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This divided land: An examination of regional inequalities in exposure to brownfield land and the association with morbidity and mortality in England



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ABSTRACT

This paper is the first empirical examination of the association between brownfield land and spatial inequalities in health. Linear mixed modelling of ward-level data suggests that there is higher exposure and susceptibility to brownfield land in the Northern compared to the Southern regions (with the exception of London); that brownfield exposure has an association with regional inequalities in mortality and morbidity within regions (particularly in the North West); that brownfield has an association with inequalities between regions (particularly between the North West and the South East); but that brownfield land only makes a small independent contribution to the North–South health divide in England. However, brownfield land could be a potentially important and previously overlooked independent environmental determinant of spatial inequalities in health in England.

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1. Introduction

1.1. Regional inequalities in health

England has some of the largest regional inequalities in health in Europe, particularly between the Northern regions (North West, North East and Yorkshire and the Humber) and those of the South (particularly London and the South East). By way of example, recent data from Public Health England shows that between 2009 and 2011 people in Manchester were more than twice as likely to die early (455 deaths per 100,000) as people living in Wokingham (200 deaths per 100,000) (PHE, 2013). A baby boy born in Manchester can expect to live for 17 fewer years in good health, than a boy born in Richmond in London. Similarly, a baby girl born in Manchester can expect to live for 15 fewer years in good health. The health divide has increased over the past four decades (Hacking et al., 2011), the North of England has persistently had higher all-cause mortality rates than the South of England, with people in the North consistently found to be less healthy than those in the South-across all social classes and amongst men and

women (Dorling, 2010). Since 1965, this has amounted to 1.5 million excess premature deaths (CLES, 2014). The scale of the divide is such that the life expectancy gap for women between the North East and North West compared to London and the South East was similar to the gap between the former West Germany and post-communist East Germany in the mid-1990s (Bambra et al., 2014a). There are also significant inequalities in health between areas within the English regions: area-level health is inversely associated with socio-economic disadvantage, resulting in the large inequalities in health between deprived and affluent areas. These within region inequalities in health are larger in the North than in the South and the social gradient is steeper. For example, the local authority with the largest gap in male life expectancy in England is the borough of Stockton-on-Tees in the North East, where the gap between the most and least affluent wards is 16 years (Marmot Indicators, 2012).

1.2. Deprivation and regional inequalities in health

Traditionally, most research in health geography has focused on socio-economic explanations of these regional inequalities in health, citing both compositional and contextual factors, particularly the interplay of individual and area-level socio-economic

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E-mail address: clare.bambra@durham.ac.uk (C. Bambra).

Box 1–Description of data and variables (reproduced from Bamba et al. (2014a, 2014b) under open access)**Brownfield land data and variables**

Data on the proportion of previously developed land (brownfield) was obtained from the 2009 National Land Use Database (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 was 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 was 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 the 31st of March of a given year, and where a submission was not made, the previous years’ data was 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 non-response. 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 was obtained from the 2001 Census and calculated as the proportion of ‘not good’ responses to 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 was 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) was 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 seven-fold 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 downloaded from: <http://cresh.org.uk/cresh-themes/environmental-deprivation/medix-and-medclass/>

Demographic and socio-economic data and variables

Area-level socio-economic deprivation was measured using the well-validated Townsend Index of Deprivation for 2001 ([Townsend et al., 1988](#)). This index uses unemployment, private renting, no car ownership, and overcrowding census variables to define material deprivation. Individual-level data relating to demographic and socio-economic 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) residents. The proportion of the 16–74 year old population of non-professional socio-economic class (intermediate occupations, lower supervisory and technical occupations, semi-routine occupations, routine occupations, never worked, and long-term unemployed) was calculated using the National Statistics socio-economic classification. Educational qualification was measured as the proportion of adults age 16–74 with no qualifications. The proportion of 16–74 year olds who were in full or part-time 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 was obtained from the [Office for National Statistics \(2004\)](#) and is based on the Department for Environment and Rural Affairs’ rural/urban classification which defines the urbanity/rurality of different geographies. CASWARDS are classified using a threefold grouping: (1) urban; (2) town & fringe; and (3) village, hamlet or dispersed.

Regions

Each CAS ward was assigned to one of nine regions: North East, North West, Yorkshire and Humber, East Midlands, West Midlands, East of England, London, South East and South West. Until 2013, the nine regions all had Government Offices which were administratively and economically important in terms of having some devolved responsibility for the local economy including the allocation of regional development funds, drawing up regional economic strategies, and encouraging inward regional investment (including the receipt of European Union funding). Regional public health groups and Strategic Health Authorities also existed at a regional level and some public health interventions were regionally operated and coordinated. To examine the North–South divide, in common with other research, the North East, North West, and Yorkshire and Humber were merged to be the North whilst the East Midlands, West Midlands, East of England, London, South East and South West were merged to be the South ([CLES, 2014](#)).

deprivation. For example, [Sloggett and Joshi \(1998\)](#) observed regional variations in mortality and the North–South differences in mortality remained significant (although small) even after controlling for individual level deprivation. Certainly, there is strong evidence of socio-economic inequalities as over the past 20 years the North has consistently had lower employment rates – of at least 10 percentage points – than the South for both men and women ([ONS, 2012](#); [Jenkins and Leaker, 2010](#)). Welfare receipt, ill health related worklessness and poverty rates are also much

higher in the North than the South. By way of example, poverty disproportionately affects the North – whilst it has 30% of the population of England it includes 50% of the poorest neighbourhoods ([CLES, 2014](#)). Further, the most deprived areas in the South have better health outcomes than equally deprived areas in the North ([CLES, 2014](#)). It is often argued that this is related to the economic effects of deindustrialisation as, in the latter part of the 20th century, there were regionally concentrated falls in the demand for labour (most notably in the North East, North West and

Table 1

Prevalence of brownfield land by region in hectares (ha), percentage of area (%) and by categories of previously developed land (n/%, small, medium, large PDL).

Regions	Land Areas (ha)	Brownfield Land (ha)	Percentage of Brownfield land (%)	Comparison of average brownfield area (ha) with South East (MD (95% CI))	Prevalence of Brownfield by ward categories (n(%))		
					Small < 28	Moderate > 28 and < 250	Large > 250
South East	1188592.7	7089.5	0.60	–	383 (42.6)	395 (43.9)	122 (13.5)
South West	1501446.7	4041	0.27	–2.089 (–4.77, 0.61)	233 (33.7)	387 (55.9)	72 (10.4)
North East	527152.2	3385.4	0.64	3.37 (–0.17, 6.91)	116 (38.5)	120 (39.8)	65 (21.6)
North West	719760.7	8851.9	1.23	4.43 (1.77, 7.09)*	327 (45.4)	197 (27.4)	196 (27.2)
Yorkshire & Humber	1067889.0	5126.4	0.48	6.52 (3.19, 9.85)*	160 (44.9)	145 (40.7)	51 (14.3)
East Midlands	955592.7	4265.6	0.40	–0.54 (–3.37, 2.30)	217 (37.3)	283 (48.7)	81 (13.9)
West Midlands	691961.1	3787.1	0.54	0.03 (–2.98, 3.04)	201 (42.0)	191 (39.9)	87 (18.1)
East of England	965592.7	4401.2	0.40	–1.39 (4.09, 1.32)	250 (36.9)	363 (53.5)	65 (9.6)
London	118143.0	3047.9	2.58	–0.59 (–3.74, 2.56)	193 (46.2)	93 (22.2)	132 (31.6)

MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

* $P < 0.05$.

South Yorkshire), particularly affecting those with less education (Nickell and Quintini, 2002). The occupational legacy of diseases associated with heavy industry in the North is also sometimes cited as a contributory factor (Bamba, 2011). However, there is a need for public health geographers to look beyond the purely socio-economic explanations and to look at the wider environmental effects of deindustrialisation and how these have shaped places, health within these places and health between places – specifically between the Northern and Southern regions of England.

This is where a new body of work which examines environmental deprivation and health could be usefully applied. Environmental deprivation is the extent of exposure to key characteristics of the physical environment that are either health promoting or health damaging such as air pollution, climate temperature, solar UV radiation, proximity to industry, proximity to waste facilities (including incinerators, landfills, and hazardous waste sites), and access to green space (Pearce et al., 2010; Richardson et al., 2010; Braubach and Fairburn, 2010; Martuzzi et al., 2010). A UK wide study found that mortality was associated with environmental deprivation even after controlling for socio-economic factors: area-level health progressively worsened as the multiple environmental deprivation increased (Pearce et al., 2010). In a previous paper, we argued that brownfield land should also be considered as an element of environmental deprivation as we found a significant and strong, area-level association at a national scale in England between brownfield land and morbidity: people living in areas (wards) with a high proportion of brownfield land were significantly more likely to suffer from poorer health than those living in wards with a small proportion of brownfield (Bamba et al., 2014b). Brownfield land is a way of capturing some of the aspects of environmental deprivation that are associated with deindustrialisation: regionally concentrated declines in heavy industries, such as coal mining, steel, ship building, engineering and textiles, not only led to higher levels of unemployment and associated socio-economic deprivation but also left a legacy of environmental deprivation in the form of a higher prevalence of disused, often contaminated, industrial sites – brownfield land.

In this paper brownfield land 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). It is 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, p. xii)] as a result of their previous industrial, landfill, or transport use (p. 36).

Brownfield land could potentially be an important environmental factor in the aetiology of regional inequalities in health in England in at least two ways: (1) there may be spatial inequalities in exposure to the health risks associated with brownfield land if it is spatially concentrated; and (2) there may be spatial inequalities in susceptibility to the negative health risks of brownfield land. In this paper, ‘exposure’ is simply proximity to brownfield land since the measure we are using does not allow us to examine public accessibility to such land. ‘Susceptibility’ refers to the extent to which poor health (measured by mortality and morbidity) is influenced by exposure to brownfield land.

Firstly, previous research has suggested that brownfield sites (particularly those of low value and of a small size) are disproportionately located in deprived areas. For example, over 67% of people in the most deprived areas of Scotland live within 600 m of derelict land compared to only 13.9% of people in the most affluent areas (Braubach and Fairburn, 2010). This was also demonstrated in an urban study of local neighbourhood resources in Glasgow, Scotland which found a stepwise significant small area association between level of deprivation and proximity to vacant or derelict land or buildings (MacIntyre et al., 2008). 64% of the least deprived quintile of small areas was within 500 m of a vacant or derelict land or building compared to 97% of the most deprived quintile of small areas (MacIntyre et al., 2008). USA research into brownfield land has also found that it is geographically concentrated in low income neighbourhoods (Litt et al., 2002). People living in deprived ex-industrial communities are therefore far more likely to be exposed to brownfield land and its toxicological and any other ill-health effects. Similarly, environmental deprivation studies conducted in the UK have found considerable spatial inequalities with greater environmental deprivation in urban and industrial areas and the Northern region (Richardson et al., 2010).

Secondly, there are also issues about potential spatial inequalities in susceptibility to the effects of exposure to environmental health risks. For example, a study by Stafford and colleagues (2008) demonstrates that the health effects of exposure to poor environments varies by individual level characteristics as some people within a neighbourhood will have higher levels of exposure (e.g. because they spend more time in the neighbourhood), and some are more vulnerable to exposure. Often these are the old, the young, and those of lower socio-economic status (Pearce et al., 2010). There is also evidence to suggest that the negative health effects of the physical environment vary by gender with women

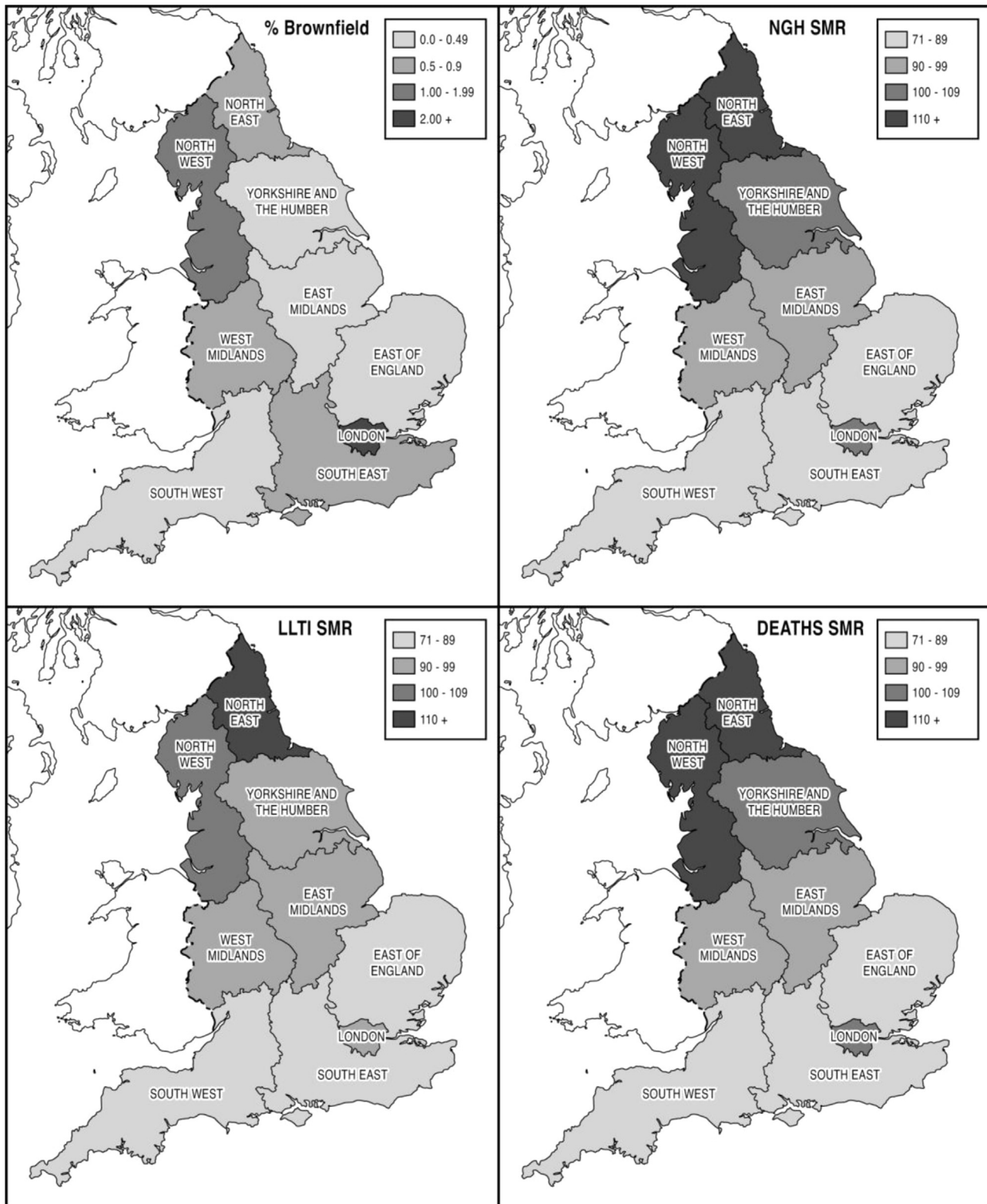


Fig. 1. Regional comparison of the prevalence of brownfield land (%) standardised mortality rates (deaths SMR) and standardised morbidity rates for limiting longterm illness (LLTI) and not good health (NGH).

more affected than men (Stafford et al., 2005; Martuzzi et al., 2010; Cummins et al., 2005) and that the beneficial impacts of green space are felt more by men than women (Richardson and Mitchell, 2010). Susceptibility to the negative health effects of brownfield might be similarly socially patterned.

There is an absence in the literature of experimental studies

that have investigated the potential aetiological pathways through which brownfield land may affect health. However, it seems plausible that the mechanisms through which brownfield land contributes to health inequalities may be both physiological via direct toxicological effects of contamination and psychosocial via stigmatisation and the 'spoiled identity' that comes with residing

Table 2

Model based distribution of age and sex standardised premature all-cause mortality ratio by regions (*within*) and brownfield categories. The adjusted analysis accounted for multiple environmental deprivation score, Townsend Index of Deprivation (area-level), and individual-level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types.

Region	Brownfield categories MEAN(SE)			Unadjusted Spatial inequality within regions MD (95% CI) ^a		Adjusted Spatial inequality within regions MD (95% CI) ^a	
	Small < 28	Moderate > 28 and < 250	Large > 250	Medium	Large	Medium	Large
South East	81.4 (1.5)	89 (1.5)	103.1 (2.1)	7.5 (4.8; 10.3)*	21.7 (17.6; 25.8)*	-0.6 (-2.7; 1.4)	4.5 (1.5; 7.6)*
South West	78.2 (1.6)	91.1 (1.7)	99.6 (2.6)	12.9 (9.8; 16)*	21.4 (16.6; 26.2)*	2.0 (-1.7; 5.8)	3.3 (-0.5; 7.1)
North East	105.7 (2.9)	118.4 (2.9)	145.7 (3.8)	12.6 (5; 20.3)*	39.9 (30.8; 49)*	1.2 (-1.7; 5.8)	8.9 (6.4; 12.4)*
North West	101.6 (2.8)	115.1 (2.5)	138.9 (2.9)	13.5 (8.4; 18.7)*	37.3 (31.4; 43.2)*	1.9 (-0.7; 4.4)	9.4 (6.4; 12.4)*
Yorkshire & Humber	91.7 (3.2)	106.2 (3.2)	125.6 (4.1)	14.5 (9.2; 19.8)*	33.8 (26.4; 41.3)*	0.4 (-2.9; 3.7)	0.5 (-4.2; 5.2)
East Midlands	92.8 (2.6)	102.6 (2.6)	106.8 (3.3)	9.9 (5.7; 14)*	14.0 (8.1; 20)*	-1.2 (-3.8; 1.4)	1.0 (-2.7; 4.7)
West Midlands	89.8 (2.5)	101.1 (2.5)	114.2 (3.1)	11.3 (6.8; 15.8)*	24.4 (18.5; 30.3)*	-0.6 (-3.6; 2.4)	2.8 (-1.1; 6.7)
East of England	84.4 (1.6)	91.6 (1.7)	99.9 (2.7)	7.2 (4; 10.3)*	15.5 (10.3; 20.7)*	-1.9 (-4.3; 0.4)	0.8 (-3.0; 4.7)
London	101.3 (3.5)	106.2 (3.1)	114.5 (3.2)	4.9 (-0.4; 10.2)	13.2 (7.5; 18.8)*	-3.1 (-1.6; 0.5)	-0.1 (-4.0; 3.7)

MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

* $p < 0.05$.

^a Reference is small for each region.

in a discredited area as a result of environmental factors such as air pollution or 'dirt' (Bush et al., 2001; Mitchell and Popham, 2007; Bamba et al., 2014b). Cattell (2001) and Airey (2003) have shown that such environmental place-based stigma can result in psychosocial stress (and associated ill health) and feelings of shame.

2. Research questions

In this paper, we examine (1) whether exposure to brownfield land is regionally patterned in England; (2) whether the association between brownfield land and health varies within and between the regions of England – including any differences in the North of England compared to the South of England; and (3) what contribution, if any, exposure to brownfield land makes to the North–South health divide in England. As such, it is the first academic paper to set out the regional distribution of brownfield land in England, the first study internationally to explore whether the association between brownfield land and health varies regionally within a country and the first to quantify its contribution to the health divide between the North and the South of England. The paper is also therefore the first to examine how a specific element of environmental deprivation contributes to regional inequalities in health.

3. Methods

3.1. Data and variables

Data on the proportion of previously developed land (brownfield) was obtained from the 2009 National Land Use Database (NLUD) (Homes and Communities Agency, 2012a). This represents the most recent, comprehensive, publicly available, national dataset of "previously developed land" in England (detailed further in Box 1). The dataset lists the size and geographic location of 72% of previously developed land (PDL) across England. 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 of 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 UK BORDERS. CAS wards represent small-area geographies of varying size with an average ward comprising 2,570 households (ranging from 222 households to 14,396 households). Wards in the District of the City of London were combined and the Isles of Scilly were omitted 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. Each CAS ward was assigned to one of the nine regions: North East, North West, Yorkshire and Humber, East Midlands, West Midlands, East of England, London, South East and South West (ONS Geography, 2010). This is detailed further in Box 1.

The proportion of previously developed land 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 a R-PDL equal to 50. The 7,941 wards were categorised by R-PDL using a finite component mixture model. The three resulting categories were (1) wards with no brownfield or no recorded brownfield ($n=2842$) or small amounts ($n=2146$) of brownfield (R-PDL = < 28), (2) wards with medium/moderate amounts ($n=2084$) of brownfield (R-PDL = > 28 and < 250) and (3) wards with relatively large amounts ($n=869$) of brownfield (R-PDL = > 250). The thresholds (< 28; > 28 and < 250; > 250) were based on finite component mixture model assuming three subgroups. A ward is allocated to the subgroup for which it had the highest probability based on the model. Bamba et al. (2014a, 2014b) discussed how different thresholds may affect the association between health outcome and brownfield. These thresholds (< 28; > 28 and < 250; > 250) were more conservative than the thresholds obtained when a higher number of subgroups was used.

Each CAS ward was assigned to one of nine regions: North East, North West, Yorkshire and Humber, East Midlands, West Midlands, East of England, London, South East and South West (ONS Geography, 2010). The regions are detailed further in Box 1.

Table 3

Model based distribution of age and sex standardised premature all-cause mortality ratio by regions (between) and brownfield categories. The adjusted analysis accounted for multiple environmental deprivation score, Townsend index of deprivation (area-level), and individual-level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types.

Region	Brownfield categories MEAN(SE)			Unadjusted spatial inequality between regions (MD (95% CI)) ^a			Adjusted spatial inequality between regions (MD (95% CI)) ^a		
	Small < 28	Moderate > 28 and < 250	Large > 250	Small	Medium	Large	Small	Medium	Large
South East	81.4 (1.5)	89 (1.5)	103.1 (2.1)	–	–	–	–	–	–
South West	78.2 (1.6)	91.1 (1.7)	99.6 (2.6)	–	2.1 (–3.5; 7.6)	–3.6 (–11.5; 4.3)	–	–4.3 (–7.4; –1.2)*	–7.3 (–12.0; –2.6)*
North East	105.7 (2.9)	118.4 (2.9)	145.7 (3.8)	–	27.4 (20.4; 34.4)*	39.3 (30.6; 48.0)*	–	1.9 (–2.2; 6.0)	3.6 (–1.7; 8.9)
North West	101.6 (2.8)	115.1 (2.5)	138.9 (2.9)	–	26.1 (20.8; 31.4)*	35.7 (29.0; 42.3)*	–	10.0 (6.9; 13.1)*	12.5 (8.4; 16.5)*
Yorkshire & Humber	91.7 (3.2)	106.2 (3.2)	125.6 (4.1)	–	17.3 (10.5; 24.2)*	22.6 (13.3; 31.8)*	–	–3.0 (–6.9; 0.8)	–8.1 (–13.6; –2.5)*
East Midlands	92.8 (2.6)	102.6 (2.6)	106.8 (3.3)	–	13.9 (8.2; 19.6)*	4.1 (–3.6; 11.8)	–	0.7 (–2.6; 4.0)	–2.2 (–6.8; 2.4)
West Midlands	89.8 (2.5)	101.1 (2.5)	114.2 (3.1)	–	12.3 (6.3; 18.2)*	11.3 (3.5; 19.2)*	–	0.0 (–3.4; 3.4)	–1.7 (–6.4; 3.0)
East of England	84.4 (1.6)	91.6 (1.7)	99.9 (2.7)	–	2.6 (–2.8; 8.0)	–3.2 (–11.2; 4.7)	–	–3.8 (–6.8; –0.7)*	–6.2 (–10.9; –1.4)*
London	101.3 (3.5)	106.2 (3.1)	114.5 (3.2)	–	17.0 (11.0; 23.0)*	11.7 (4.5; 18.9)*	–	–13.6 (–17.4; –9.8)*	–15.8 (–20.3; –11.2)*

MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

* $p < 0.05$.

^a The reference group is the South East small, medium and large respectively.

CAS ward-level age and sex standardised morbidity ratios (SMR) 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) mortality using data from the Office for National Statistics (ONS) for 1998/1999–2002/2003. Five years data for premature mortality was 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. The health variables are detailed further in Box 1.

CAS ward level data on potential confounders were also obtained: settlement type (from the ONS classification (2004)); 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 socio-economic characteristics: socio-economic classification, educational qualification, ethnic composition, economic activity, housing tenure and car ownership. These variables are detailed further in Box 1.

3.2. Data analysis

Descriptive data on the prevalence of brownfield land by region is presented in Table 1. In order to investigate the area-level association of health by brownfield categories and regions, we fitted two sets of multilevel models with the local authorities specified as random effects in order to capture variability of the health outcomes attributable to local authority's specific characteristics. The random effect model implies a population average model with exchangeable correlation between wards from the same local authority. The first set of models was used to investigate the association both unadjusted and adjusted between health and brownfield land within regions (2–9). The second set of models was used to investigate the association, both unadjusted and adjusted, between health and brownfield land between regions (2–9). The multilevel models were adjusted for multiple environmental deprivation score, Townsend Index of Deprivation (area-level), and individual level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types. The adjusted analyses rely on the assumption that spatial inequality does not interact with the other factors in the models.

In addition, we also quantified the percentage of the North–South health divide that can be independently attributed to brownfield for each health outcome. Initially, we fitted a model with only the region as the predictor and estimated the difference in the health outcomes between the North and the South (reference model). Several models (shown in Table 10) were then fitted with various confounders added. The percentage contribution of a variable or a combination of variables to the North–South health divide is defined as $100 * (\text{North–South health divide from reference model} - \text{North–South health divide from the model including the variable or combination of variables}) / \text{North–South health divide from the reference model}$. A similar definition of a percentage contribution was used by Skalická et al. (2009) for hazard ratios.

Table 4

Model based distribution of age and sex standardised self-reported not good health ratio by regions (*within*) and brownfield categories. The adjusted analysis accounted for multiple environmental deprivation score, Townsend Index of Deprivation (area-level), and individual-level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types.

Region	Brownfield categories MEAN(SE)			Unadjusted spatial inequality within regions (MD (95% CI) ^a)		Adjusted spatial inequality within regions (MD (95% CI) ^a)	
	Small < 28	Moderate > 28 and < 250	Large > 250	Medium	Large	Medium	Large
South East	68.3 (1.8)	74.7 (1.8)	83.4 (2.2)	6.4 (4; 8.7)*	15.1 (11.4; 18.7)*	-0.9 (-2.3; 0.4)	-0.6 (-2.7; 1.4)
South West	76.1 (1.9)	87.6 (2)	96.5 (2.5)	11.5 (8.8; 14.2)*	20.5 (16.3; 24.7)*	-0.1 (-1.8; 1.5)	2.9 (0.4; 5.4)*
North East	119.2 (5.5)	123.3 (5.5)	144.6 (6.1)	4.1 (-3.8; 12)	25.4 (15.7; 35)*	-0.2 (-2.7; 2.3)	0.9 (-2.2; 3.9)
North West	101.5 (3.7)	115.7 (3.4)	138.6 (3.7)	14.2 (9; 19.4)*	37.1 (31.1; 43.1)*	1.9 (0.2; 3.6)*	6.7 (4.7; 8.6)*
Yorkshire & Humber	95.4 (5.3)	107.7 (5.3)	129.2 (6.1)	12.3 (6.4; 18.1)*	33.8 (25.6; 42)*	-2.0 (-4.2; 0.2)	-1.2 (-4.3; 1.9)
East Midlands	88.7 (3.3)	98.6 (3.4)	98.7 (3.8)	9.9 (6; 13.8)	10 (4.5; 15.5)*	-1.0 (-2.8; 0.8)	-1.7 (-4.1; 0.8)
West Midlands	88 (3.4)	97.2 (3.4)	113.7 (3.9)	9.1 (4.5; 13.8)*	25.7 (19.6; 31.8)*	-1.7 (-3.7; 0.3)	2.3 (-0.4; 4.9)
East of England	75.8 (1.9)	82.6 (2)	87.4 (2.7)	6.9 (4.1; 9.6)*	11.6 (7.1; 16.1)*	-1.2 (-2.7; 0.4)	0.2 (-2.3; 2.8)
London	97.2 (4.4)	104.4 (4.1)	111.6 (4.2)	7.1 (2; 12.3)*	14.3 (8.8; 19.9)*	0.1 (-2.4; 2.4)	1.4 (-1.1; 3.9)

MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

* $p < 0.05$.

^a Reference is small for each region.

4. Results

4.1. Inequalities in exposure to brownfield land by region

The total land area for the wards in our dataset was 7,869,686 ha; 0.56% (43,977.83 ha) of this is classified as brownfield land. Table 1 provides data on the prevalence of brownfield land according to region. From this table we can see that in the main the North of the country has higher concentrations of brownfield land (e.g. North West has 1.23% amounting to 8,851.9 ha) compared to the South (e.g. South West has 0.27% amounting to 4,041 ha), with the exception of London which contains the highest concentration of brownfield land (2.58%; 3,047.9 ha) – for a full breakdown of brownfield land prevalence for all regions in England see Table 1 and Fig. 1. Based on the total brownfield land in England the contribution for each region is as follows: South East 16.11%; South West 9.18%; North East 7.69%; North West 20.12%; Yorkshire & Humber 11.65%; East Midlands 9.70%; West Midlands 8.61%; East of England 10.00%; London 6.93%.

Brownfield land prevalence in CAS wards was broken down further into small, moderate and large categories which clearly illustrates that wards in the North have greater exposure to large amounts of brownfield land (e.g. 27.2% of wards in the North West compared to 10.4% in the South West) but again the highest exposure of brownfield land is found in London with 31.6% of wards within London exposed to large areas of brownfield land.

4.2. Brownfield land and health within and between regions

4.2.1. Premature mortality

Table 2 displays the results from the unadjusted and adjusted analyses *within* regions for premature mortality. The adjusted results show that there is an additional 9.4% premature mortality rate in wards with large amounts of brownfield compared to wards with small amounts of brownfield land in the North West. The gap is 8.9% in the North East ($p < 0.05$). In contrast, in the South East there is only an additional 4.5% premature mortality rate ($p < 0.05$) in wards with large compared to small amounts of brownfield land.

Table 3 shows the results from the unadjusted and adjusted analyses *between* regions for premature mortality. After adjustments for confounders were made, the spatial inequalities *between* regions that remained statistically significant ($p < 0.05$) were for

the North West, South West, Yorkshire and Humber, East of England, and London (compared to the South East reference group). The region with the highest amount of additional mortality was the North West with 7.6%, 10%, and 12.5% in small, medium and large brownfield areas respectively compared to similar reference areas in the South East. On the contrary, London shows the opposite association with 11.1%, 13.6%, and 15.8% less mortality in small, medium and large brownfield areas respectively.

4.2.2. Self-reported not good health

Table 4 displays the results from the unadjusted and adjusted analyses *within* regions for self-reported 'not good health' (NGH). After adjusting for confounders, the only statistically significant ($p < 0.05$) gaps between wards with large and small amounts of brownfield land are in the North West (additional 6.7% cases of NGH) and the South West (additional 2.9% of cases of NGH). There are no significant differences in cases of NGH within areas of large and small brownfield in the other regions.

Table 5 shows the results from the unadjusted and adjusted analyses *between* regions for NGH. The adjusted analysis reveals that the regions which have statistically significant ($p < 0.05$) additional self-reported NGH compared to the South East reference are the South West, North East, North West, and East and West Midlands. The North West again has the highest number of additional cases of not good health with an excess of 20.2%, 23%, and 7.3% in small, medium and large brownfield areas respectively compared to similar reference areas in the South East.

4.2.3. Limiting long-term illness

Table 6 displays the results from the unadjusted and adjusted analyses *within* regions for limiting long-term illness (LLTI). The adjusted analysis shows that large brownfield areas within the North West have 3.3% additional LLTI compared to areas in the North West with low amounts of brownfield. The gap in the South West is 1.9% (as with NGH, the only two regions with results that were still significant ($p < 0.05$) after adjustments were made for confounders).

Table 7 shows the results from the unadjusted and adjusted analyses *between* regions for this health outcome. In the adjusted analysis, all of the regional differences except for the East of England and London remained statistically significant ($p < 0.05$). Similarly, the Northern regions had the highest burden of ill health across all types of brownfield relative to the South East reference areas. In the North West region there is an additional 15.1%, 15.6%,

Table 5
Model based distribution of age and sex standardised self-reported not good health ratio by regions (*between*) and brownfield categories. The adjusted analysis accounted for multiple environmental deprivation score, Townsend index of deprivation (area-level), and individual-level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types.

Region	Brownfield categories MEAN(SE)			Unadjusted Spatial inequality between regions (MD (95% CI) ^a)			Adjusted Spatial inequality between regions (MD (95% CI) ^a)		
	Small < 28	Moderate > 28 and < 250	Large > 250	small	Medium	Large	small	Medium	Large
South East	68.3 (1.8)	74.7 (1.8)	83.4 (2.2)	–	–	–	–	–	–
South West	76.1 (1.9)	87.6 (2)	96.5 (2.5)	7.7 (0.5; 15.0)*	12.8 (5.5; 20.2)*	13.1 (4.0; 22.3)*	4.2 (0.9; 7.6)*	5.0 (1.6; 8.4)*	7.8 (3.6; 11.9)*
North East	119.2 (5.5)	123.3 (5.5)	144.6 (6.1)	50.9 (41.7; 60.1)*	48.5 (39.3; 57.8)*	61.1 (50.6; 71.7)*	21.5 (17.2; 25.9)*	22.3 (17.9; 26.6)*	23.1 (18.2; 28.0)*
North West	101.5 (3.7)	115.7 (3.4)	138.6 (3.7)	33.2 (25.7; 40.8)*	40.8 (33.6; 48.1)*	55.1 (46.8; 63.3)*	20.2 (16.7; 23.8)*	23.0 (19.6; 26.5)*	27.5 (23.7; 31.4)*
Yorkshire & Humber	95.4 (5.3)	107.7 (5.3)	129.2 (6.1)	27.0 (17.7; 36.3)*	33.3 (24.0; 42.6)*	46.1 (35.1; 57.2)*	11.4 (7.1; 15.7)*	10.3 (6.0; 14.7)*	10.9 (5.8; 16.0)*
East Midlands	88.7 (3.3)	98.6 (3.4)	98.7 (3.8)	20.2 (12.7; 27.7)*	24.1 (16.5; 31.7)*	15.6 (6.5; 24.7)*	7.3 (3.8; 10.8)*	7.2 (3.7; 10.7)*	6.3 (2.1; 10.4)*
West Midlands	88 (3.4)	97.2 (3.4)	113.7 (3.9)	19.7 (11.6; 27.7)*	22.5 (14.5; 30.5)*	30.3 (21.0; 39.7)*	7.6 (3.9; 11.4)*	6.9 (3.2; 10.6)*	10.6 (6.3; 14.8)*
East of England	75.8 (1.9)	82.6 (2)	87.4 (2.7)	7.5 (0.4; 14.6)*	7.9 (0.8; 15.2)*	4.0 (–5.1; 13.2)*	–0.9 (–4.2; 2.3)	–1.2 (–4.5; 2.1)	–0.1 (–4.2; 4.0)
London	97.2 (4.4)	104.4 (4.1)	111.6 (4.2)	28.6 (19.8; 37.3)*	29.6 (21.5; 37.6)*	28.4 (19.4; 37.3)*	–0.8 (–5.0; 3.4)	0.1 (–3.8; 4.1)	1.2 (–3.1; 5.5)

MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

* $p < 0.05$.

^a The reference group is the South East small, medium and large respectively.

Table 6

Model based distribution of age and sex standardised limiting long-term illness ratio by regions (*within*) and brownfield categories. The adjusted analysis accounted for multiple environmental deprivation score, Townsend index of deprivation (area-level), and individual-level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types.

Region	Brownfield categories MEAN(SE)			Unadjusted Spatial inequality within regions (MD (95% CI) ^a		Adjusted Spatial inequality within regions (MD (95% CI) ^a	
	Small < 28	Moderate > 28 and < 250	Large > 250	Medium	Large	Medium	Large
South East	76.1 (1.5)	81.2 (1.5)	87.2 (1.8)	5.1 (3.3; 7)*	11.2 (8.4; 14)*	0.0 (−1.1; 1.0)	0.2 (−1.3; 1.7)
South West	84 (1.4)	91.5 (1.5)	98.3 (1.9)	7.6 (5.6; 9.6)*	14.3 (11.2; 17.4)*	−0.8 (−2.0; 0.4)	1.9 (0.0; 3.8)*
North East	115.1 (4)	118.4 (4)	133.7 (4.5)	3.3 (−2.4; 9)	18.6 (11.6; 25.6)*	0.4 (−1.5; 2.2)	1.2 (−1.0; 3.5)
North West	101.2 (2.6)	110.5 (2.5)	126 (2.7)	9.4 (5.8; 13)*	24.8 (20.7; 28.9)*	0.5 (−0.7; 1.8)	3.3 (1.8; 4.8)*
Yorkshire & Humber	95 (3.9)	103.2 (3.9)	116.8 (4.4)	8.2 (4.1; 12.3)*	21.8 (16; 27.5)*	−1.9 (−3.5; −0.2)	−2.9 (−5.2; −0.5)
East Midlands	92.5 (2.5)	99.4 (2.5)	99.4 (2.9)	6.9 (4; 9.8)*	6.9 (2.8; 11)*	−1.0 (−2.4; 0.3)	−1.4 (−3.2; 0.5)
West Midlands	91 (2.4)	98.1 (2.3)	108.6 (2.7)	7.1 (3.8; 10.5)*	17.6 (13.2; 22)*	−0.9 (−2.4; 0.6)	1.4 (−0.6; 3.3)
East of England	82.6 (1.5)	87.3 (1.5)	90.5 (2.0)	4.7 (2.7; 6.7)*	8.0 (4.6; 11.3)*	−1.0 (−2.0; 2.3)	0.3 (−1.6; 2.2)
London	93 (3)	98.1 (2.8)	102.8 (2.9)	5.1 (1.2; 8.9)*	9.9 (5.8; 14)*	0.6 (−1.2; 2.3)	0.3 (−1.6; 2.2)

MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

* $p < 0.05$.

^a Reference is small for each region.

and 18.2% LLTI in small, medium and large brownfield land areas respectively compared to the South East reference areas. This is paralleled with the results in the North East (additional LLTI amounts to 17.1%, 17.5%, and 18.1% in small, medium and large brownfield areas respectively compared to reference areas).

4.3. Brownfield land and the North South divide

Table 8 examines the association of brownfield land with health *within* the North and *within* the South. The results from the adjusted analysis reveal that some spatial inequality exists between areas with large compared to small amounts of brownfield in both the North and South, although this varies by outcome. In the North, areas with large amounts of brownfield have statistically ($p < 0.05$) higher amounts of premature mortality (8.4%) and NGH (3.7%) but not LLTI. In the South, areas with large amounts of brownfield have a stronger association with premature mortality (2.4%) and LLTI (1.6%) but not NGH.

Table 9 shows the results from the unadjusted and adjusted analyses for the *between* North and South association between brownfield land and health for the three health outcomes. In the adjusted analyses, there is significant ($p < 0.05$) between-region spatial inequality in premature mortality with areas with large amounts of brownfield in the North experiencing an additional 4.7%, 7.4%, and 10.7% premature mortality in small, medium and large brownfield land areas respectively compared to similar areas in the South. There is a similar but even stronger pattern for NGH and LLTI: 15.9%, 17%, and 18% additional not good health and 11.2%, 11.5%, and 12.3% additional LLTI in small, medium and large brownfield land areas respectively in the North compared to the South.

The percentage contribution of brownfield land exposure to the North–South health divide were calculated and are presented in Table 10. The North–South health divide was estimated as 20.4% for premature mortality, 30.4% for NGH, and 22.1% for LLTI. The unadjusted brownfield contribution (i.e. % contribution of model 2) to these health divides were 6.9%, 4.1%, and 3.9% respectively. After adjusting for all confounders, the independent contribution (i.e. % contribution of model 5 – % contribution of model 4) of exposure to brownfield land to the North–South divide was calculated as 0.25% for premature mortality, 0.1% for NGH, and 0.1% for LLTI.

5. Discussion

This analysis has shown that brownfield land is regionally patterned in England with higher exposure to brownfield land in the Northern compared to the Southern regions; that brownfield exposure has an association with regional inequalities in mortality and morbidity *within* regions (particularly in the North West); that brownfield has an association with inequalities *between* regions (particularly between the North West and the South East); but that brownfield land only makes a small independent contribution to the North–South health divide in England.

From these results it is also clear that brownfield land exposure is on the whole higher in the North and that susceptibility to the health effects of brownfield land appears to be much greater for both mortality and morbidity in the North. This is particularly the case for the North West. This suggests that the environmental (as well as the well-established socio-economic) effects of deindustrialisation might be important for spatial health inequalities in England. There may be historical geographical reasons for this in terms of the different industrial base of the North West (where textiles, shipping and engineering dominated) compared to the Southern regions but also compared to the North East (where coal, shipping and steel dominated) which may have resulted in different post-industrial landscapes in the form of different types of brownfield land. These different ‘biographies of place’ (Warren and Garthwaite, 2014) – as well as associated different individual occupational health histories – could potentially lead to the different spatial associations between brownfield and health found in our analysis. However, brownfield land only made a very small independent contribution to the so-called North–South health divide.

It is also important to note that the association between brownfield land and mortality and morbidity in London appears to show the opposite association with a large exposure to brownfield land and yet lower susceptibility to mortality and morbidity outcomes. There may be different factors at play that may explain these ‘London effects’ one of which is the type of brownfield land itself. This suggests a third potential pathway (in addition to the two outlined in the introduction) whereby brownfield land could contribute to spatial inequalities in health – as there may be spatial inequalities in the nature of the brownfield land itself. Of the two main categories of brownfield land covered in the NLUD database, “vacant or derelict” and “in use with potential for re-development” (which account for 46% of brownfield sites in

Table 7
Model based distribution of age and sex standardised limiting long-term illness ratio by regions (between) and brownfield categories. The adjusted analysis accounted for multiple environmental deprivation score, Townsend Index of Deprivation (area-level), and individual-level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types.

Region	Brownfield categories MEAN(SE)				Unadjusted spatial inequality between regions (MD (95% CI) ^a)				Adjusted spatial inequality between regions (MD (95% CI) ^a)			
	Small < 28	Moderate > 28 and < 250	Large > 250		Small	Medium	Large		Small	Medium	Large	
South East	76.1 (1.5)	81.2 (1.5)	87.2 (1.8)		7.9 (2.6; 13.2)*	10.3 (4.9; 15.7)*	11.0 (4.3; 17.7)*	–	4.8 (2.3; 7.4)*	4.1 (1.4; 6.7)*	–	6.5 (3.4; 9.7)*
South West	84 (1.4)	91.5 (1.5)	98.3 (1.9)		39.1 (32.3; 45.9)*	37.2 (30.4; 44.0)*	46.4 (38.7; 54.1)*	–	17.1 (13.8; 20.4)*	17.5 (14.1; 20.8)*	–	18.1 (14.4; 21.8)*
North East	115.1 (4)	118.4 (4)	126 (2.7)		25.2 (19.6; 30.7)*	29.3 (23.9; 34.6)*	38.6 (32.6; 44.7)*	–	15.1 (12.4; 17.8)*	15.6 (13.0; 18.2)*	–	18.2 (15.3; 21.1)*
North West	101.2 (2.6)	110.5 (2.5)	116.8 (4.4)		18.9 (12.0; 25.7)*	22.2 (15.4; 29.1)*	29.7 (21.6; 37.8)*	–	6.9 (3.6; 10.2)*	5.0 (1.7; 8.3)*	–	3.8 (0.0; 7.7)*
Yorkshire & Humber	95 (3.9)	103.2 (3.9)	99.4 (2.9)		16.3 (10.8; 21.9)*	18.3 (12.7; 23.9)*	12.3 (5.7; 19.0)*	–	6.2 (3.6; 8.9)*	5.2 (2.5; 7.9)*	–	4.6 (1.5; 7.8)*
East Midlands	92.5 (2.5)	99.4 (2.5)	108.6 (2.7)		15.0 (9.0; 20.9)*	16.9 (11.0; 22.8)*	21.3 (14.4; 28.1)*	–	5.6 (2.8; 8.5)*	4.7 (1.9; 7.6)*	–	6.8 (3.5; 10.0)*
West Midlands	91 (2.4)	98.1 (2.3)	90.5 (2.0)		6.5 (1.3; 11.8)*	6.1 (0.8; 11.4)*	3.3 (–3.4; 9.9)	–	0.2 (–2.3; 2.7)	–0.9 (–3.4; 1.7)	–	0.2 (–2.9; 3.3)
East of England	82.6 (1.5)	87.3 (1.5)	102.8 (2.9)		16.8 (10.4; 23.2)*	16.8 (10.9; 22.7)	15.7 (9.1; 22.2)	–	–1.0 (–4.2; 2.2)	–0.4 (–3.5; 2.6)	–	0.1 (–3.1; 3.4)
London	93 (3)	98.1 (2.8)										

MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

* $p < 0.05$

^a The reference group is the South East small, medium and large respectively.

England), it is possible to speculate that London has more of the latter, and the North more of the former which would result in different health effects. This study is not the first to identify unexpected findings for London – it seems to consistently be an outlier in terms of health: for instance, some studies have found that London performs better in life expectancy, mortality and morbidity outcomes despite similar levels of deprivation with other parts of England (Doran et al., 2006; Cairns, 2013; Cairns-Nagi and Bamba, 2013). Due to the limitations in the dataset we are unable to identify what types of brownfield land there are in each region so it is unknown whether the brownfield land is contaminated or not. Likewise, we are unable to examine the quality of brownfield land – some land may be aesthetically better than others. Another explanation may be that not all poorer neighbourhoods lack health promoting resources or are exposed to health damaging features (i.e. brownfield land in this particular case) (MacIntyre, 2007). London also differs considerably from the other regions in terms of population mobility. There is far greater population movement in London compared to any other region in the country given that there is a greater proportion of student and immigrant population located in this city. Norman et al. (2005) argue that although there is a strong evidence base for the association between deprivation and mortality, life expectancy and other health outcomes, these apparent associations are based on comparing the measured deprivation in a person's residential area at the time of their death for instance; the underlying assumption therefore is that the deprivation score of current area of residence is an adequate measure of exposure to possible health risk overlooking social and physical mobility. Furthermore, there may be competing health-promoting (salutogenic) and health-damaging (pathogenic) factors in play in London. For instance, the potential supply of salutogenic aspects of the environment in London may mediate against the pathogenic factors that may enable individuals to live well despite such environmental stressors. As Shortt et al. (2011) point out there have been few attempts to simultaneously capture salutogenic and pathogenic aspects in relation to the physical environment. These authors found that wards within the 'London-esque' MED-Ix cluster were at a lower risk of limiting long-term illness, all-cause mortality and cardiovascular disease suggesting that there may be elements of the environment that are salutogenic which may buffer against the pathogenic physical environment such as brownfield land.

The uneven geographical distribution of brownfield and its concentration in income deprived communities (MacIntyre et al., 2008; Braubach and Fairburn, 2010; Litt et al., 2002) and differences in susceptibility to ill health effects of exposure to brownfield means that it is potentially another element of environmental injustice (Hofrichter, 1993). Areas which already suffer from the ill health effects of social deprivation and other elements of environmental deprivation (such as air pollution or waste facilities) may also experience the increased likelihood of ill health associated with higher levels of exposure to brownfield through both physiological and psychosocial mechanisms. Brownfield could thus be an additional factor behind spatial inequalities in health and it may comprise a further way in which individual-level deprivation is amplified by area-level deprivation – particularly in the North (MacIntyre, 2007). There is a need to examine if there are more area-level inequalities in the association between brownfield land and health at a smaller scale and also by area-levels of socio-economic deprivation.

6. Limitations

This study is subject to some general design limitations. Given the cross-sectional study design it is not possible to rule out

Table 8

Model based distribution of age and sex standardised premature all-cause mortality ratio, self-reported health and long-term limiting illness by regions (*within*) and brownfield areas. The adjusted analysis accounted for multiple environmental deprivation score, Townsend index of deprivation (area-level), and individual-level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types.

Regions	Brownfield categories MEAN(SE)			Unadjusted Spatial inequality within regions (MD (95% CI) ^a		Adjusted Spatial inequality within regions (MD (95% CI) ^a	
	Small < 28	Moderate > 28 and < 250	Large > 250	Medium	Large	Medium	Large
All-cause premature deaths							
South	86.2 (0.9)	95.4 (0.9)	105.5 (1.2)	9.1 (7.5; 10.8)*	19.2 (16.9; 21.5)*	-0.8 (-1.9; 0.3)	2.4 (0.9; 4.0)*
North	100.7 (1.7)	113.2 (1.6)	136.7 (1.9)	12.5 (9.7; 15.3)*	36.0 (32.6; 39.4)*	1.9 (0.1; 3.7)*	8.4 (6.1; 10.6)*
Self-reported not good health							
South	79.9 (1.3)	88.2 (1.3)	96.3 (1.5)	8.3 (6.7; 9.9)*	16.4 (14.2; 18.6)	-0.9 (-1.6; -0.1)	0.7 (-0.4; 1.7)
North	104.8 (2.3)	115.8 (2.7)	138.2 (2.4)	10.9 (8.3; 13.7)*	33.3 (30.1; 36.6)*	0.2 (-1.0; 1.4)	3.7 (2.2; 5.2)*
Long-term limiting illness							
South	84.9 (0.9)	90.9 (0.9)	96.3 (1.1)	5.9 (4.8; 7.0)*	11.3 (9.7; 12.9)*	-0.2 (-1.1; 0.6)	1.6 (0.4; 2.7)*
North	103.4 (1.7)	110.9 (1.6)	125.9 (1.8)	7.4 (5.4; 9.4)*	22.5 (20.1; 24.9)*	-0.5 (-1.1; -0.1)	0.5 (-0.2; 1.2)

MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

* $p < 0.05$.

^a Reference is small in each region.

Table 9

Model based distribution of age and sex standardised premature all-cause mortality ratio, self-reported health and long-term limiting illness by regions (*between*) and brownfield areas. The adjusted analysis accounted for multiple environmental deprivation score, Townsend index of deprivation (area-level), and individual-level variables including ethnicity, education, unemployment, socio-economic status, car ownership, housing tenure and settlement types.

Regions	Brownfield categories MEAN(SE) ^a			Unadjusted			Adjusted		
	Small < 28	Moderate > 28 and < 250	Large > 250	Small < 28	Moderate < 250	Large > 250	Small < 28	Moderate < 250	Large > 250
All-cause premature deaths (MD (95% CI))									
South	86.2 (0.9)	95.4 (0.9)	105.5 (1.2)	-	-	-	-	-	-
North	100.7 (1.7)	113.2 (1.6)	136.7 (1.9)	14.4 (10.6; 18.2)*	17.8 (14.1; 21.5)*	31.3 (26.8; 35.6)*	4.7 (2.4; 7.0)*	7.4 (5.1; 9.7)*	10.7 (7.9; 13.5)*
Self-reported not good health (MD (95% CI))									
South	79.9 (1.3)	88.2 (1.3)	96.3 (1.5)	-	-	-	-	-	-
North	104.8 (2.3)	115.8 (2.7)	138.2 (2.4)	24.9 (19.7; 30.0)*	27.6 (22.5; 32.7)*	41.8 (36.2; 47.4)*	15.9 (13.5; 18.3)*	17.0 (14.7; 19.4)*	18.0 (16.5; 21.6)*
Long-term limiting illness (MD (95% CI))									
South	84.9 (0.9)	90.9 (0.9)	96.3 (1.1)	-	-	-	-	-	-
North	103.4 (1.7)	110.9 (1.6)	125.9 (1.8)	18.5 (14.7; 22.2)*	20.0 (16.3; 23.7)*	29.7 (25.6; 33.8)*	11.2 (9.3; 13.0)*	11.5 (9.7; 13.3)*	12.3 (10.3; 14.3)*

* $p < 0.05$.

^a The reference group is the South East small; medium and large. MD (95% CI) denotes mean difference with its associated 95% confidence intervals.

Table 10

Causal modelling framework for independent contribution of brownfield exposure to North–South health divide.

Model	NGH		LLTI		DEATHS	
	Estimates	% Contribution	Estimates	% Contribution	Estimates	% Contribution
1. Region (North–South)	30.44 (25.14; 35.74)		22.06 (18.24; 25.88)		20.44 (16.53; 24.35)	
2. Region + brownfield	29.20 (24.37; 34.04)	4.07	21.21 (17.67; 24.75)	3.85	19.03 (15.73; 22.33)	6.90
3. Region + Med1X	23.79 (19.14; 28.43)	21.85	17.39 (13.92; 20.86)	21.17	13.64 (10.29; 16.99)	33.27
4. Region + brownfield + Med1X	24.08 (19.69; 28.46)	20.89	17.60 (14.29; 20.91)	20.22	13.92 (10.94; 16.91)	31.90
4. Region + Med1x + Others ^a	16.88 (14.62; 19.14)	44.55	11.51 (9.75; 13.27)	47.82	6.89 (4.78; 8.94)	66.29
5. Region + brownfield + Med1X + Others ^a	16.85 (14.60; 19.11)	44.65	11.49 (9.73; 13.25)	47.91	6.84 (4.80; 8.88)	66.54

^a Others = Townsend index of deprivation; ethnicity; education; unemployment; socio-economic status; car ownership; housing tenure and settlement types.

selection effects whereby people with worse health end up residing in areas with more brownfield. We did not consider population weighting of the wards in relation to the R-PDL values and it may be that a more densely populated ward has more of an environmental-human impact than a less densely populated ward.

Also, this study has only been able to examine cross-sectional association and a longitudinal design would be required to explore issues of causation. Future experimental or natural experiment studies that explore aetiological pathways through which exposure and susceptibility of brownfield land may lead to morbidity

and mortality would be beneficial. 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 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 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. This study has also only looked at the quantity of brownfield rather than the quality. The extent to which brownfield 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.

A value of zero in the NLUD database could either indicate no brownfield present or no brownfield recorded (e.g. missing data). It was not possible to determine and so in our analysis, all zero scores were used in the small R-PDL group. This may have resulted in an underestimation of effects in the analysis. Limitations in the data sources available meant that brownfield data from 2009 was necessarily compared to census data from 2001 and premature all-cause mortality data from 1998/9 to 2002/3, since 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 increased in scope and accuracy between then and 2009, the decision to compare the most up-to-date health and brownfield datasets was 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 does 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.

7. Conclusions

This study is the first to examine the association between brownfield land and regional inequalities in mortality and morbidity at a national level using the example of England. We have found that brownfield exposure has an association with regional inequalities in mortality and morbidity within regions (particularly in the North West); that brownfield has an association with inequalities between regions (particularly between the North West and the South East); but that brownfield land only makes a small independent contribution to the North–South health divide in England. Whilst this study is subject to a number of limitations,

it suggests that the environmental (as well as the economic) aspects of spatial inequalities in health need to be examined further and that brownfield land should be considered as part of environmental deprivation. However, there are exceptions in the association between exposure and susceptibility to brownfield land and spatial inequalities in health as demonstrated for London. Nonetheless, the remediation and redevelopment of brownfield land should be considered as a public health issue and a subject of analysis for future geographical research.

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Author contribution statement

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

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