the disproportionate burden of poorer quality environments among socially disadvantaged groups portends adverse health effects. Exposure to environmental ‘goods’ and ‘bads’ may have dissimilar effects on communities

differentiated in terms of their socioeconomic profile. Socioeconomic disadvantage could act to compound the influence of environmental deprivation on health status.

The available evidence suggests that the socio-spatial distribution of health-related environmental characteristics can be an important driver of geographical inequalities in health status. Again, most work in this area has focused on the implications of differential exposure among assorted social and ethnic groups to various types of air pollution. For instance, research in Hamilton, Canada found that socioeconomic status modified the relationship between air pollution exposure and mortality (Jerrett et al., 2004). The greatest health effects from exposure to air pollution occurred in lower socioeconomic areas. In the same city, a separate study noted that differences in exposure to air pollution accounted for some of the socioeconomic differences in circulatory disease (cardiovascular and stroke) mortality (Finkelstein et al., 2005). These findings are consistent with studies in other countries such as Norway (Naess et al., 2007), Brazil (Martins et al., 2004) and the United States (Zeka et al., 2006 ; Krewski et al., 2003) which have also established that socioeconomic status modifies the relationship between air pollution and various respiratory-related health outcomes. However, other researchers, including some in these same countries, have often drawn different conclusions. A study of three large Latin American cities found that educational level did not modify the relationship between particulate air pollution exposure and mortality (O'Neill et al., 2008). Findings in France (Laurent et al., 2008 ; Filleul et al., 2005) and the United States (Schwartz, 2000) also established that socioeconomic status did not affect the association between pollution exposure and health. More surprisingly, a study in China found that elderly residents living in areas with a higher gross domestic product (GDP) were more susceptible to the effects of

air pollution than those living in low GDP areas (Sun & Gu, 2008). A possible explanation for the discrepancy in these findings is the methodological differences between studies, particularly the geographical scale at which socioeconomic characteristics are captured. Finer measures of socioeconomic status (e.g. individual level or small geographical areas) have tended to find that socioeconomic characteristics modify the relationship between air pollution and mortality (Laurent et al., 2007). Further, comparisons across studies and between countries are problematic due to the different types of air pollution studied, as well as the diversity of methods used to capture pollution exposure (Bowen, 2002).

Beyond research into air pollution there are surprisingly few studies that have considered the influence of the biophysical environment in modifying inequalities in health status. There is some evidence that the ‘natural environment’ or ‘greenspace’ may have an effect. Mitchell and Popham (2008) calculated the proportion greenspace for small areas across the UK and considered whether the well established relationship between income deprivation and mortality (all-cause and cause-specific) varied across areas stratified by the measure of greenspace after adjustment for potential confounders. They found that income-related inequalities in health status were less marked among populations with greater exposure to greenspace. The findings suggest that, in the UK context at least, enhancements to the physical environment may reduce health inequalities. However, other than this work on greenspace, surprisingly little attention has been given to investigating whether aspects of the physical environment that are considered to be beneficial for health (e.g. sunlight) influence socioeconomic inequalities in health status.

Methods

In this research we select a set of health-related environmental measures to evaluate the socio-spatial distribution of environmental factors. The environmental factors are used to develop a UK-wide area-level measure of multiple environmental deprivation. Our measure of multiple environmental deprivation is analogous to the many area-level indices of social deprivation that have been developed such as the Carstairs, Townsend, and Jarman indices, and the national Indices of Multiple Deprivation. However, instead of capturing area-level measures of the social environment (e.g. poverty, unemployment, car ownership, educational attainment etc), our index captures five key dimensions of the physical environment that have proven consequences for health and well being. We then consider the implications of these environmental factors for health inequalities in the UK.

Identifying environmental characteristics

The first stage was to identify the characteristics of the physical environment to include in our analyses. Full details of the decisions taken to distinguish the key health-related features of the physical environment including the reasoning for including or excluding particular environmental variables are provided elsewhere (Richardson et al., 2010a ; Richardson et al., 2009). A brief summary is provided here. We restricted our definition of the physical environment to include external physical, chemical and biological factors but to exclude social and cultural factors. We were concerned with aspects of the physical environment that had health salience and hence it was important to identify factors with a proven association with health outcomes in a UK context. A broad scoping review of peer-reviewed and grey literature was conducted to identify a ‘long list’ of environmental factors with the

potential for a health impact. We then systematically searched publication databases for empirical evidence of the health impacts of these factors. Environmental factors to be included were selected on the basis of four criteria: (i) the factor had been plausibly associated with health; (ii) the association with health had been demonstrated in the literature as robust; (iii) at least 10% of the UK population were exposed; and (iv) comprehensive, spatially contiguous and contemporary data were available for the entire UK. Spatial datasets were sought to enable assessment of population exposure to factors when exceedance of the 10% threshold was not apparent from the literature. The pathogenic factors meeting our criteria were outdoor ambient air pollutants, exposure to certain kinds of industrial facilities and cold climate. The salutogenic factors meeting our criteria were exposure to ultraviolet (UV) radiation and access to greenspace (Table 1).

Multiple Environmental Deprivation Index (MEDIX)

For each of the eight environmental variables the most suitable datasets were obtained and processed (see Table 1). All datasets were rendered to the same geographical scale; Census Area Statistics (CAS) wards (2001) ($n = 10654$, mean population size 5518). Wards offer a balance between the requirement for a relatively small unit to reflect the fine spatial variation in both physical and socio-economic environment, and the need for units that were sufficiently large to permit robust analyses of any association between our measure of environment and health. Wards are also advantageous because many other social and economic data in the UK are reported at this spatial level.

[Table 1]

The ward-level measures of the environment were then used to develop a summary measure: the Multiple Environmental Deprivation Index (MEDIx). We rendered the wards into exposure quintiles for each environmental factor. For each pathogenic factor, wards in the highest exposure quintile were given a score of +1, and for each salutogenic factor the wards in the highest exposure quintile scored -1. Detrimental air pollution was defined as the upper quintile of any of the air pollutants (PM₁₀, NO₂, SO₂ or CO). Summing the scores within each ward gave a MEDIx score. The index thus reflects the number and the balance of environmental attributes in the ward recognised as being either a ‘threat’ or a ‘boost’ to health. MEDIx scores ranged from -2 to +3, with a score of +3 denoting the most environmentally deprived areas.

Mortality and population data

Individual-level mortality records (including age, sex, cause of death and area of residence at death) were obtained from the Office for National Statistics (ONS) for England and Wales, the General Register Office for Scotland (GROS) and the Northern Ireland Statistics and Research Agency (NISRA). The data were matched to 2001 CAS wards. The records covered a five-year period centred on the 2001 census (1999 to 2003), except for in Scotland where pre-2001 georeferencing issues made the use of 2001 to 2005 data more appropriate. Counts of key causes of death in the UK (ONS, 2002) were generated by age-sex group and CAS ward. We analysed mortality from all causes excluding external causes (International Classification of Disease: ICD-9 codes <800, ICD-10 codes A00–R99).

Ward-level age-group and sex-specific population estimates were obtained for 2001 from ONS, NISRA and GROS, and were updated to 2003 for Scottish wards using

annual small area population estimates from GROS. This provided a total study population of 58.8 million, with 2.9 million deaths (excluding those from external causes) across the 5 year period. Ward-level socioeconomic deprivation was measured using the Income Deprivation domains from the Indices of Multiple Deprivation calculated separately for the four countries of the UK (NISRA, 2005 ; Noble et al., 2004 ; Scottish Executive, 2004 ; Welsh Assembly Government, 2005). This measure provided the proportion of the population of an area experiencing income deprivation (i.e., the percentage of the population that are receiving financial support from the government because they have a low income and additionally are either: unemployed and looking for work; not available for full-time work; 60 or over; or responsible for at least one child). Separate calculation of the domains for the four countries has resulted in some differences: they represent 2001 and 2002 in England and Scotland, 2002 in Wales and 2003 in Northern Ireland; and they include asylum seekers receiving financial support in England and Wales, but not in Scotland or Northern Ireland. As the temporal difference is marginal, and the inclusion/exclusion of asylum seekers reflects the relative numerical importance of these populations in each region, we considered it feasible to combine the domains into a UK-wide income deprivation measure.

Analyses

In order to examine the socio-spatial distribution of the health-related features of the physical environment, we first explored the associations between the individual environmental variables and the area-level measure of income deprivation. For each of the eight derived environmental measures, the mean value (e.g. annual mean concentration of carbon monoxide) was calculated for groups of wards divided into

quintiles according to their level of income deprivation. To allow us to evaluate whether concurrently examining multiple dimensions of the physical environment furthered our interpretation of environmental justice in the UK we then examined the relationship between the MEDIX scores and income deprivation. The mean income deprivation score for each MEDIX group was calculated. In addition, the numbers of wards and the total population in each quintile of income deprivation was determined for all of the MEDIX groups.

To enable us to directly compare the disparity in income deprivation across the individual environmental characteristics and between the MEDIX groups, we then calculated a measure akin to the Slope Index of Inequality (SII) for each of these variables. The SII is the slope of the regression line (β coefficient) that runs from the most environmentally deprived ward (e.g. most polluted or highest level of multiple environmental deprivation) to least environmentally deprived ward, weighted by population. Therefore, the wards are sorted by level of environmental deprivation and a cumulative proportion of the total population is assigned to each group to provide a relative rank. The SII is a well established metric in the health inequalities literature that provides a consistent measure of inequality across a population and it is comparable across different environmental domains (see Low and Low (2004) for more details). Because the MEDIX score was on a six-value ordinal scale (rather than continuous), the SII for the MEDIX score was calculated using the cumulative proportion of the total population in each of the six categories with the mean percentage income deprived population (based on the wards in each MEDIX category) as the dependent variable.

In the final stage of the analyses, we investigated the implications of area-level multiple environmental deprivation for inequalities in health status in the UK. In order to ascertain the variation in health across areas with different levels of environmental deprivation, standardised mortality ratios (SMRs) were calculated for each MEDIx score. SMRs were firstly standardised for the age and sex structure of the populations and then further adjusted for social deprivation using income deprivation quintiles. It was also important to investigate the effect of MEDIx on health within wards sharing the same level of income deprivation as this would ascertain whether MEDIx exerted a disproportionate effect in more income deprived areas. Therefore, we used negative binomial regression models (using Stata/IC v10.0) to investigate the relationship between MEDIx and risk of mortality. Binomial regression is suitable when the outcome is a count (e.g. number of deaths) and the data are over dispersed (over dispersion of the mortality data made Poisson models unsuitable). The age- and sex-specific population for each ward was set as the exposure variable. All models also took account of spatial clustering of the data using robust standard errors. In order to quantify the implications of multiple environmental deprivation for inequalities in health status, we ran a sequence of stratified models which examined the association between MEDIx and health *within* income deprivation quintiles. Therefore, this analysis contrasted populations in which the level of income deprivation was similar but for whom physical environmental deprivation varied. For each MEDIx score, Incidence Rate Ratios (IRRs) were calculated using wards with a MEDIx score of zero as the reference category.

Results

Environmental disparities and social deprivation

In the first stage of the analysis, we investigated whether there was evidence of social disparities in exposure to the eight environmental variables across wards divided into quintiles according to the area-level measure of income deprivation (Figure 1). For five of the environmental measures there was clear evidence of inequalities in environmental deprivation that disadvantaged the more income deprived wards. Concentrations of sulphur dioxide and carbon monoxide, and the proportion of the population in proximity to industry tended to increase across the quintiles of income deprivation. The percentage of greenspace and the UVB index (for which higher values are beneficial for health) reduced in an approximately linear fashion between quintile 1 (low social deprivation) and quintile 5 (high social deprivation). Further, for each of these environmental measures the gradient was reasonably strong. For example, the ratio of values in quintile five compared to quintile one was 1.4 for sulphur dioxide and 2.1 for the proportion of the population in proximity to industry, whereas for the percentage of greenspace the ratio value was 0.6. However, for particulate matter, nitrogen dioxide, and average temperature there was little evidence of a social gradient across the deprivation quintiles.

[Figure 1]

Multiple Environmental Deprivation

Having considered the social distribution of the eight environmental variables, we then used these variables to create our composite measure of multiple environmental deprivation. The index varied from -2 (best environments) to +3 (worst environment).

There were distinct geographical variations in the MEDIX scores across the UK with a broad north-south gradient (Figure 2). Levels of physical environmental deprivation generally rose with increased latitude. This observation is likely to reflect the inclusion of cold climate as a pathogenic component of environment and higher UV as a salutogen; both factors are strongly related to latitude. Further, greater levels of physical environmental deprivation were located in urban and industrial areas of the UK. A band of best quality physical environment (in terms of health) across southern England is also strongly driven by climate and UV.

[Figure 2]

An examination of the mean income deprivation scores for each MEDIX value showed that income deprivation increased in an approximately linear pattern from the best to worst physical environments (Figure 3). The proportion of the population who were income deprived increased sharply from 6.8 percent for wards with a MEDIX score of -2 (best environment) to 17.4 percent (MEDIX score =+2) and then decreased slightly to 14.7 percent in wards with the worst physical environment (MEDIX score +3). Given the association between income deprivation and MEDIX, it was unsurprising that a higher proportion and a larger number of residents of more income deprived areas also inhabit more environmentally deprived wards (Figure 4). We also found significant differences across income deprivation quintiles (Figure 5). For example, 82 percent of the population living in the most income deprived quintile of wards had a MEDIX score of between +1 and +3 (the most environmentally deprived wards). Similarly, none of the wards in the highest quintile of income deprivation had a MEDIX score of -2 (least environmentally deprived wards). Conversely, in the

quintile of wards with the lowest proportion of income deprived residents only 34 percent of the population live in the most environmentally deprived wards (MEDIX score -1 and -2). It should be noted however that the largest number of wards (and hence larger populations) were assigned a MEDIX score of between -2 and +1 and the number of wards with the two extreme scores (-3 and +2) was relatively small. Nonetheless, these findings provide evidence of a social gradient in multiple environmental deprivation that is disadvantageous to more socially deprived groups.

[Figures 3, 4 and 5]

The Slope Index of Inequality (SII) values for each environmental characteristic and the MEDIX scores are shown in Table 2. The SII can be interpreted as the absolute gap in income deprivation across the wards stratified by the various environmental characteristics. With the exception of average temperature, the SII for each of the environmental characteristics was negative which suggests that in each case as the level of income deprivation reduced the environments improved. However, of the variables with a negative association with income deprivation, the SII ranged from -7002 (particulate matter) to -13614 (proximity to industry) which suggests that there were significant differences in the degree of inequality across the environmental characteristics. Only average temperature demonstrated a positive (pro-equity) relationship with income deprivation. However, this association was not statistically significant. The SII for the composite MEDIX score was higher than most of the separate environmental characteristics with the exception of the Carbon Monoxide and Greenspace variables. This finding suggests that in the UK, multiple

environmental deprivation is firmly patterned by income deprivation to the disadvantage of areas with a higher proportion of income deprived people.

[Table 2]

Multiple Environmental Deprivation Index and Health

In the final stage of the analyses we examined the variation in health across areas characterised by different degrees of multiple environmental deprivation. After adjustment for variations in the age and sex distribution of the population, we found that health differed between groups of areas with the same MEDIx score (Figure 6). The all-cause mortality SMRs were lowest (i.e. the best health) in areas with the least environmental deprivation (MEDIx score -2, SMR=0.84). There was then an approximately linear worsening in health as environmental deprivation increased. The SMR for the most environmentally deprived areas (MEDIx score of +3) was 1.18, which suggests that there were 18 percent more deaths than expected (given the age- and sex-structure of these wards) over the study period in wards with the poorest physical environments compared to all other wards across the UK. Further, this relationship between MEDIx and health remained after additional adjustment for the level of social deprivation in an area. Therefore, these findings suggest that in the UK multiple environmental deprivation exerts an influence on health independently of the age, sex and socio-demographic profiles of areas.

[Figure 6]

In order to investigate the implications of multiple environmental deprivation for inequalities in health status, the final analyses used regression to consider whether the relationship between area-level social deprivation and health varied between areas stratified according to the MEDIx score (Figure 7). For each income deprivation quintile, the graph provides the all-cause mortality IRR for every MEDIx category relative to the reference group (MEDIx=0). In this analysis, the IRR is the ratio of the mortality incidence rate in each MEDIx category relative to MEDIx group zero (the reference category). The IRR expresses the effect of the exposure on the rate of mortality. Therefore, this figure indicates the size of the effect of each MEDIx category *within* each income deprivation quintile. Within each income deprivation quintile there was an approximately linear deterioration in health from the least to most environmentally deprived wards which suggests that multiple environmental deprivation exerts an influence on health regardless of the level of income deprivation. Further, with the exception of the most environmentally deprived wards, the size of the effect that multiple environmental deprivation exerts on health was reasonably consistent across the income deprivation quintiles. However, for wards with the highest levels of multiple environmental deprivation (MEDIx=+3) the size of the effect on health was significantly greater in the least income deprived quintile of wards. The IRR for wards with a MEDIx score of +3 ranged from 1.44 in income deprivation quintile 1 (low income deprivation) to 1.09 in income deprivation quintile 5. This finding suggests that high levels of multiple environmental deprivation have a greater influence on the health of less disadvantaged populations. However, it is important to be cautious in interpreting these findings as only a small number of wards were assigned a MEDIx score of -2 or +3.

[Figure 7]

Discussion

Inequalities in health between social groups and areas differentiated by measures of social deprivation are ubiquitous in most developed countries. Identifying the key mechanisms that underpin the uneven spatial distribution in health outcomes has emerged as an important domain of academic enquiry in human geography (Smyth, 2008). Research considering differential exposure to environmental features that potentially harm or benefit health and well being is one potential driver. Much of the international evidence points towards socially disadvantaged and ethnic minority populations bearing a disproportionate burden of the least auspicious environmental conditions. However, most previous studies have considered only a single environmental issue and ignored the complex array of environmental factors that may shape health outcomes. Hence there have been calls in the literature for environmental justice research to consider multiple exposures to harmful and beneficial environmental exposures among disadvantaged populations (Jerrett, 2009). Further, there is a paucity of studies that have directly tested whether multiple environmental risk factors help to account for the disparities in health status between different socioeconomic groups. Rather, with few exceptions, the literatures on environmental disparities and health inequalities have tended to operate autonomously. In this national-level study in the UK we address this research niche and simultaneously assess how multiple environmental risk factors combine to produce a cumulative burden that has potential repercussions for the social gradient in health.

The results of our study have shown clear evidence that in the UK the scale of environmental disamenities is contingent on the degree of income deprivation in the locality. Each of the eight area-level measures of the physical environment demonstrated a gradient across income deprivation groupings, with poorer physical environments in more income disadvantaged localities. Importantly, combining these variables to produce a summary measure of environmental deprivation across all of the environmental domains (Multiple Environmental Deprivation Index: MEDIx) showed a clear relationship with area-level income deprivation. Ward-level environmental deprivation rose as income deprivation increased which suggests that more income deprived wards tend to suffer from the double jeopardy of economic and environmental deprivation. In this respect our results are consistent with previous UK studies that have tended to find that poverty levels are positively associated with poorer quality physical environments (Brainard et al., 2002 ; Higgs & Langford, 2009 ; Mitchell & Dorling, 2003 ; Walker et al., 2005 ; Stevenson et al., 1998). Using a framework of distributional justice, the findings of this study reveal unambiguous evidence of multiple environmental injustice in the UK.

The explanations for why low income areas experience disproportionately high levels of multiple environmental deprivation are likely to be multifaceted. In the field of urban political ecology there is an emergent discussion on the social production of urban environments (including natural environments) that has sought to develop accounts for why some urban residents benefit from the geographical distribution of environmental amenities when many others do not (Heynen et al., 2006 ; Walker, 2009). Investigations within this framework have emphasised the role of past and present structural processes operating in a neoliberal setting that render low income

residents less able to influence the investment of public and private resources that are directed towards the environmental infrastructure. Similarly, Morello-Frosch (2002) draws attention to processes through which the political economy of different places act to mould the local environment and the distribution of people which ultimately gives rise to the observed environmental inequalities. These processes include historical patterns of industrial development, labour markets, suburbanisation and segregation, and economic restructuring. It is plausible that in the UK the lack of political empowerment and economic resources available hinders low income communities from resisting the development of polluting resources and influencing local investment in beneficial environmental assets. Indeed some researchers have extended these notions to imply 'deliberate strategic intent' in the siting of noxious facilities in socially deprived areas (Walker, 2009). The evidence from various localities in the United States suggests that the process of commodifying urban nature has acted to hamper the maintenance or enhancement of environmental integrity including pollution management and the investment in environmental goods such as greenspace and urban forestry in low income areas (Keil & Desfor, 2003 ; Perkins et al., 2004). As a key study in the Los Angeles basin demonstrated, vulnerable communities have been systematically selected for the positioning of noxious facilities (Pastor et al., 2001). It is worth noting that in the current study, the composite environmental measures include two climate-related variables (average temperature and UV radiation) that could be considered 'preordained' and hence exposure is less malleable to the structural processes that lead to the unequal social production of the environment. This observation suggests that an array of social processes may be operating to explain our findings, and that the importance of particular mechanisms may vary between the environmental measures.

The findings of this study also demonstrated that in the UK multiple environmental deprivation exerted an influence on health (measured using mortality data) that was independent of the age, sex and income deprivation structure of the population. We found that health progressively worsened as physical environmental deprivation increased. However, contrary to the North American evidence (Jerrett et al., 2004 ; Zeka et al., 2006 ; O'Neill et al., 2003) the physical environment did not exert a disproportionately detrimental effect on the health of the most income deprived groups. Rather, the size of the effect of multiple environmental deprivation was greatest among the least income deprived populations. This finding might suggest that, unlike the United States, in the UK environmental justice may not be an antecedent for health inequalities. It is well established that health-related resources such as housing, occupation, employment security, health care and education are unequally distributed across populations to the disadvantage of low income communities (Davey Smith & Krieger, 2008 ; Pearce & Dorling, 2009). Our findings could suggest that addressing the numerous and multifaceted social determinants of health, and the social processes that determine their unequal distribution will be more potent in addressing health inequalities in the UK than mitigating the unequal burden of multiple environmental deprivation. However, this interpretation should be treated with caution. In the UK few people reside in highly socially deprived areas that also have a low MEDIx score (low levels of multiple environmental deprivation). Therefore, given that this is an unusual combination, it is difficult to ascertain whether living in a 'high quality' physical environment (low MEDIx score) has a disproportionate beneficial effect on the health of the residents of socially disadvantaged places.

Our study has limitations that highlight some future research priorities. First, we recognise that there are other environmental characteristics that are important for health for which we were unable to obtain adequate ward-level data and hence have not been included in our index. It is also worth noting that there are additional environmental features that influence health but that do not relate to the biophysical environment such as housing quality and overcrowding. Second, it is feasible that there is confounding at the individual-level that has not been accounted for. Health-related behaviours such as smoking, alcohol consumption and physical activity each have distinct geographies, and it is plausible that behavioural factors explain or mediate the observed associations between multiple environmental deprivation and health. Future research could usefully evaluate these pathways. Third, we have assumed that residential location is an adequate proxy for environmental exposure when settings other than the residential neighbourhood such as schools or workplaces may be pertinent. Similar to most studies in the field of neighbourhoods and health research, in the absence of detailed longitudinal information we have relied on cross-sectional data. Our study cannot therefore ascertain causality, and consequently it is not possible to establish whether multiple environmental deprivation is associated with income deprivation due to low income communities moving to areas with poorer quality environments (and possibly low cost housing) or whether low income areas disproportionately suffer from the siting of polluting facilities and a lack of investment in facilities with health benefits such as greenspaces. Future research could usefully consider the temporal course of environmental risk exposure and health.

Fourth, we have not evaluated the implications of undertaking our analysis at the spatial scale of UK ward. It is feasible that our environmental measure lacks the geographical specificity to fully capture the environmental effects on health that we have evaluated. As has been argued in the literature pertaining to environmental exposure to air pollution, because pollution levels vary over relatively small areas (e.g. neighbourhoods across a city) (Wilson et al., 2005), precise estimates of exposure at apposite spatial scales is a primary consideration when evaluating the relationship between air pollution and health (Bowen, 2002 ; Maantay, 2002). Undertaking our analyses at an alternative spatial scale could have altered our findings. Fifth, whilst we have examined the relationship between income, environmental deprivation and all-cause mortality, our analyses did not consider specific causes of death or alternative measures of health. An examination of health outcomes that have an established causal link with the environment (e.g. respiratory disease) may have led us to draw different conclusions. Finally, our study is unable to ascertain ‘responsibility’ for the observed environmental outcomes. As Walker (2009) argues, distributional justice constitutes only one dimension of the discourse of environmental justice concerns. The distinction here is whether the poorer quality physical environments results from the actions of the individuals or communities that are affected. This concern is important because previous research in the UK has found that whilst low income communities often endure poorer quality environments, they tend not to be liable for the production of the environmental disamenities. Rather the displacement between waste production and waste disposal has tended to favour more advantaged communities. Mechanisms such as the transportation of toxic waste from wealthier areas to less socially and economically advantaged areas (Dunion, 2003) or due to commuter patterns which entails higher income individuals

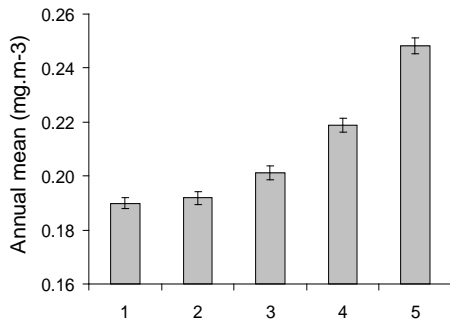
who reside in suburban or rural areas commuting into or through low income urban areas have been highlighted (Mitchell & Dorling, 2003 ; Stevenson et al., 1998). Future UK research could usefully concentrate on roles of responsibility for the observed inequalities in multiple environmental deprivation, and develop a better theoretical understanding of the social and political mechanisms that underpin the findings of the current study.

In conclusion, this study has contributed to the important UK debates on environmental justice and health inequalities through the development of a nationwide index of multiple environmental deprivation to demonstrate a clear social gradient across areas divided into income deprivation groups. Area-level multiple environmental deprivation exerts an effect on health that is not accounted for by the age, sex and income deprivation profile of the areas. However, the physical environment does not have a substantial influence on health inequalities as the effect of multiple environmental deprivation is greatest in the least income deprived wards, which demonstrates a different form of environmental justice in the UK compared to the United States. These observations have important implications for policy makers. It remains unclear whether policy developments such as ‘new urbanism’ will help to address or exacerbate environmental and health inequalities but it will be important that the development of environmental and sustainability policy initiatives do not neglect social equity concerns. We argue that there is an urgent need for further research that uncovers the various societal, political and institutional processes that lead to more income deprived groups occupying spaces of multiple environmental deprivation. Enhancing our understanding of the mechanisms linking the uneven exposure to the physical environment, and the potential of such processes to generate

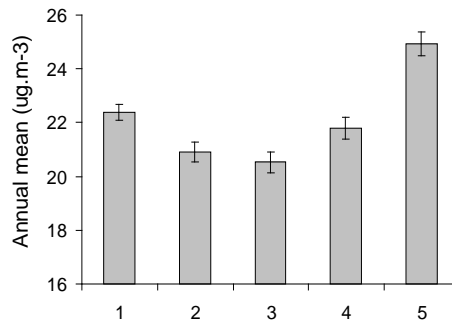
and amplify health inequalities is warranted. In particular, there is a pressing need to use individual-level quantitative and qualitative data to evaluate how vulnerability among different social and demographic groups interacts with the multiple environmental deprivation to determine the production and reproduction of vulnerability.

Figure 1. Mean values for eight environmental factors that influence health in the UK by quintiles of income deprivation (1=low, 5=high). Bars indicate 95% confidence intervals.

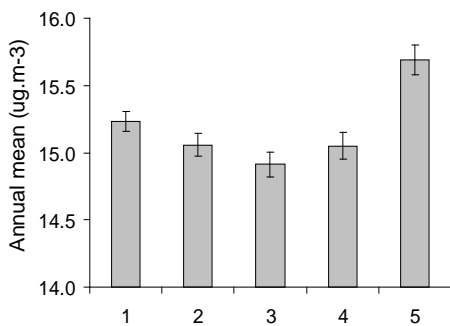
(a) Carbon monoxide (CO)



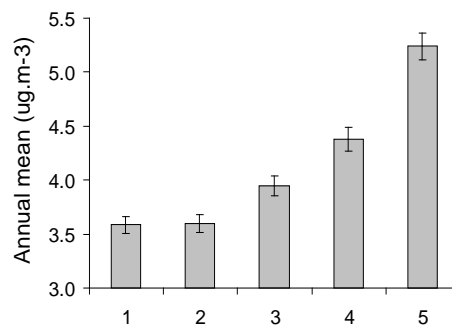
(b) Nitrogen dioxide (NO2)



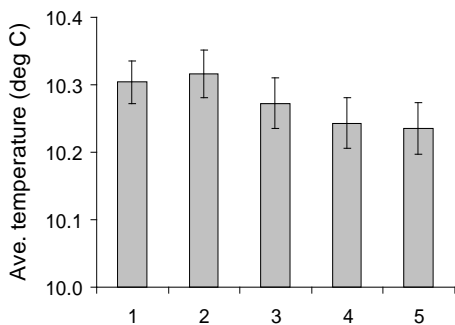
(c) Particulate matter (PM10)



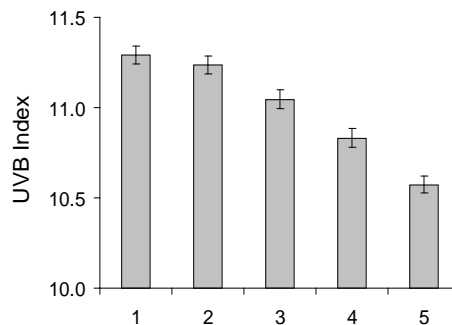
(d) Sulphur dioxide (SO2)



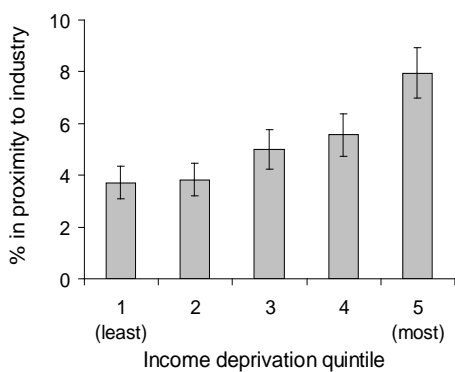
(e) Average annual temperature



(f) UVB Index



(g) Proximity to industry



(h) Green space availability

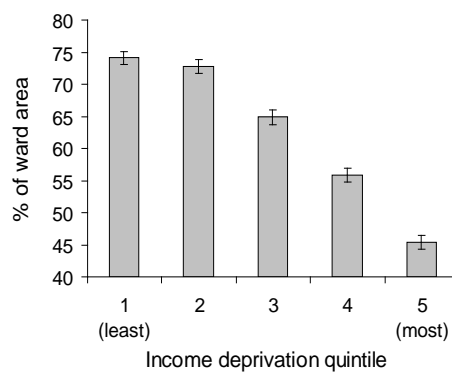


Figure 2. Geographical distribution of MEDix scores (a measure of multiple environmental deprivation) across UK CAS wards.

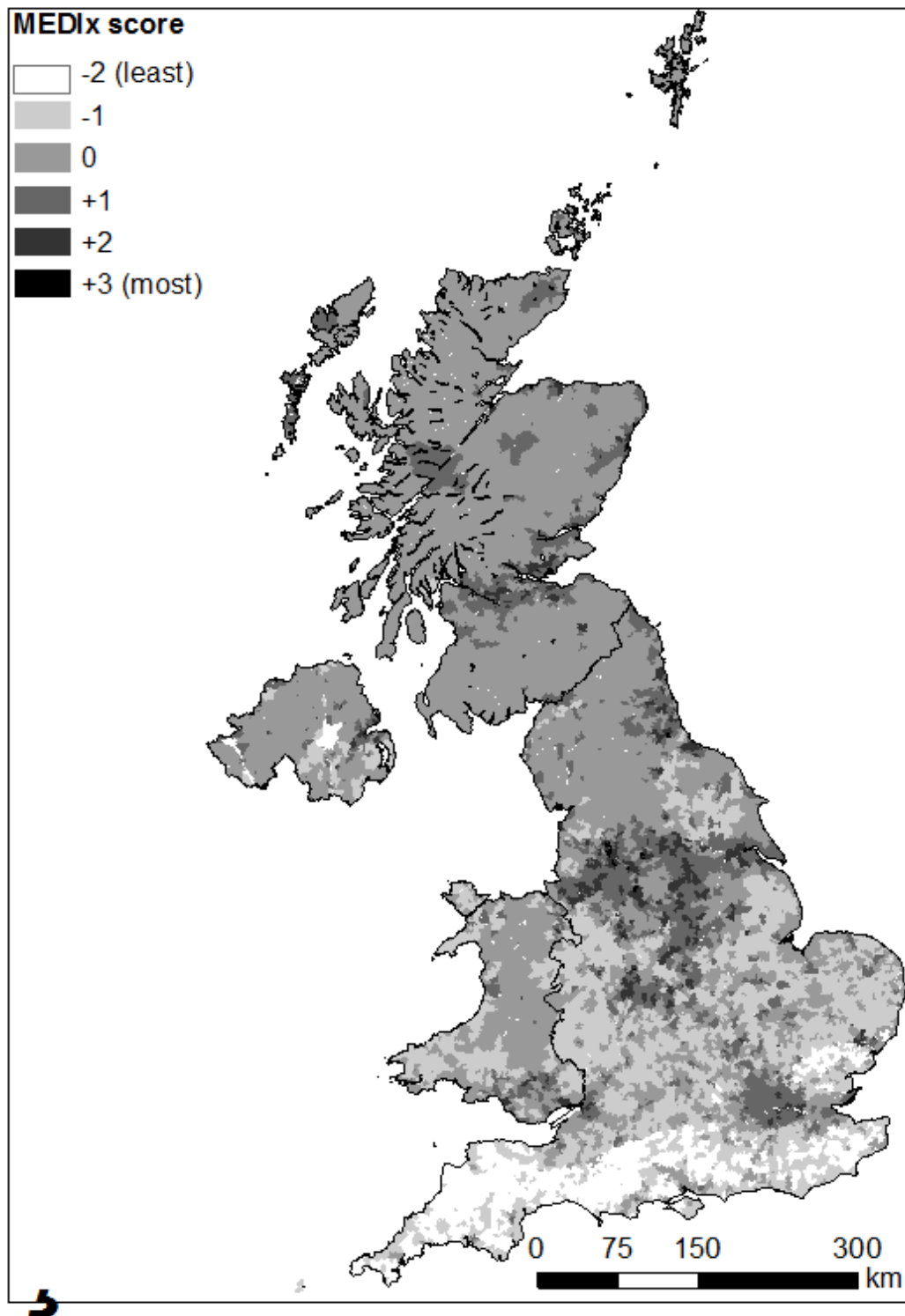


Figure 3. Mean percent income deprived population for each MEDIx score (a measure of multiple environmental deprivation).

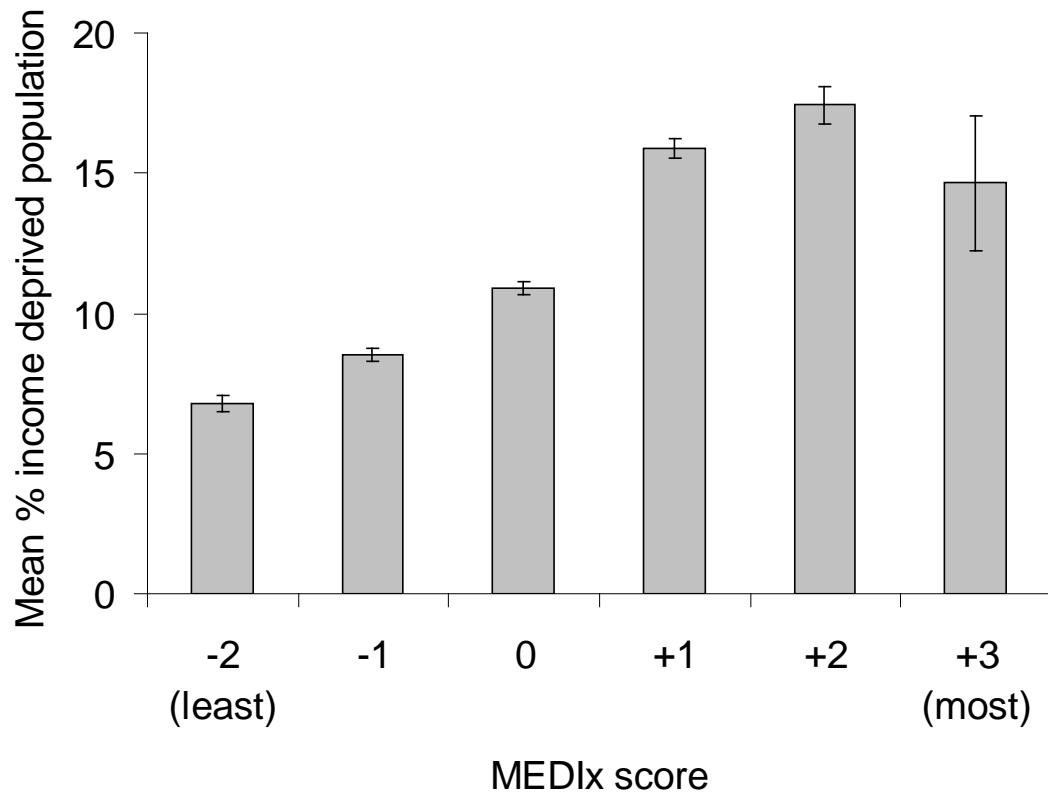
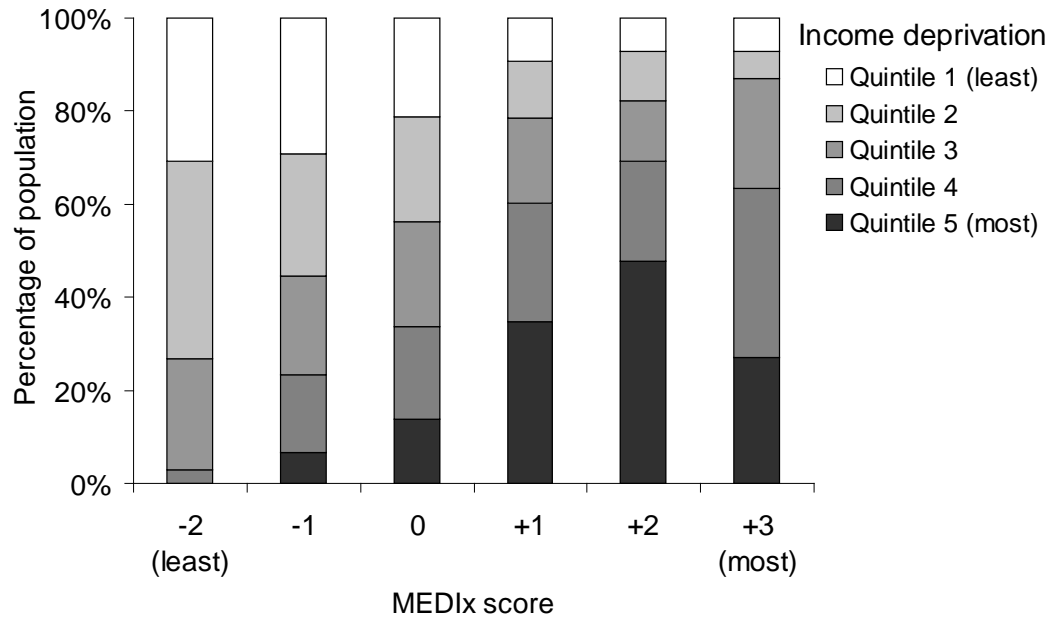


Figure 4. Distribution of population across the six MEDIX scores, by income deprivation quintile, in 2001.

a. Percentage of the population



b. Count of population

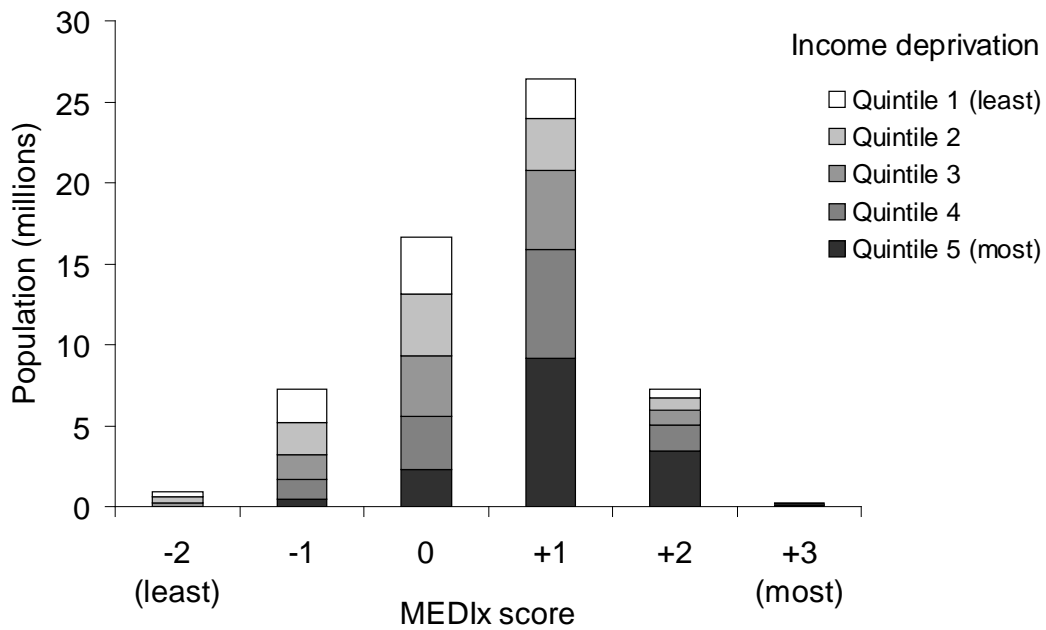


Figure 5. Percentage of the population residing in MEDix wards stratified by quintiles of income deprivation.

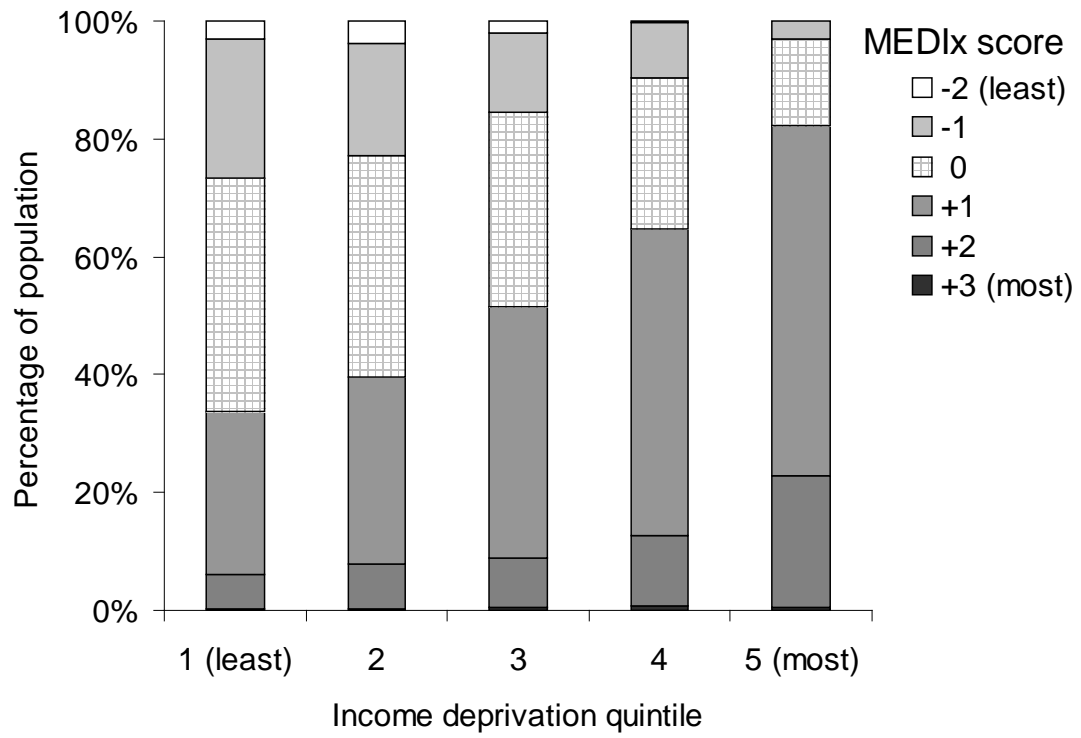


Figure 6. All-cause mortality Standardised Mortality Ratios (SMRs) by MEDIx score adjusted for a) age and sex b) age, sex and social deprivation (Income deprivation quintile). Bars indicate 95% confidence intervals.

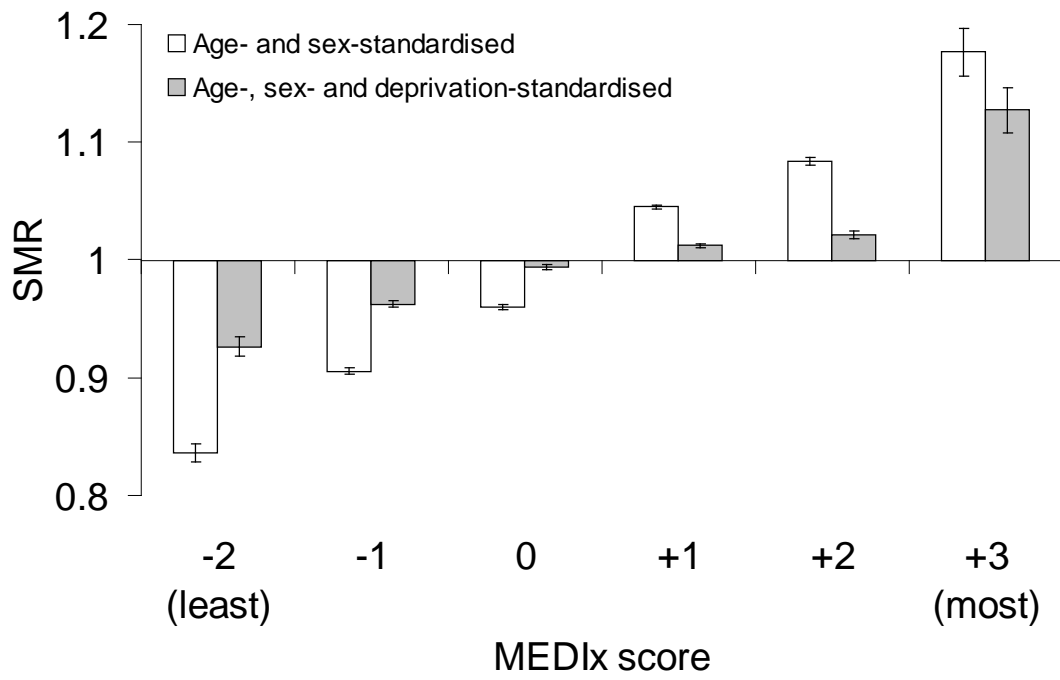


Figure 7. Incidence Rate Ratios (IRRs) for the association between MEDix and all-cause mortality stratified into income deprivation quintiles. Bars indicate 95% confidence intervals.

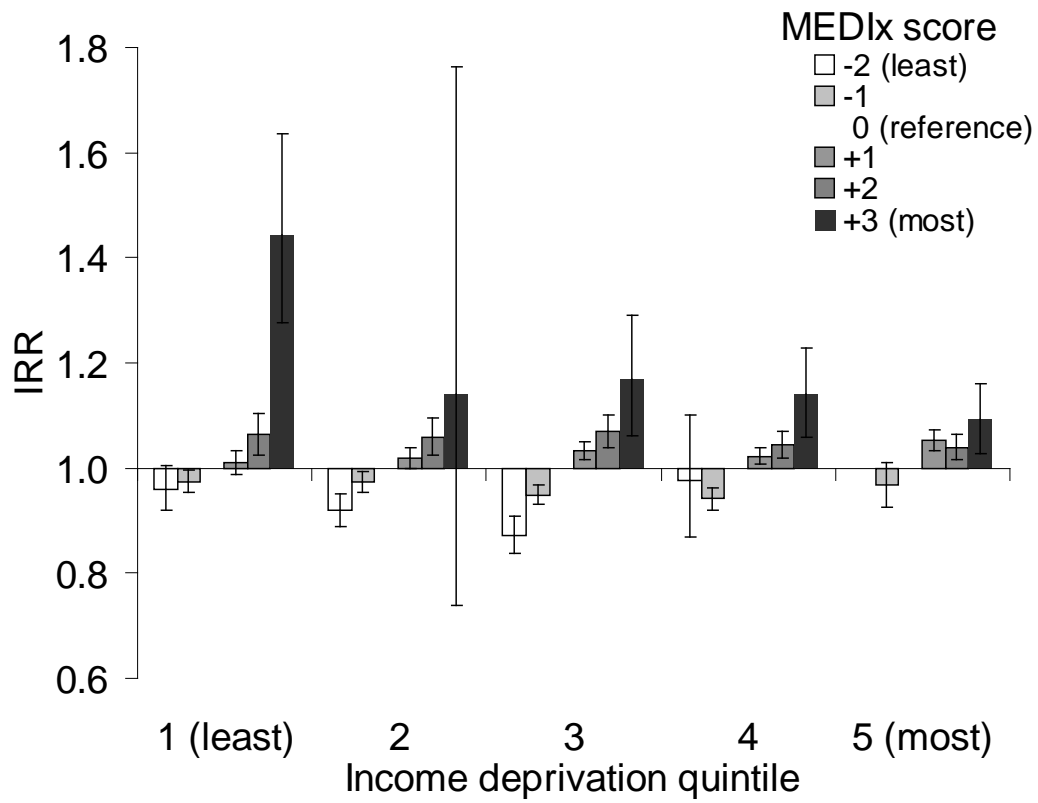


Table 1. Environmental characteristics included in MEDix and the variables and data sources used to capture them

Environmental Domain	Specific environmental variable	Data source	Measure derived	Examples of relevance for health
<i>Pathogenic factors</i> Air pollution	Particulate matter (PM ₁₀) Nitrogen dioxide (NO ₂) Sulphur dioxide (SO ₂) Carbon monoxide (CO)	AEA Technology (1 km grids, modelled from National Atmospheric Emissions Inventory (NAEI) data, 1999-2006)	Population-weighted average of each pollutant for ward (averaged 1999 to 2003 for all except CO: 2001 to 2006)	Respiratory disease Cardiovascular disease
Climate	Average temperature	Met Office UK Climate Impact Programme data (5 km grids, 1996-2003)	Population-weighted (averaged 1999 to 2003)	Respiratory disease Cardiovascular disease
Industrial facilities	Locations of waste management and metal production/processing sites	European Pollutant Emission Register (EPER) (grid references, 2001-2002)	Proportion of ward population living within 4 km of waste site or 1.6 km of metal site (2001 – 2002)	Cancer risk
<i>Salutogenic factors</i> UV radiation	-	UVB Index (Mo & Green, 1974) calculated using Met Office monthly cloud cover data (1 km grid, 1991-2000) and latitude	Population-weighted average UVBI for ward (1991 – 2000)	Protective effect against breast, prostate and colorectal cancers
Greenspace	-	Generalised Land Use Database (GLUD, England, 2001) and CORINE Land Cover Data (UK, 2000)	Estimated proportion of small area land surface classified as greenspace	Beneficial effect on self-perceived health, blood pressure, overweight and obesity

Table 2. Slope Index of Inequality (SII) for MEDIX score and the composite environmental variables. 95% confidence intervals in brackets.

Environmental Variable	SII (no. of income deprived persons per 100,000 population)
Multiple Environmental	
Deprivation Index (MEDIX)	-11490 (-14920 to -8060)*
Sulphur dioxide (SO ₂)	-8397 (-9011 to -7783)
Particulate matter (PM ₁₀)	-7002 (-7622 to -6381)
Nitrogen dioxide (NO ₂)	-9054 (-9664 to -8443)
Carbon monoxide (CO)	-13614 (-14194 to -13035)
Average temperature	126 (-508 to 761)**
UV radiation	-7867 (-8484 to -7251)
Industrial facilities	-10853 (-11453 to -10253)
Greenspace	-13178 (-13761 to -12595)

*Calculated using a six-value ordinal scale (the MEDIX categories) rather than continuous values

**Non-significant

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