Bambra, C., Robertson, S., Kasim, A., Smith, Joe, Cairns, J., Copeland, A., Finlay, N. and Johnson, K. (2014) Healthy land? an examination of the area-level association between brownfield land and morbidity and mortality in England. Environment and Planning A: Economy and Space, 46 (2). pp. 433-454. ISSN 0308-518X.

https://doi.org/10.1068/a46105

Environment and Planning A 2014, volume 46, pages 433 – 454

doi:10.1068/a46105

Healthy land? An examination of the area-level association between brownfield land and morbidity and mortality in England

Clare Bambra¶
Wolfson Research Institute for Health and Wellbeing, Durham University, Queens Campus, Stockton on Tees, TS17 6BH, England; e-mail: clare.bambra@durham.ac.uk and Department of Geography, Durham University, Durham, DH1 3LE, England and Institute of Hazard, Risk and Resilience, Durham University, Durham DH1 3LE, England

Steve Robertson
Wolfson Research Institute for Health and Wellbeing, Durham University, and Institute of Hazard, Risk and Resilience, Durham University, and School of Engineering and Computing Sciences, Durham University; e-mail: steven.robertson@durham.ac.uk,

Adetayo Kasim
Wolfson Research Institute for Health and Wellbeing, Durham University; e-mail: a.s.kasim@durham.ac.uk

Joe Smith
Wolfson Research Institute for Health and Wellbeing, Durham University, and Institute of Hazard, Risk and Resilience, Durham University, and School of Engineering and Computing Sciences, Durham University; e-mail: j.c.smith@durham.ac.uk

Joanne Marie Cairns-Nagi, Alison Copeland
Wolfson Research Institute for Health and Wellbeing, Durham University, and Department of Geography, Durham University, and Institute of Hazard, Risk and Resilience, Durham University; e-mail: j.m.cairns@durham.ac.uk, alison.copeland@durham.ac.uk

Nina Finlay
Institute of Hazard, Risk and Resilience, Durham University, and School of Engineering and Computing Sciences, Durham University; e-mail: n.c.finlay@durham.ac.uk

Karen Johnson
Wolfson Research Institute for Health and Wellbeing, Durham University, and Institute of Hazard, Risk and Resilience, Durham University, and School of Engineering and Computing Sciences, Durham University; e-mail: karen.johnson@durham.ac.uk

Received 22 July 2012; in revised form 13 March 2013

Abstract. It is increasingly understood that the physical environment remains an important determinant of area-level health and spatial and socioeconomic health inequalities. Existing research has largely focused on the health effects of differential access to green space, the proximity of waste facilities, or air pollution. The role of brownfield—or previously developed—land has been largely overlooked. This is the case even in studies that utilise multiple measures of environmental deprivation. This paper presents the results of the first national-scale empirical examination of the association between brownfield land and morbidity and mortality, using data from England. Census Area Statistical ward-level data on the relative proportion of brownfield land (calculated from the 2009 National Land Use Database), standardised morbidity (2001 Census measures of 'not good' general health and limiting long-term illness), and premature (aged under 75 years) all-cause

¶ Corresponding author.

mortality ratios from 1998/99 to 2002/03 were examined using linear mixed modelling (adjusting for potential environmental, socioeconomic, and demographic confounders). A significant and strong, adjusted, area-level association was found between brownfield land and morbidity: people living in wards with a high proportion of brownfield land are significantly more likely to suffer from poorer health than those living in wards with a small proportion of brownfield land. This suggests that brownfield land could potentially be an important and previously overlooked independent environmental determinant of population health in England. The remediation and redevelopment of brownfield land should therefore be considered as a public health policy issue.

Keywords: regeneration, environment, deprivation, neighbourhood

Introduction

It is well established that the physical environment is an important—and socially produced—determinant of public health and health inequalities (World Health Organisation, 2008). There is a sizeable international literature on the public health effects of the environment (eg, Craft et al, 1985; Openshaw et al, 1988), housing quality (eg, Thomson et al, 2001), residential location (eg, Braubach and Fairburn, 2010), neighbourhood physical characteristics (eg, Cummins et al, 2005), access to green space (eg, de Vries et al, 2003; Maas et al, 2006; 2009; Mitchell and Popham, 2007; 2008; Nielsen and Hansen, 2007), waste facilities (eg, Martuzzi et al, 2010), and air pollution (eg, Stafford and McCarthy, 2006). There have also been calls for researchers to engage more with the physical environment and environmental deprivation as a determinant of health and health inequalities (Litt et al, 2002; Shortt et al, 2011). However, with the exception of work conducted at the city level in the USA by Litt et al (2002), such research has not examined the role of derelict, contaminated, vacant, or previously developed land (collectively referred to as 'brownfield land' in this paper). This study is therefore the first to examine the area-level association between brownfield land and health at a national scale (England).

Brownfield land and health

Land is a finite resource and redevelopment of previously used sites is common in developed countries. The term 'brownfield land' is often applied to such previously used sites and is defined as sites that

> "have been affected by former uses of the site or surrounding land; are derelict or underused, are mainly in fully or partly developed urban areas; require intervention to bring them back to beneficial use; and may have real or perceived contamination problems" (Concerted Action on Brownfield and Economic Regeneration Network, 2012).

In practice, there is a broad continuum of brownfield site types, from large, very high-value sites within central business districts, through to small parcels of land and 'vacant lots' on the urban fringe and in the rural hinterland. It is estimated that there are some 62 000 ha of brownfield land in England (Homes and Communities Agency, 2011).

Brownfield land has long been recognised as a potential health hazard from a toxicological perspective, as there is a large degree of overlap with contaminated land (Catney et al, 2007). The Environment Agency estimated that of the 300 000 ha of land in England with a history of industrial use, around 22% (67 500 ha) are, or are likely to be, contaminated [defined as "land potentially affected by both chemical and radiological contamination" (Environment Agency, 2005, page xii)] as a result of their previous industrial, landfill, or transport use (page 36). Contaminants include potentially toxic elements (eg, lead or arsenic), inorganic chemicals (eg, asbestos), organic compounds (eg, petroleum hydrocarbons), and, in some cases, radiation (Environment Agency, 2005; Health Protection Agency, 2010). The health effects of these contaminants vary but, as an example, effects of chronic lead exposure include neurological disturbances, anaemia, anorexia, fatigue, depression, vomiting, hypertension, gastrointestinal conditions and, in some cases, renal failure (Batuman et al, 1983; Lin et al, 2003; Prasad and Nazareth, 2000). Maternal lead exposure has been associated with elevated risks of miscarriage, foetal development problems, and preterm births (Gardella, 2001). Lead is also considered to be carcinogenic and studies have linked it with bladder, stomach, and lung cancers (Fu and Bofetta, 1995). The effects of lead toxicity most frequently result from ingestion or inhalation (Health Protection Agency, 2012).

In many national contexts, the potential risks to physical health of brownfield land are assessed through consideration of the 'source–pathway–receptor' model, whereby the presence of a chemical compound on a site—the 'source'—is judged to be of concern only if there is a route or mechanism (eg, ingestion of soil on vegetables grown on site)—the 'pathway'—that can affect someone or something (eg, a young child)—the 'receptor'—and, in a UK context, is causing or is capable of causing a "significant possibility of significant harm" (SPOSH), or pollution of 'controlled waters' (Catney et al, 2007, page 38). Human health risk is usually assessed using acceptable-threshold levels, except for mutagens and genetic carcinogenic contaminants (Environment Agency, 2009; Health Protection Agency, 2010). The toxicological health effects of brownfield land at an area level were examined by Litt et al (2002) in a district of Baltimore, USA. They found that, amongst those aged over 45, mortality rates from cancer, lung cancer, and respiratory diseases (causes of death that are plausibly linked to the toxicological effects of brownfield land) were 27%, 33%, and 39% higher, respectively, in areas with larger amounts of brownfield land.

However, aside from the direct toxicological effects of contamination, it has also been suggested that low-quality, previously developed open spaces (brownfield land which may or may not be contaminated), particularly in low-income urban areas, could have wider negative impacts on the general health of communities, potentially operating through psychosocial mechanisms (Mitchell and Popham, 2007). It is well established that how residents feel about their area is associated with health outcomes. For example, in an extension of Goffman's (1963) individual notion of stigma (1963), Bush et al (2001) demonstrated that places can obtain a 'spoiled identity' and become stigmatised and discredited as a result of environment factors such as air pollution or 'dirt'. Residents of stigmatised places can also be discredited by association with these place characteristics. Indeed, work by Cattell (2001) and Airey (2003) has shown that such environmental place-based stigma can result in psychosocial stress (and associated ill health) and feelings of shame. Brownfield land can often be unsightly and is by its very nature disused, derelict, or 'dirty' land.

This is also reinforced by studies of environmental stress. Environmental stress is the "process by which environmental events threaten, harm or challenge an organism's existence or well-being and by which the organism responds to this threat" (Baum et al, 1985, page 186). Research into the health effects of waste facilities has established the plausibility of a psychosocial pathway between the environment and health (Elliot et al, 1993). Similarly, studies of the association between neighbourhood characteristics and self-rated health in England and Scotland found that fair to very bad self-rated general health was significantly associated with a poor-quality 'physical residential environment'—a composite measure which included the proportion of vacant and derelict land alongside missed waste collections and public sector vacancy rate (Cummins et al, 2005). A follow-up study found that the magnitude of the association was larger for women than for men (Stafford et al, 2005). Further, research has also demonstrated that the "impact of the perceptions of risk to health can be as real as the toxicological health risks from contaminated land" (Health Protection Agency, 2010, page 17).

Continuing with this theme, it is also possible to speculate that brownfield land could perhaps be acting on health as a form of 'untherapeutic' landscape. The health geography literature has established the role of natural or green spaces as 'therapeutic' or health-promoting landscapes. So, for example, studies have found that walking in natural, rather than urban, settings reduces stress levels (Hartig et al, 2003) and that people residing in 'green areas' report less poor health than do those in 'less green' surroundings (Maas et al, 2006). Research also indicates that green space can impact on health by attention restoration, stress reduction, and/or the evocation of positive emotions (Abraham et al, 2010). Biophilia also underpins the therapeutic landscape and green space research. Biophilia theory argues that "our response to nature today is influenced by universal, inherited human characteristics, which would have conveyed primeval evolutionary advantages for the human species" (Curtis, 2010, page 38). Subsequently, humans have preferences for natural settings which offer "resources for life and protection" (page 38). Although brownfield land is not necessarily the opposite of green space (and its relationship with health could be more complicated), it is possible that it contributes to a less positive health environment—or what could be termed an 'untherapeutic', 'unnatural', and postindustrial landscape. It could be argued that brownfield land is thereby a marker for long-term industrial decline, forming part of the 'postindustrial landscape' in deprived communities—a symptom of the environmental legacy of the industrial past. There is a widespread literature (such as that by Wakefield and McMullan, 2005) which considers the health effects of the shift from industrial to postindustrial production and how this has been associated not only with economic but also environmental and social decline. Such deindustrialisation has had significant implications for long-term job prospects, job security, migration patterns, housing quality, and many other social determinants of health and health inequalities (Whitehead and Dahlgren, 1991).

Health behaviours also need to be considered as a possible pathway between brownfield land and health outcomes. For example, in the green space literature there is speculation that part of the explanation of the association with better health outcomes is that green spaces may encourage exercise (eg, walking or jogging in a green park) (Richardson and Mitchell, 2010). Some brownfield land in contrast may limit the opportunity for exercise as such areas may not only be visually offputting but they may also contribute to a sense of physical insecurity and concerns about crime and safety.

Environmental deprivation and health

More widely, the health effect of the environment has been encapsulated through the concept of 'environmental deprivation' (Pearce et al, 2010). Environmental deprivation is the extent of exposure to key characteristics of the physical environment that are either health promoting or health damaging (Pearce et al, 2010). Richardson et al (2010) developed a UK index of health-related multiple environmental deprivation (MED-Ix), a composite index which contains small-area (ward-level) measures of air pollution, climate temperature, solar UV radiation, proximity to industry, and access to green space. They also further classified areas in the UK depending on these index characteristics ('MED-class', see box 1) (Richardson et al, 2010; Shortt et al, 2011). In an empirical study testing the index, they found a linear area-level association between environmental deprivation (MED-Ix) and all-cause mortality: age-and-sex standardised all-cause mortality ratios (adjusted for social deprivation) were lowest in areas with the least environmental deprivation (0.84) and highest in the most environmentally deprived (1.18) (Pearce et al, 2010). Similarly the MED-class typology was also strongly associated with mortality, with incidence rate ratios for all-cause mortality higher than average in four types of area (Industrial; fair-weather conurbations; cold, cloudy conurbations; and isolated, cold, and green areas) and lower than average in three area types (London and 'Londonesque'; mediocre green sprawl; and sunny, clean, and green) (Shortt et al, 2011).

The concept of environmental deprivation also provides a useful way of including environmental contextual factors which may be important determinants of health but which are not usually components of the more widely used indices of multiple deprivation [eg, the Townsend Index (see Townsend et al, 1988)] which comprise area-level socioeconomic indicators of homeownership, car access, unemployment, socioeconomic status, or overcrowding (Stafford et al, 2005). Richardson et al (2010) argue that, whilst socioeconomic deprivation accounts for much of spatial inequalities in health, differences in exposure to the physical environment could explain some of the remainder. Indeed, in a UK-wide area-level study they found that mortality was associated with environmental deprivation even after controlling for socioeconomic factors: area-level health progressively worsened as the multiple environmental deprivation increased (Pearce et al, 2010). However, brownfield land was not included as a component of the multiple environmental deprivation index. This was probably because the specific association between brownfield land and population health has not yet been extensively empirically examined (the MED-Ix was based on environmental factors with an established association with health) (Richardson et al, 2010).

This paper adds to the environmental deprivation and health literature by being the first to interrogate the relationship between brownfield land and health using national-scale data (for England).

Methods

Data and variables

Data on the proportion of previously developed land (PDL) (brownfield land) were obtained from the 2009 National Land Use Database (NLUD) of previously developed (brownfield) land (Homes and Communities Agency, 2012a). This represents the most recent, comprehensive, publicly available, national dataset of PDL in England (and is described in detail in box 1). The dataset lists the size and geographic location of 72% of PDL across England (see box 1). The location of each parcel of land is given as a UK National Grid Reference (via Easting and Northing). No information is given as to whether the grid reference refers to the central point of the site, the entrance to the site, or the postcode centroid. Equally, there is no information given on the boundaries of the site to determine the exact shape, just the size of the area covered. Therefore, using ArcMap, the effective site radius was calculated by assuming that each site was a perfect circle centred about the Easting/Northing coordinate, with the area of each circle totalling the area of each site. Census Area Statistical (CAS) ward boundaries were downloaded from EDINA UKBORDERS. CAS wards represent small-area geographies of varying size, with an average ward comprising 2570 households (ranging from 222 households to 14 396 households). Wards in the District of the City of London were combined into the district of the City of London and the Isles of Scilly as corresponding census data were not available at ward level in the Isles of Scilly due to the scarcity of population there. ArcMap was used to associate each brownfield site with a particular ward. Where a brownfield site fell across several wards, it was allocated using a standard GIS 'best fit' principal, where the ward containing the majority of the estimated brownfield site was chosen.

The proportion of PDL was then calculated by combining all the individual sites within each CAS ward and calculating the percentage area of PDL within the ward. This was then standardised across the wards to create a relative measure of PDL (R-PDL) for each ward. A ward containing exactly the average proportion of PDL had an R-PDL value equal to 100, whilst a ward containing half the average proportion of PDL had an R-PDL equal to 50. The 7941 wards were categorised by R-PDL using a finite component mixture model. The three resulting categories were: (1) wards with no ($n = 2842$) or small amounts ($n = 2146$) of brownfield (R-PDL $\leqslant 28$), (2) wards with medium/moderate amounts ($n = 2084$) of

Box 1. Description of data and variables.

Brownfield-land data and variables

Data on the proportion of previously developed land (brownfield) were obtained from the 2009 National Land Use Database of previously-developed brownfield land (NLUD) available from the Homes and Communities Agency website (2012a). This listed the size and geographic location of brownfield in England—'previously developed land' (PDL). This classified PDL in England into five categories: "currently in use with permission or allocation for redevelopment" (28%); "derelict land/buildings" (25%); "previously developed vacant land" (22%); "other currently in use with known potential for redevelopment" (18%); and "vacant buildings" (7%). The data were used as released by the Homes and Communities Agency, without additional verification. English local authorities provided the Homes and Communities Agency with data about previously developed sites in their area, and the submitted site-level data were made publically available through yearly revisions of the NLUD between 2001 and 2009 (Homes and Communities Agency, 2012b). Nominally, the submissions related to the situation in each local authority on 31 March of a given year and, where a submission was not made, the previous year's data were included in the Homes and Communities agency's release (Homes and Communities Agency, 2012c). A "small number" of local authorities made no submissions (Homes and Communities Agency, 2012c). As such, the category 'no brownfield' may indeed mean no brownfield present or simply be a nonresponse. Local authorities are required to estimate the percentage of the total that their submission covers (Homes and Communities Agency, 2012c). This is estimated to be between 58% (in the South West) and 82% (in London) of total brownfield, with the dataset covering an average of 72% of brownfield across England. Census Area Statistics (CAS) ward boundaries were downloaded from EDINA UK BORDERS.

Health data and variables

Self-reported general health data were obtained from the 2001 Census and calculated as the proportion of 'not good' responses to the question: "Over the last twelve months would you say your health has on the whole been ... Good? Fairly good? Not good?" Limiting long-term illness data were also obtained from the 2001 Census and calculated as the proportion of positive responses to the question: "Do you have any long-term limiting illness, health problem or disability which limits your daily activities or the work you can do?" All-cause premature mortality data (deaths under age 75 years) were obtained from the Office for National Statistics for the five year period 1998/9 to 2002/3.

Physical environment data and variables

Measures of the physical environment were obtained from the MED-Ix and MED-Class databases developed by Richardson et al (2010) and Shortt et al (2011) MED-Ix is a UK index of health-related multiple environmental deprivation: a composite index which contains ward-level measures of air pollution, climate temperature, solar UV radiation, proximity to industry, and access to green space. MED-Ix provides a scale of −2 to +3 (most environmentally deprived). MED-Class is a sevenfold typology based on MED-Ix: London and 'London-esque' (London and other urban centres in England); industrial (spread throughout UK); mediocre green sprawl (spread throughout UK); fair-weather conditions (spread throughout UK); cold, cloudy conurbations (major urban centres of Scotland, Newcastle and urban areas of Northern Ireland); isolated, cold and green (rural Scotland, Northern England, Northern Ireland, and Wales); sunny, clean and green (spread throughout UK). Data were downloaded from http://cresh.org.uk/cresh-themes/environmental-deprivation/medix-and-medclass/

Demographic and socioeconomic data and variables

Area-level socioeconomic deprivation was measured using the well-validated Townsend Index of Deprivation for 2001 (Townsend et al, 1988). This index use unemployment, private renting, no car ownership, and overcrowding census variables to define material deprivation. Individual-level data relating to demographic and socioeconomic variables were all obtained from the 2001 Census. Ethnic composition was calculated as the proportion of white (British, Irish and other White background) adult (aged 16–74 years) residents. The proportion of the 16–74-year-old population of nonprofessional socioeconomic class (intermediate occupations, lower supervisory and technical occupations, semiroutine occupations, routine occupations, never worked, and long-term unemployed) was calculated using the National Statistics socioeconomic classification. Educational qualification was measured as the proportion of adults aged 16–74 years with no qualifications. The proportions of 16–74 year olds who were in full or part-time

Demographic and socioeconomic data and variables (continued)
employment were calculated using the economic activity variable. Housing tenure was calculated as the proportion of owner occupiers (owns outright, owns with a mortgage or loan, or shared ownership). Car ownership was the proportion of the population with no car or van.
Settlement-type data and variables
Data were obtained from the Office for National Statistics (http://www.ons.gov.uk/ons/guide-method/geography/products/area-classifications/rural-urban-definition-and-la/rural-urban-definition–england-and-wales-/index.html) and were based on the Department for Environment and Rural Affairs' rural/urban classification which defines the urbanity/rurality of different geographies. CASwards were classified using a threefold grouping: (1) urban; (2) town and fringe; (3) village, hamlet, or dispersed.

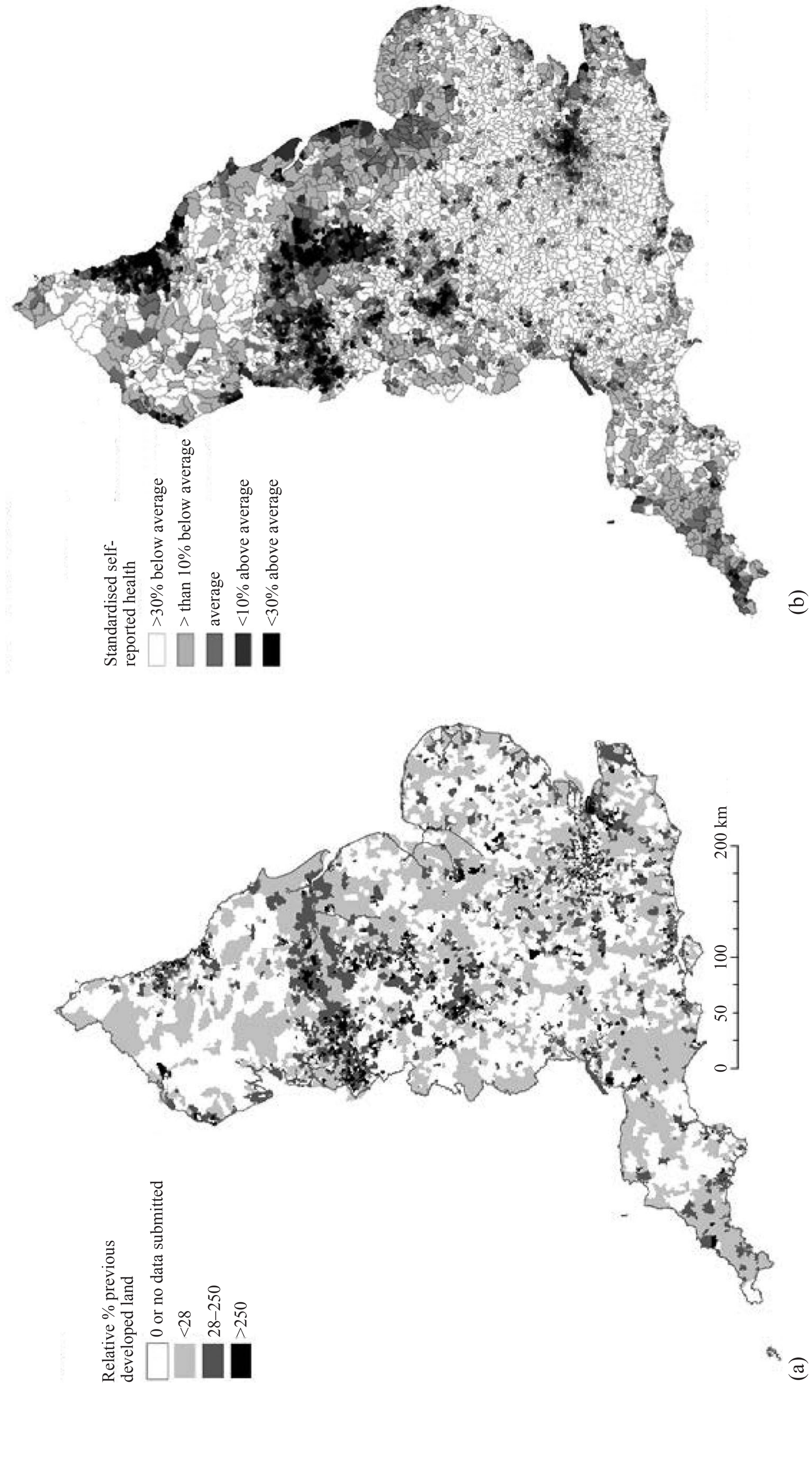
brownfield (R-PDL $\leqslant 250$) and (3) wards with relatively large amounts ($n = 869$) of brownfield (R-PDL $\geqslant 250$).

CAS ward-level age and-sex-standardised morbidity ratios (SMRs), with England as the reference population were indirectly calculated for self-reported 'not good' general health and limiting long-term illness using data from the 2001 English Census. As subjective measures of morbidity, these indicators may be subject to reporting bias and could be interpreted variably (Cairns et al, 2012). Therefore, CAS ward-level age and sex standardised mortality ratios, with England as the reference population, were also indirectly calculated for all-cause premature (under the age of 75 years) mortality using data from the Office for National Statistics (ONS) for 1998/99–2002/03. Five years data for premature mortality were used to ensure that the number of deaths in each CAS ward were large enough for meaningful statistical analysis. The 2001 Census and 2003 ONS data represented the most up-to-date health data available at ward level in England at the time of analysis. The standardised morbidity and mortality ratios compare wards with the English average (100), with values above or below 100 representing better or worse than average health, respectively. The health variables are described in more detail in box 1.

The health and brownfield data were mapped at CAS ward level using ARC-GIS to visually demonstrate the ward-level geographical association between the relative proportion of brownfield land and health. The R-PDL classification used reflects the threefold classification used above (small, medium, and large R-PDL); however, wards with no brownfield were mapped separately. For each of the health datasets, maps are shown with values reflecting 10% and 30% above and below average alongside an average SMR value. These cut off values have previously been shown to be significant in explaining variations in SMRs (Copeland, 2002).

Statistical analysis

A finite component mixture model with Gaussian distribution was used to identify latent groups among the wards based on their relative percentage of brownfield land. Wards with no brownfield data submitted were treated as a known group and were therefore not included in the mixture model. A mixture of Gaussian distributions is an elegant and flexible way to capture unknown sub-classes of a population based on their individual latent distributions. For a fixed number of components, the model investigates the likelihood of each ward belonging to a latent group conditioning on other members of the group, a ward is assigned to a component where it has the highest likelihood. In the second stage of the analysis, a general linear mixed effects model was used to investigate associations between the health outcomes and brownfield land based on the categories of brownfield land obtained from the mixture model. The model treated the local authorities as random effects in order to capture variability of the health outcomes attributable to local authorities' specific characteristics. The random-effect model implies a population-average model with exchangeable correlation between


Standardised self-reported health
>30% below average
> than 10% below average
average
<10% above average
<30% above average
(b)
Relative % previous developed land
0 or no data submitted
<28
28–250
>250
0
50
100
200 km
(a)

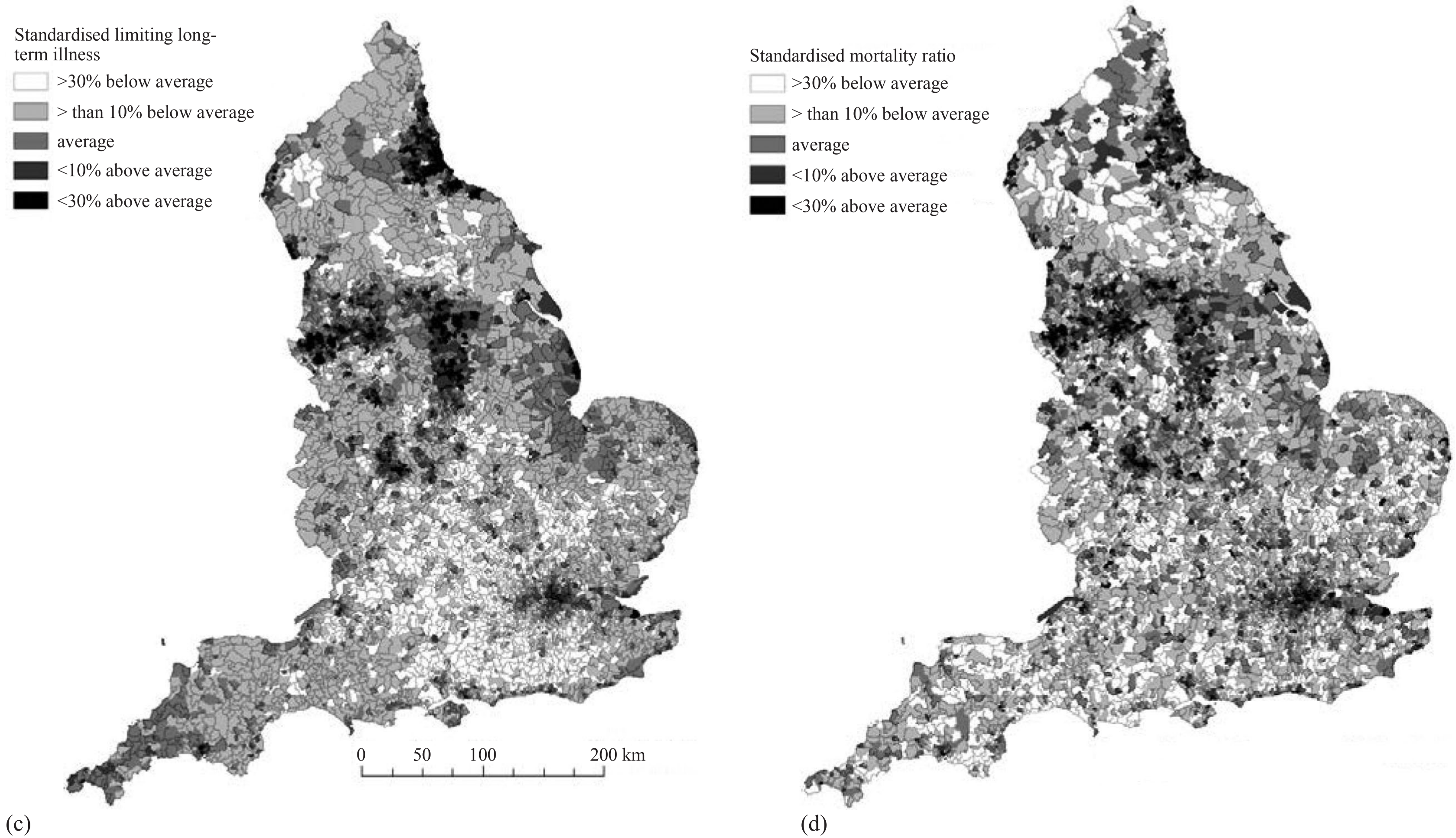


Figure 1. Geographic distribution of brownfield sites, ‘not good health’, limiting long-term illness, and premature all-cause mortality, by ward. (Results are based on data provided through EDINA UKBORDERS with the support of the ESRC and JISC and use boundary material which is copyright of the Crown.) (a) Relative proportion of brownfield land; (b) ‘not good health’; (c) limiting long-term illness; (d) mortality.

wards from the same local authority. Settlement type was also included to account for ward size, and rural compared with urban population distributions (see box 1). The model also accounted for potential confounders, including: multiple environmental deprivation [using MED-Ix from Richardson et al (2010)]; area-level deprivation [using the Townsend Index of Deprivation for 2001 (Townsend et al, 1988)]; and 2001 individual-level census measures of demographic and socioeconomic characteristics—socioeconomic classification, educational qualification, ethnic composition, economic activity, housing tenure, and car ownership. Sensitivity analyses using four and five categories of brownfield were also conducted.

Area-level (Townsend scores) and individual-level (socioeconomic classification; educational level) indictors of socioeconomic deprivation were included in the analysis as they have a strong relationship with population health (Marmot, 2010). Car ownership is also a well-used indicator of social deprivation as it is socially—and spatially—patterned (MacIntyre et al, 2000). Economic activity was included because of the well-established negative relationship between worklessness and morbidity and mortality (Bambra, 2011). Ethnic composition was included because there are associations between ethnicity and health (Davey Smith et al, 2001). Housing tenure was included because there are strong associations between housing tenure and health, with owner-occupiers having better health (eg, less limiting long-term illness, depression, and anxiety) than tenants (Macintyre et al, 2000; 2001). These variables are described further in box 1.

Results

The geographical distribution of brownfield land is presented in figure 1(a) alongside the SMRs for 'not good health', limiting long-term illness, and mortality in figures 1(b)–1(d). In each case, the maps show that areas with high levels of R-PDL broadly correspond with those with higher than average SMRs. Areas of high brownfield density tend to be located in the North (covering the former heavy industry areas of the North East, the North West, and South and West Yorkshire) and in Central London. Areas of low brownfield density and above-average health form the majority of wards.

A significant, strong, nonlinear bivariate relationship was observed between 'not good health', limiting long-term illness, and mortality, and R-PDL. Wards with large areas of R-PDL had higher 'not good health', limiting long-term illness, and mortality than wards with no or relatively small amounts of brownfield land. The wards with no brownfield land and those with a relatively small area of brownfield land (R-PDL <28) were combined together as a reference category because the average 'not good health', limiting long-term illness, and mortality for the two groups are similar (figure 2). The unadjusted effect sizes are presented in table 1 (as standardised ratios) and the association is shown visually in figure 3. These results suggest that in England there was a 20.2 unit increase in 'not good health', a 13.8 unit increase in limiting long-term illness, and a 23.8 unit increase in mortality over what would be expected (given the age and sex structures of these wards) in wards with large amounts of brownfield compared with wards with no or a relatively small amount of brownfield land. The random-effect component of the mixed model shows a substantial variation in the health outcomes between local authorities and residuals. The large residual variation is expected as other known factors associated with the health outcomes are not included in the model.

After conducting linear mixed effects model analysis to control for economic (Townsend Index) and multiple environmental (MED-Ix) deprivation, and socioeconomic and demographic characteristics (table 2), the strong association between health and R-PDL remained for the outcomes 'not good health' and limiting long-term illness, but there was no longer a significant association with mortality. The average rate of 'not good health' is about 15.4 units higher than expected (given the age and sex structure of these wards) in those wards that have a large proportion of brownfield land. Similarly, limiting long-term illness rates are about

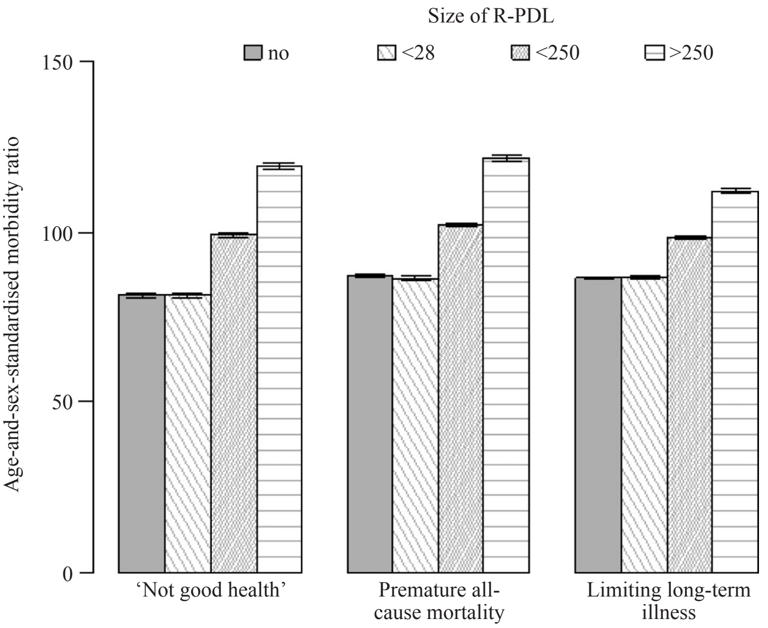


Figure 2. Unadjusted association between 'not good health', limiting long-term illness, premature all-cause mortality, and previously developed land (R-PDL) in wards with no brownfield and those with relative proportion of brownfield land less than 28%.

Table 1. Unadjusted ward-level association between 'not good health', limiting long-term illness, and premature all-cause mortality, and the proportion of brownfield land (R-DPL).

Effect	'Not good health'			Limiting long-term illness			Mortality		
	estimate	SE	*p*-value	estimate	SE	*p*-value	estimate	SE	*p*-value
Intercept	87.033	1.258	<0.0001	90.175	0.920	<0.0001	90.088	0.839	<0.0001
brownfield (ref. < 28)									
<250	7.763	0.571	<0.0001	5.500	0.415	<0.0001	9.577	0.606	<0.0001
>250	20.223	0.817	<0.0001	13.839	0.594	<0.0001	23.885	0.866	<0.0001
Random effects									
Intercept	523.11	41.06		279.86	21.92		209.80	17.596	
Residuals	403.14	6.54		213.30	3.46		459.03	7.457	

14.3 units higher. Therefore people living in wards with a higher proportion of brownfield land are significantly more likely to suffer from poorer health than those living in wards with little or no brownfield. The results of the sensitivity analyses using different categories of brownfield are presented in tables 3 and 4. The results are consistent with the main analysis and, importantly, the higher the number of categories, the larger the effect of brownfield. This is expected since the higher the number of components from the mixture model, the more homogenous are the groupings, and the definition of the wards with the smallest and largest areas of brownfield move further towards the tail of the distribution. These findings suggest that in England the relative proportion of brownfield land is associated with health outcomes at ward level independently of the age, sex, and sociodemographic profiles of the areas. The association with health is independent of other measures of socioeconomic and environmental deprivation.

Table 2. Adjusted ward-level association between 'not good health', limiting long-term illness, premature all-cause mortality, and the proportion of brownfield land (adjusted for multiple environmental deprivation (Med-Ix), Townsend Index of Deprivation, ethnicity, education, unemployment, socioeconomic status, car/van owned, and housing tenure, settlement type).

Effect	'Not good health'			Limiting long-term illness		
	estimate	SE	*p*-value	estimate	SE	*p*-value
Intercept	57.510	3.910	<0.0001	54.582	2.909	<0.0001
Brownfield (ref. <28)						
<250	8.775	3.054	0.0041	5.441	2.271	0.0166
>250	15.405	4.523	0.0007	14.354	3.363	<0.0001
MED-Ix (ref. −2)						
−1	0.607	0.631	0.3366	−0.116	0.469	0.8035
0	0.054	0.732	0.9407	−0.114	0.544	0.8328
1	1.018	0.814	0.2107	0.467	0.605	0.4398
2	2.252	0.907	0.0131	1.194	0.674	0.0767
3	3.815	2.111	0.0707	0.630	1.570	0.6882
White	−0.166	0.021	<0.0001	−0.015	0.015	0.3380
Unemployment	0.071	0.035	0.0424	0.064	0.026	0.0129
Education	1.011	0.039	<0.0001	0.811	0.029	<0.0001
Socioeconomic status	0.520	0.040	<0.0001	0.383	0.030	<0.0001
Cars	0.301	0.039	<0.0001	0.199	0.029	<0.0001
Tenure	−0.009	0.026	0.7180	0.021	0.019	0.2795
Settlement type (ref. village)						
urban	−0.819	0.480	0.0878	−0.166	0.356	0.6417
town	−0.407	0.430	0.3438	−0.374	0.319	0.2413
Deprivation	3.944	0.267	<0.0001	2.894	0.199	<0.0001
Interactions						
Car×brownfield <250	−0.071	0.055	0.2017	−0.100	0.041	0.0157
Car×brownfield >250	0.104	0.075	0.1619	−0.029	0.055	0.5952
Deprivation×brownfield <250	0.207	0.355	0.5593	0.523	0.264	0.0474
Deprivation×brownfield >250	−1.158	0.444	0.0091	−0.589	0.330	0.0743
Tenure×brownfield <250	−0.101	0.040	0.0124	−0.032	0.030	0.2773
Tenure×brownfield >250	−0.281	0.055	<0.0001	−0.203	0.041	<0.0001
Random effects						
Intercept	123.61	9.97		69.57	5.62	
Residuals	78.64	1.28		43.47	0.70	

Effect	Premature all-cause mortality		
	estimate	SE	*p*-value
Intercept	62.567	5.267	<0.0001
Brownfield (ref. <28)			
<250	−0.273	4.760	0.9541
>250	−3.280	7.048	0.6416
MED-Ix (ref. −2)			
−1	0.697	0.969	0.4719
0	0.602	1.093	0.5815
1	2.386	1.195	0.0459
2	3.929	1.334	0.0032
3	7.691	3.181	0.0156
White	0.064	0.029	0.0288
Unemployment	−0.027	0.050	0.5772
Education	0.319	0.057	<0.0001
Socioeconomic status	0.469	0.059	<0.0001
Cars	0.734	0.059	<0.0001
Tenure	−0.119	0.040	0.0032
Settlement type (ref. village)			
urban	−3.813	0.734	<0.0001
town	−3.205	0.667	<0.0001
Deprivation	2.807	0.410	<0.0001
Interactions			
Car×brownfield <250	0.109	0.087	0.2078
Car×brownfield >250	0.673	0.116	<0.0001
Deprivation×brownfield <250	−0.067	0.554	0.9027
Deprivation×brownfield >250	−3.029	0.691	<0.0001
Tenure×brownfield <250	−0.023	0.063	0.7140
Tenure×brownfield >250	−0.237	0.085	0.0056
Random effects			
Intercept	44.74	4.40	
Residuals	194.28	3.17	

Table 3. Adjusted ward-level effects between 'not good health', limiting long-term illness, premature all-cause mortality, and brownfield land (R-DPL), assuming four categories for brownfield.

Effects	'Not good health'			Limiting long-term illness		
	estimate	SE	*p*-value	estimate	SE	*p*-value
Intercept	57.238	3.929	<0.0001	54.463	2.925	<0.0001
Brownfield (ref. <11)						
<69	6.635	3.287	0.0436	3.997	2.445	0.1022
<378	10.306	3.671	0.0050	9.007	2.730	0.0010
>378	20.336	5.523	0.0002	18.079	4.108	<0.0001
MED-Ix (ref. −2)						
−1	0.673	0.632	0.2870	−0.094	0.470	0.8411
0	0.109	0.734	0.8811	−0.110	0.546	0.8396
1	1.111	0.816	0.1736	0.497	0.607	0.4133
2	2.321	0.910	0.0108	1.201	0.677	0.0760
3	3.716	2.113	0.0787	0.572	1.572	0.7156
White	−0.170	0.021	<0.0001	−0.019	0.015	0.2168
Unemployment	0.067	0.035	0.0529	0.062	0.026	0.0173
Education	1.013	0.038	<0.0001	0.814	0.028	<0.0001
Socioeconomic status	0.520	0.040	<0.0001	0.384	0.030	<0.0001
Cars	0.281	0.041	<0.0001	0.188	0.030	<0.0001
Tenure	0.012	0.027	0.6600	0.037	0.020	0.0644
Settlement type (ref. village)						
urban	−0.812	0.480	0.091	−0.203	0.357	0.5691
town	−0.409	0.430	0.3417	−0.407	0.320	0.2040
Deprivation	4.112	0.279	<0.0001	3.016	0.208	<0.0001
Interactions						
Car×brownfield <69	0.053	0.063	0.3960	−0.001	0.047	0.9797
Car×brownfield <378	−0.014	0.065	0.8303	−0.071	0.048	0.1419
Car×brownfield >378	0.075	0.086	0.3797	−0.052	0.064	0.4157
Deprivation×brownfield <69	−0.616	0.410	0.1331	−0.173	0.305	0.5696
Deprivation×brownfield <378	−0.193	0.397	0.6266	0.062	0.295	0.8313
Deprivation×brownfield >378	−1.340	0.528	0.0112	−0.809	0.392	0.0395
Tenure×brownfield <69	−0.137	0.045	0.0023	−0.066	0.033	0.0484
Tenure×brownfield <378	−0.159	0.046	0.0006	−0.109	0.034	0.0016
Tenure×brownfield >378	−0.342	0.068	<0.0001	−0.252	0.051	<0.0001
Random effects						
Intercept	123.95	10.00		69.90	5.64	
Residuals	78.67	1.28		43.52	0.70	

Effects	Premature all-cause mortality		
	estimate	SE	*p*-value
Intercept	62.370	5.324	<0.0001
Brownfield (ref. <11)			
<69	−2.205	5.132	0.6674
<378	8.245	5.717	0.1492
>378	−9.485	8.610	0.2706
MED-Ix (ref. −2)			
−1	0.612	0.971	0.5286
0	0.490	1.097	0.6549
1	2.274	1.200	0.0581
2	3.794	1.339	0.0046
3	7.199	3.186	0.0239
White	0.063	0.029	0.0315
Unemployment	−0.033	0.050	0.4989
Education	0.318	0.057	<0.0001
Socioeconomic status	0.474	0.059	<0.0001
Cars	0.754	0.063	<0.0001
Tenure	−0.113	0.042	0.0070
Settlement type (ref. village)			
urban	−3.977	0.736	<0.0001
town	−3.383	0.668	<0.0001
Deprivation	2.821	0.430	<0.0001
Interactions			
Car×brownfield <69	0.041	0.099	0.6787
Car×brownfield <378	0.112	0.102	0.2715
Car×brownfield >378	0.771	0.134	<0.0001
Deprivation×brownfield <69	−0.146	0.642	0.8202
Deprivation×brownfield <378	−0.560	0.620	0.3665
Deprivation×brownfield >378	−3.191	0.822	0.0001
Tenure×brownfield <69	0.012	0.070	0.8604
Tenure×brownfield <378	−0.154	0.072	0.0331
Tenure×brownfield >378	−0.199	0.107	0.0625
Random effects			
Intercept	45.56	4.46	
Residuals	194.45	3.17	

Table 4. Adjusted ward-level effects between 'not good health', limiting long-term illness, premature all-cause mortality and brownfield land (R-DPL) assuming five categories for brownfield.

Effects	'Not good health'			Limiting long-term illness		
	estimate	SE	*p*-value	estimate	SE	*p*-value
Intercept	57.301	3.971	<0.0001	54.804	2.956	<0.0001
Brownfield (ref. <5)						
<32	1.277	3.343	0.7024	−1.307	2.486	0.5992
<152	10.934	3.466	0.0016	7.273	2.578	0.0048
<708	13.982	4.371	0.0014	12.959	3.251	<0.0001
>708	23.953	7.764	0.0020	17.497	5.775	0.0025
MED-Ix (ref. −2)						
−1	0.624	0.631	0.323	−0.113	0.469	0.8083
0	0.065	0.731	0.9292	−0.114	0.544	0.8336
1	1.022	0.814	0.2091	0.464	0.605	0.4434
2	2.233	0.907	0.0138	1.178	0.674	0.0808
3	3.711	2.109	0.0786	0.621	1.569	0.6922
White	−0.171	0.021	<0.0001	−0.019	0.015	0.2187
Unemployment	0.065	0.035	0.0596	0.060	0.026	0.0194
Education	1.017	0.038	<0.0001	0.817	0.028	<0.0001
Socioeconomic status	0.521	0.040	<0.0001	0.384	0.030	<0.0001
Cars	0.276	0.043	<0.0001	0.177	0.032	<0.0001
Tenure	0.013	0.028	0.6290	0.036	0.021	0.0890
Settlement type (ref. village)	−0.774	0.480	0.1071	−0.150	0.357	0.6746
urban	−0.375	0.431	0.3836	−0.354	0.320	0.2691
town	0			0		
Deprivation	4.106	0.291	<.0001	3.029	0.216	<0.0001
Interactions						
Car×brownfield <32	0.049	0.068	0.4688	0.039	0.050	0.4326
Car×brownfield <152	−0.046	0.064	0.4665	−0.077	0.047	0.1064
Car×brownfield <708	0.069	0.072	0.3593	−0.034	0.056	0.5407
Car×brownfield >708	0.132	0.113	0.2428	0.029	0.084	0.7239
Deprivation×brownfield <32	−0.348	0.455	0.4440	-0.147	0.338	0.6629
Deprivation 1×brownfield <152	−0.171	0.406	0.6743	0.157	0.302	0.6035
Deprivation×brownfield <708	−0.834	0.450	0.0641	−0.437	0.335	0.1917
Deprivation×brownfield >708	−2.098	0.727	0.0039	−1.302	0.540	0.0160
Tenure×brownfield <32	−0.053	0.047	0.2672	−0.005	0.035	0.8883
Tenure×brownfield <152	−0.155	0.046	0.0008	−0.080	0.034	0.0206
Tenure×brownfield <708	−0.252	0.053	<0.0001	−0.186	0.039	<0.0001
Tenure×brownfield >708	−0.420	0.100	<0.0001	−0.280	0.074	0.0002
Random effects						
Intercept	124.13	10.01		69.796	5.63	
Residuals	78.49	1.27		43.423	0.70	

Effects	Premature all-cause mortality		
	estimate	SE	*p*-value
Intercept	63.163	5.392	<0.0001
Brownfield (ref. <5)			
<32	−2.897	5.221	0.5790
<152	−0.509	5.404	0.9249
<708	6.582	6.820	0.3345
>708	0.011	12.118	0.9993
MED-Ix (ref. −2)			
−1	0.606	0.969	0.5314
0	0.544	1.094	0.6189
1	2.325	1.196	0.0519
2	3.818	1.335	0.0042
3	7.484	3.181	0.0187
White	0.056	0.029	0.0584
Unemployment	−0.029	0.050	0.5611
Education	0.327	0.057	<0.0001
Socioeconomic status	0.474	0.059	<0.0001
Cars	0.760	0.066	<0.0001
Tenure	−0.136	0.043	0.0018
Settlement type (ref. village)	−3.826	0.735	<0.0001
urban	−3.235	0.669	<0.0001
town	0		
Deprivation	2.578	0.448	<0.0001
Interactions			
Car×brownfield <32	−0.138	0.107	0.1953
Car×brownfield <152	0.066	0.100	0.5058
Car×brownfield <708	0.359	0.118	0.0024
Car×brownfield >708	0.894	0.176	<0.0001
Deprivation×brownfield <32	1.096	0.713	0.1244
Deprivation 1×brownfield <152	0.310	0.630	0.6256
Deprivation×brownfield <708	−1.917	0.703	0.0064
Deprivation×brownfield >708	−5.017	1.133	<0.0001
Tenure×brownfield <32	0.122	0.074	0.1011
Tenure×brownfield <152	0.005	0.072	0.9397
Tenure×brownfield <708	−0.240	0.083	0.0040
Tenure×brownfield >708	−0.427	0.156	0.0064
Random effects			
Intercept	45.201	4.440	
Residuals	194.080	3.169	

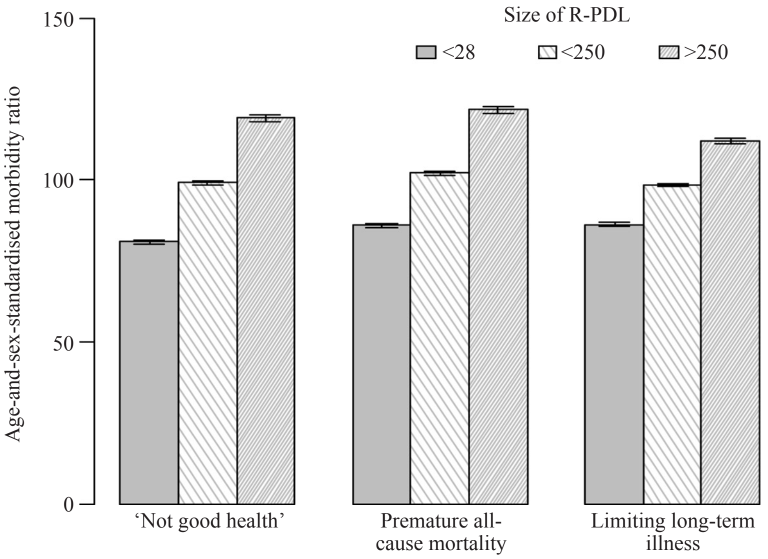


Figure 3. Unadjusted association between 'not good health', limiting long-term illness, premature all-cause mortality, and the proportion of brownfield land (R-PDL).

Discussion

This study—the first to examine the national-level association between brownfield land and health—has found a significant, strong, nonlinear bivariate area-level association between brownfield land and 'not good health', limiting long-term illness, and all-cause premature mortality. Wards with larger proportions of brownfield land had significantly higher morbidity and mortality, compared with wards with smaller amounts of brownfield. This relationship remained for both of the morbidity (but not the mortality) outcomes after adjusting for multiple environmental deprivation and individual and area-level socioeconomic and demographic characteristics. The results of this analysis suggest that brownfield land is potentially an important environmental determinant of population health.

These results reinforce other research which has emphasised the need to reexamine the importance of the physical environment as part of the contextual area effects on health and wellbeing (Shortt et al, 2011). As a result of our study, it can also now be argued that brownfield land should itself be considered as an element of environmental deprivation. Previous studies of environmental deprivation have focused largely on differential access to green space (de Vries et al, 2003; Maas et al, 2006; 2009 Mitchell and Popham, 2007; 2008; Nielsen and Hansen, 2007), waste facilities (Maruzzi et al, 2010), and air pollution (Stafford and McCarthy, 2006); and even the multiple environmental deprivation index developed by Richardson and colleagues (2010) did not feature brownfield land as a physical hazard. The findings of this study demonstrate that any future development or refinement of measures of environmental deprivation should take the proportion of brownfield land in neighbourhoods into account.

There is also a need to further explore the mechanisms behind the association between brownfield land and morbidity to establish whether it is toxicological, psychosocial, or behavioural in origin. This will require additional studies and the collection of new data.

Limitations

This study is subject to some general design limitations. Given the cross-sectional study design, it is not possible to rule out selection effects whereby people with worse health end up residing in areas with more brownfield. This study has only been able to examine association and a longitudinal design would be required to explore issues of causation. Further, as this is an area-level study, it is also prone to the ecological fallacy and it needs to be kept in mind that what holds at the area level may not necessarily be true at the individual level. The geographic level of the analysis should also be considered as this study only examined small-scale geographies (wards). It is possible that the relationship between brownfield land and health could vary at larger geographic levels such as local authorities (Macintyre et al, 2008).

A more specific study limitation relates to the definition of brownfield land. The definition used is very encompassing and covers a wide variety of land uses. Some brownfield land may be contaminated, some not; some may be used recreationally, some not; and so forth. It was not possible given the NLUD database to discriminate in our analysis between different types of brownfield land. We have also looked only at the quantity of brownfield rather than the quality. The extent to which brownfield land differs from green space also needs to be considered as, whilst the NLUD used in this study only recorded PDL, it is possible that some of this could be categorised as green space depending on how broadly green space is defined and measured (Mitchell et al, 2011). However, this study has used the best—and only—data source available on brownfield land in England, although the caveats applying to the dataset (Homes and Communities Agency, 2012c) apply also to this research—most notably that only an average of 72% of brownfield land in England is covered by the dataset.

Limitations in the data sources available meant that brownfield-land data from 2009 were necessarily compared with census data from 2001 and premature all-cause mortality data from 1998/99–2002/03, as these were the most up-to-date data available at ward-level at the time of analysis. This will have inevitably introduced some inaccuracies, as demographic changes between 2001 and 2009 in particular would not be reflected. There were small changes in PDL, which declined by 6% between 2002 and 2009, with vacant and derelict land decreasing by 18% and land currently in use with potential for redevelopment increasing by 12% (Homes and Communities Agency, 2011). Since the NLUD has only been compiled since 2002, and has been increased in scope and accuracy between then and 2009, the decision to compare the most up-to-date health and brownfield datasets was made in order to ensure the best available data for all variables. Further, the assumption of circular sites centred on the 'location' coordinate from the NLUD is a necessary but consistent abstraction, given that the NLUD data do not specify whether the 'location' grid reference relates to an entrance, centre point, boundary, or other distinguishing feature. Manual identification of the boundaries of each brownfield site was not feasible within the context of the present study and adoption of a consistent method was a necessary compromise.

Conclusion

This paper is the first to examine the area-level association between brownfield land and health using national-level data. It has demonstrated a strong, significant, small-area-level, independent association between brownfield land and morbidity in England. This suggests that exposure to brownfield land could be an important environmental determinant of population health and a hitherto overlooked additional element of environmental deprivation. The remediation and redevelopment of brownfield land should therefore be considered as a public health policy issue However, the mechanisms underpinning the association need to be explored further.

Acknowledgements. The authors would like to thank the wider ROBUST project team and steering group for general advice. The national land-use data are Crown Copyright. Census Area Statistics (CAS) ward boundaries are Crown Copyright and were provided through EDINA UKBORDERS with the support of the ESRC and JISC. The census and mortality data for England are Crown Copyright and have been provided by the Office for National Statistics. We gratefully acknowledge this support. Research data for this paper is available—contact clare.bambra@durham.ac.uk for details.

Funding. The work was supported by EPSRC grant number EP/G028958/1 (Investigators KJ and CB) and by a Durham University Wolfson Research Institute for Health and Wellbeing Small Grant.

Author contribution statement. The idea for the study originated from discussions between CB and KJ. CB designed and supervised all stages of the study with support from SR. Data collection was conducted by JS and SR with support from JC. Mapping was done by AC. Data analysis was conducted by AK with input from AC and CB. CB drafted the paper and all authors contributed to editing and revising the paper.

References

Abraham A, Sommerhalder K, Abel T, 2010, "Landscape and well-being: a scoping study on the health-promoting impact of outdoor environments" *International Journal of Public Health* **55** 59–69

Airey, L, 2003 " 'Nae as nice a scheme as it used to be': lay accounts of neighbourhood incivilities and well-being" *Health and Place* **9** 129–137

Bambra C, 2011 *Work, Worklessness and the Political Economy of Health* (Oxford University Press, Oxford)

Batuman V, Landy E, Maesaka J K, Wedeen R P, 1983, "Contribution of lead to hypertension with renal impairment" *The New England Journal of Medicine* **309** 17–21

Baum A, Fleming R, Singer J E, 1985, "Understanding environmental stress: strategies for conceptual and methodological integration", in *Advances in Environmental Psychology* Eds A Baum, J E Singer (Erlbaum Associates, New Jersey) pp 185–205

Braubach M, Fairburn J, 2010, "Social inequities in environmental risks associated with housing and residential location—a review of the evidence" *European Journal of Public Health* **20** 36–42

Bush J, Moffat S, Dunn C, 2001, " 'Even the birds round here cough': stigma, air pollution and health in Teesside" *Health and Place* **7** 47–56

Cairns J M, Curtis S E, Bambra C, 2012, "Defying deprivation: a cross-sectional analysis of area-level health resilience in England" *Health and Place* **18** 928–933

Catney P, Eiser D, Henneberry J, Stafford T, 2007, "Democracy, trust and risk related to contaminated sites in the UK", in *Sustainable Brownfield Regeneration: Liveable Places from Problem Spaces* Eds T Dixon, M Raco, P Catney, D N Lerner (Blackwell, Oxford) pp 35–66

Cattell V, 2001. "Poor people, poor places and poor health: the mediating role of social networks and capital" *Social Science and Medicine* **52** 1501–1516

Concerted Action on Brownfield and Economic Regeneration Network, 2012, "Model 2: 'Brownfield Redevelopment Types, the A-B-C Model', http://www.cabernet.org.uk/index.asp?c=1312

Copeland A, 2002 *Elderly People in Barking & Dagenham and Havering: Small Area Variations in the Population and Use of Care* Institute of Community Health Sciences, Queen Mary, University of London

Craft A W, Openshaw S, J M Birch, 1985, "Childhood cancer in the Northern Region, 1968–82: incidence in small geographical areas" *Journal of Epidemiology and Community Health* **39** 53–57

Cummins S, Stafford M, Macintyre S, Marmot M, Ellaway A, 2005, "Neighbourhood environment and its association with self-rated health: evidence from Scotland and England" *Journal of Epidemiology and Community Health* **59** 207–213

Curtis S, 2010 *Space, Place and Mental Health* (Farnham, Ashgate)

Davey Smith G, Charsley K, Lambert H, Paul S, Fenton S, Ahmad W, 2001, "Ethnicity, health and the meaning of socio-economic position", in *Understanding Health Inequalities* Eds H Graham (Buckingham, Open University Press) pp 25–37

de Vries S, Verheij RA, Groenewegen PP, Spreeuwenberg, 2003, "Natural environments—healthy environments? An exploratory analysis of the relationship between greenspace and health" *Environment and Planning A* **35** 1717–1731

Elliott S J, Taylor M, Walter S, Stieb D, Franks J, Les J, 1993, "Modeling psychosocial effects of exposure to solid waste facilities" *Social Science and Medicine* **37** 791–804

Environment Agency, 2005 *Indicators for Land Contamination. Science Report SC030039/SR* Environment Agency, Bristol, publications.environment-agency.gov.uk/.../SCHO0805BJMD-e-e.pdf

Environment Agency, 2009 *Human Health Toxicological Assessment of Contaminants In Soil. Science Report SC050021/SR2* Environment Agency, Bristol, http://www.environment-agency.gov.uk/static/documents/Research/TOX_guidance_report_-_final.pdf

Fu H, Boffetta P, 1995, "Cancer and occupational exposure to inorganic lead compounds: a meta-analysis of published data" *Occupational and Environmental Medicine* **52** 73–81

Gardella C, 2001, "Lead exposure in pregnancy: a review of the literature and argument for routine prenatal prenatal screening" *Obsterical and Gynecological Survey* **56** 231–238

Goffman E, 1963 *Stigma: Notes on the Management of Spoiled Identity* (Penguin, Harmondsworth, Middx)

Hartig T, Evans G W, Jamner L D, Davis D S, Garling T, 2003, "Tracking restoration in natural and urban field settings" *Journal of Environmental Psychology* **23** 109–123

Health Protection Agency, 2010 *An Introduction to Land Contamination for Public Health Professionals Cardiff* http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1242198452810

Health Protection Agency, 2012 *Compendium of Chemical Hazards* http://www.hpa.org.uk/Topics/ChemicalsAndPoisons/CompendiumOfChemicalHazards/

Homes and Communities Agency

2011, "Previously developed land that may be available for development: results from the 2009 National Land Use Database of Previously-Developed Land in England", http://www.homesandcommunities.co.uk/sites/default/files/our-work/nlud-report-2009.pdf

2012a, "2009 Site level data reported in the National Land Use Database (NLUD)", http://www.homesandcommunities.co.uk/sites/default/files/our-work/NLUD2009SitesMV.zip

2012b, "Publications and data: previously developed land report", http://www.homesandcommunities.co.uk/ourwork/publications-and-data

2012c, "NLUD-PDL results and analysis, 2009 site level data", http://www.homesandcommunities.co.uk/nlud-pdl-results-and-analysis

Lin J L, Lin-Tan D T, Hsu K H and Yu C C, 2003, "Environmental lead exposure and progression of chronic renal diseases in patients without diabetes" *The New England Journal of Medicine,* **348** 277–286

Litt JS, Burke TA, 2002. "Uncovering the historic environmental hazards of urban brownfields". *Journal of Urban Health*, **79** 464–481

Litt J S, Tran N L, Burke T A, 2002, "Examining urban brownfields through the public health 'macroscope'" *Environmental Health Perspectives* **110** 183–193

Maas J, Verheij R A, Groenewegen P P, de Vries S, Spreeuwenberg P, 2006, "Green space, urbanity, and health: how strong is the relation?" *Journal of Epidemiology and Community Health* **60** 587–592

Maas J, Verheij R A, de Vries S, Spreeuwenberg P, Schellevis F G, Groenewegen P P, 2009, "Morbidity is related to a green living environment" *Journal of Epidemiology and Community Health* **63** 967–973

Macintyre S, Ellaway A, Kearn A, Hiscock R, 2000, "Housing tenure and car ownership: why do they predict health and longevity?", Research Findings from the Health Variations Programme, Economic and Social Research Council, Swindon

Macintyre S, Hiscock R, Kearns A, Ellaway A, 2001, "Housing tenure and health inequalities: a three-dimensional perspective on people, homes and neighbourhoods", in *Understanding Health Inequalities* Ed. H Graham (Open University Press, Buckingham) pp 129–142

MacIntyre S, Macdonald L, Ellaway A, 2008, "Do poorer people have poorer access to local resources and facilities? The distribution of local resources by area deprivation in Glasgow, Scotland" *Social Science and Medicine* **67** 900–914

Marmot M, 2010 *Fair Society, Healthy Lives: The Marmot Review* University College, London

Martuzzi M, Mitis F, Forastiere F, 2010, "Inequalities, inequities, environmental justice in waste management and health" *European Journal of Public Health* **20** 21–26

Mitchell R, Popham F, 2007, "Greenspace, urbanity and health: relationships in England" *Journal of Epidemiology and Community Health* **61** 681–683

Mitchell R, Popham F, 2008, "Effect of exposure to natural environment on health inequalities: an observational population study" *Lancet* **372** 1655–1660

Mitchell R, Astell-Burt T, Richardson E A, 2011, "A comparison of green space indicators for epidemiological research" *Journal of Epidemiology and Community Health* **65** 853–858

Nielsen T S, Hansen K B, 2007, "Do green areas affect health? Results from a Danish survey on the use of green areas and health indicators" *Health and Place* **13** 839–850

Openshaw S, Charlton M, Craft A W, Birch J M, 1988, "Investigation of leukaemia clusters by use of a geographical analysis machine" *Lancet* **331** 8580, 272–273

Pearce J R, Richardson E A, Mitchell R J, Shortt N K, 2010, "Environmental justice and health: the implications of the socio-spatial distribution of multiple environmental deprivation for health inequalities in the United Kingdom" *Transactions of the Institute of British Geographers, New Series* **35** 522–539

Prasad L R, Nazareth B, 2000, "Contamination of allotment soil with lead: managing potential risks to health" *Journal of Public Health Medicine* **22** 525–530

Richardson E A, Mitchell R, 2010, "Gender differences in relationships between urban green space and health in the United Kingdom" *Social Science and Medicine* **71** 568–575

Richardson E, Mitchell R, Shortt N K, Pearce J, Dawson T, 2010, "Developing summary measures of health-related multiple physical environmental deprivation for epidemiological research" *Environment and Planning A* **42** 1650–1668

Shortt N, Richardson E A, Mitchell R, Pearce J, 2011, "Re-engaging with the physical environment: a health-related environmental classification of the UK" *Area* **43** 76-87

Stafford M, McCarthy M, 2006, "Neighbourhoods, housing and health", in *Social Determinants of Health* Eds M Marmot, R G Wilkinson (Oxford University Press, Oxford) pp 78–96

Stafford M, Cummins S, Macintyre S, Ellaway A, Marmot M, 2005, "Gender differences in the association between health and neighbourhood environment" *Social Science and Medicine* **60** 1681–1692

Thomson H, Petticrew M, Morrison D, 2001, "Health effects of housing improvement: systematic review of intervention studies" *British Medical Journal* **323** 187–190

Townsend P, Phillimore P, Beattie A, 1988 *Health and Deprivation: Inequality and the North* (Croom Helm, London)

Wakefield S, McMullan C, 2005, "Healing in places of decline: (re)imagining everyday landscapes in Hamilton, Ontario" *Health and Place* **11** 299–312

Whitehead M, Dahlgren G, 1991, "What can be done about inequalities in health?" *The Lancet* **338** 1059–1063

World Health Organisation, 2008 *Commission on the Social Determinants of Health: Closing the Gap in a Generation* (World Health Organisation, Geneva)