A Regional Measure of Neighborhood Multiple Environmental Deprivation

Citation for published version:
Richardson, EA, Pearce, J, Mitchell, R & Shortt, NK 2013, 'A Regional Measure of Neighborhood Multiple Environmental Deprivation: Relationships with Health and Health Inequalities' Professional Geographer, vol 65, no. 1, pp. 153-170. DOI: 10.1080/00330124.2012.660457

Digital Object Identifier (DOI):
10.1080/00330124.2012.660457

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
Professional Geographer

DOI: 10.1080/00330124.2012.660457

A Regional Measure of Neighborhood Multiple Environmental Deprivation: Relationships with Health and Health Inequalities

Elizabeth A. Richardson*, Jamie Pearce, Rich Mitchell and Niamh K. Shortt

*Corresponding Author

Dr Elizabeth A. Richardson
School of Geosciences
University of Edinburgh
Drummond Street
Edinburgh, UK
EH8 9XP

e.richardson@ed.ac.uk
Tel: 0131 650 2800
Fax: 0131 650 2524

A regional measure of neighbourhood multiple environmental deprivation: relationships with health and health inequalities

Abstract

The health impacts of simultaneous exposure to multiple adverse environmental factors are of concern in the UK. UK-wide indicators exist, but context-specific finer resolution measures are lacking. An environmental deprivation index was developed for 398 neighbourhoods (average population = 760) in a Scottish council area, comprising measures of air pollution, noise pollution, traffic environment, undesirable land uses and crime. Adverse environmental conditions were related to ill health in the region, and implicated in wider socioeconomic health inequalities. The results suggest an independent role for environmental deprivation in explaining poor health and health inequalities.

Key words:

Health, environment, hospital admissions, self-reported health, inequalities

Introduction

An individual's health and wellbeing can be influenced by the characteristics of their neighbourhood as well as by various individual socio-demographic characteristics (Sooman and Macintyre 1995). For instance, there is wide body of evidence to demonstrate that living in an area of high socioeconomic deprivation can be detrimental to the health of local residents, regardless of individual-level socioeconomic status (Poortinga, Dunstan, and Fone 2008). Neighbourhoods might also influence health via other pathways including numerous beneficial and harmful features of the local physical environment (Ellen, Mijanovich, and Dillman 2001; Macintyre, Ellaway, and Cummins 2002). In addition to exerting a direct effect on health outcomes, environmental conditions can also act as sources of psychosocial stress or as barriers to health-promoting activities (Carter et al. 2009; Sooman and Macintyre 1995; Mair, Diez Roux, and Morenoff 2010). However, the often close association between adverse socioeconomic and environmental conditions can make it difficult to separate out their relative contributions to poor health status and is a significant barrier to successful policymaking.

Research efforts to disentangle the influence of the neighbourhood environment on health from local socioeconomic influences have been hampered by measurement difficulties. Composite measures of socioeconomic deprivation are often used to capture the burden of socioeconomic adversity experienced by a neighbourhood. By drawing on a range of indicators, composite measures are considered to more precisely reflect complex and multi-factorial concepts such as 'deprivation' (Sol et al. 1995). For example, the Scottish Index of Multiple Deprivation (SIMD, Scottish Government 2009) summarises seven small area-level domains of deprivation (employment, income, crime, housing, health, education and access). Other composite indices of deprivation include the Carstairs score for the UK (Carstairs and Morris 1989) and the South African Index of Multiple Deprivation (Noble et al. 2009). Such measures are widely used in epidemiological research, and have greatly facilitated research into the relationships between small area-level socioeconomic deprivation and poor health (McLoone and Boddy 1994; Weich et al. 2003).

Environmental deprivation is a concept akin to socioeconomic deprivation. It relates to the presence (e.g., air pollution) or absence (e.g., green space) of physical environmental conditions that may contribute to health differences across areas. As Evans and Kantrowitz (2002, p.304) suggest “it is the accumulation of exposure to multiple, suboptimal physical conditions rather than any singular environmental exposure that will provide a fruitful explanation for the SES [socioeconomic status] health gradient”. Given that populations are simultaneously exposed to multiple physical environmental factors with distinct spatial variations (e.g., air pollution, green space, noise) it is clear that environmental deprivation will not be adequately measured by any of these factors in isolation. Our work responds to the identified need for measures that capture multiple dimensions of the physical environment, such that implications for community health can be studied (Evans and Kantrowitz 2002; Brulle and Pellow 2006).

Recently a relative index of multiple environmental deprivation was developed for neighbourhoods across the UK (Richardson et al. 2010), which permitted a UK-wide investigation of the relationship between the environment and health. The Multiple Environmental Deprivation Index (MEDIx) was constructed using data at the local level for six environmental features with the potential to affect population health in the UK (Richardson et al. 2010). The findings suggested that multiple environmental deprivation had a significant (although modest) role in shaping health in the UK and contributed to socioeconomic inequalities in health (Pearce et al. 2010).

However, while the earlier UK-wide findings were important in establishing the role of the physical environment in shaping health in the UK, the results were of limited utility in informing regional policy decisions. The index was not sufficiently finely tuned to adequately capture the range of environmental deprivation experienced within a region. This shortcoming is important because in the UK, local governments (or 'local authorities') are responsible for delivering a range of services, including planning, waste management, housing, transportation and parks. So, while regional decisions are likely to be more potent in affecting neighbourhood environments directly (compared with national decisions) there are currently no standardised small area measures of multiple environmental deprivation available for use at this scale. Such measures could be utilised to examine the relationship between environmental deprivation and health within regions, and could assist in identifying areas subject to the greatest environmental deprivation, informing regional resource allocation decisions.

This study addressed the absence of region-specific measures by developing an evidence-based health-relevant index of multiple environmental deprivation for South Lanarkshire, a local authority region in south-central Scotland. The index was used to identify environmentally deprived areas and investigate the contribution of environmental deprivation to ill health and health inequalities across the region.

The study area

The South Lanarkshire local authority area spans parts of central and southern Scotland (Figure 1). It has a population of 309,500 (2007 estimate, General Register Office for Scotland) and an area of 1,777 km^2. The region's population is centred to the north in the towns of Hamilton and East Kilbride, and the Greater Glasgow suburbs of Rutherglen and Cambuslang. Levels of socioeconomic deprivation in the region are similar to the Scottish average, with a fairly even spread of deprived and non-deprived neighbourhoods (SIMD; Scottish Government 2009). South Lanarkshire Council has prioritised "improved environments and life circumstances to support healthier lives and address health inequalities" (South Lanarkshire Community Planning Partnership 2008). Geographical inequalities in health in Scotland have widened over recent decades (Boyle, Exeter, and Flowerdew 2004), and environmental inequalities may be a contributory factor.

[Figure 1]

Methods

The development of the index

The methodology for developing the index followed the approach of comparable studies (Richardson et al. 2010; The Scottish Government 2009). First, environmental characteristics with population health relevance for South Lanarkshire were identified. Second, a suitable geographical unit was selected. Third, spatial data for each indicator were obtained and rendered to the selected geography, as a measure of exposure. Fourth, the environmental indicators were tested to ensure they were measuring health-relevant aspects of the environment as intended. Finally, the index of multiple environmental deprivation was produced by combining the indicator scores.

1. Selection of indicators

Indicators of health-related environmental deprivation were defined as any aspects of the neighbourhood physical environment (i.e., operating above the household level) that can influence individual-level health or health behaviours (e.g., air pollution, green space). Indicators of environmental deprivation were identified by reviewing empirical evidence and subsequently consulting environmental health professionals. A detailed evidence review conducted for the UK (Richardson et al. 2009) was reappraised with reference to the South Lanarkshire context. We identified additional factors for inclusion that were likely to be relevant for health in South Lanarkshire (but not in the national context; e.g. mineral extraction) as well as characteristics included in the UK-wide measure that were unlikely to exert a detectable effect within our study area (e.g. climate).

To ensure relevance for population health, an indicator was included only if clear associations with health outcomes had been demonstrated, and if the proportion of people potentially exposed exceeded 10% of the South Lanarkshire population. The result was a list of environmental indicators with population health-relevance for South Lanarkshire. The selected indicators were grouped into three separate 'domains', based on their implications for health: Hazardous Environments, Undesirable Environments and Salutogenic Environments.

The Hazardous Environments domain consisted of indicators that posed a direct health risk at the population level: air pollution, noise pollution and the traffic environment. Ambient air pollution has been consistently associated with increased risks of respiratory and cardiovascular diseases (Bell, Dominici, and Samet 2005; Ito, De Leon, and Lippmann 2005; Levy, Hammitt, and Spengler 2000; Schwartz 1994; Stieb, Judek, and Burnett 2002; World Health Organization 2004; Lee, Ferguson, and Mitchell 2009). Long-term exposure to levels of noise pollution frequently found in urban areas increases risks of high blood pressure and heart disease (van Kempen et al. 2002; Babisch 2000). An unsafe traffic environment is not only a direct health risk but can also indirectly affect health through perceived risk and increased stress levels and/or decreased opportunities for safe outdoors recreation (Gee and Takeuchi 2004).

The Undesirable Environments domain consisted of indicators most likely to have a detrimental effect on population health via indirect pathways. Industrial facilities, derelict land, potentially contaminated land, mineral extraction areas and the crime environment were included. Whilst there is evidence that direct exposure to land contaminants, chemical emissions from industry or particulate pollution from mining activities can harm health, few people in South Lanarkshire lived sufficiently close for direct exposure. Instead, these land uses have greater potential to affect the wider population through "environmental worry": an individual's perception of environmental risk that can lead to chronic stress and stress-related illness (Shusterman et al. 1991). Residents who perceive their neighbourhoods to be unpleasant or unsafe are more likely to have poor health (Poortinga 2006; Ellaway, Macintyre, and Bonnefoy 2005). Thus, grouping these environmental characteristics into an Undesirable Environments domain is sensible because the effects on population-level health are likely to operate through a 'psychosocial' pathway.

The Salutogenic Environments domain included indicators that have been implicated in producing good health and well-being, whether directly or indirectly. People living in greener areas (e.g., with a greater access to urban parks) tend to have better health than those in less green areas (Maas et al. 2006; de Vries et al. 2003; Sugiyama et al. 2008; Maas et al. 2009; Mitchell and Popham 2007, 2008). Potential reasons for this include the restorative effects of nature and the provision of opportunities for physical activity (Kaplan and Kaplan 1989; Health Council of the Netherlands and RMNO 2004). Other features of the residential environment have been linked with increased physical activity levels, including convenient access to public transport, provision of walking and cycling paths, and neighbourhood aesthetics and safety (Kaczynski and Henderson 2007; Owen et al. 2004; Trost et al. 2002). As physical inactivity is a key risk factor for obesity, cardiovascular disease and other prevalent health conditions, an absence of these physical activity-friendly neighbourhood attributes can be considered a constituent of environmental deprivation.

2. Selection of geographical unit

The index was intended to capture variations in population exposure to environmental deprivation across the region. The geographical unit selected therefore needed to be sufficiently high resolution to capture geographical variation in the environmental conditions but large enough to provide adequate populations for subsequent analyses. The data zone geography was selected: this is the key small-area statistical geography in Scotland for the reporting of neighbourhood statistics. The 398 data zones in South

Lanarkshire had an average population of 760 in 2001 (range 505 to 1038), and were considerably larger in rural areas (average 18.1 km^2) than urban areas (average 0.6 km^2).

3. *Measuring neighbourhood exposure to each indicator*

Contiguous datasets depicting spatial variation in the selected indicators across South Lanarkshire were then sought. It was stipulated that the datasets should be reliable, as contemporary as possible, and of a sufficient spatial resolution to capture environmental variation adequately. Suitable datasets were available for the majority of the selected indicators (Table 1). Noise mapping, however, was unavailable for most of the region; hence proximity to major roads and railway lines was used as a proxy. Although noise pollution can also arise from industrial and mining activities these were included as undesirable land uses only, to avoid double-counting and unduly biasing the index. Green space data were available only for urban areas and the immediate surrounds; no comparable data for rural areas were obtained. This indicator therefore measured local availability of *urban* green space. As much rural green space is private (e.g., agricultural land), and not publicly accessible, this indicator was considered a valid inclusion in the Salutogenic Environments domain. The unsafe traffic environment indicator was measured as the likelihood of accidents involving pedestrians or cyclists.

[Table 1]

Measures of exposure to each environmental indicator were then developed (Table 1). Attention was given to deriving measures that most accurately represented the environmental conditions where the population was situated, rather than across the whole data zone area, in recognition of the typically uneven population distribution within each. This 'population weighting' was achieved in a range of ways, depending on the specific indicator (Table 1). The dataset processing was conducted using geographical information system (GIS) software (ESRI ArcMap 9.2). Relative population exposure to certain features (e.g., contaminated land, cycle paths, and roads) was measured as the population-weighted proportion of each data zone within 100 m of the features.

4. Constructing and testing the domains

Construction of the domains was informed by the methodology used in the development of indices of multiple deprivation in the UK (e.g., Scottish Government 2009). For each indicator, the data zones were given a proportional rank, ranging from 0.0 for the data zone with the 'best' indicator value to 1.0 for the 'worst'. An exponential transformation (see Welsh Assembly Government 2009) was then applied because this approach emphasised the highest values and reduced the extent to which high values of one indicator could be cancelled out by low values of another. The relevant transformed indicator scores for each data zone were summed to produce a score under each of the three domains.

Before combining the indicators into an index it was necessary to test whether the three domains had the expected relationships with health. This step acted as a quality control test for the datasets. Two indicators of the health of the population in each data zone were used: self-reported general health and hospital admissions for respiratory disease. These were selected because of the empirical evidence linking both with aspects of environmental quality, as outlined below.

Self-reported measures of general health are an appropriate means of assessing population health, as they are strongly and consistently predictive of morbidity and mortality (Burström and Fredlund 2001; Charafeddine and Boden 2008). Poor self-reported health has been linked with residence in a range of poor-quality environments, including near waste disposal sites (Vrijheid 2000), in areas of increased particulate pollution (Charafeddine and Boden 2008) and in areas perceived as having multiple environmental problems (Bowling et al. 2006). For each data zone, age group and sex-specific counts of people reporting their general health as "not good" were derived from the 2001 UK Census.

This perceptual indicator of health was supplemented with an objective measure of hospital admissions for respiratory disease. Air pollution has well established links with respiratory disease (Schwartz 1994), and poor social and home circumstances (e.g., housing condition) may also play a role (Mann, Wadsworth, and Colley 1992; McCarthy et al. 1985). Total counts (all ages, both genders) of respiratory disease hospital admissions for each data zone were obtained from the Scottish Neighbourhood Statistics website for the most recent year available (2007). To enable the analyses to take account of demographic differences between data zones whole-Scotland sex and age group-specific counts of respiratory disease hospital admissions were obtained from NHS Scotland's Information Services Division (ISD) and used to calculate sex and age group specific rates for the country. An 'expected' count was then calculated for each data zone, given the sex and age structure of its population, and included as an exposure variable in the appropriate models.

Negative binomial regression modelling was used because the health outcome data were counts of individuals and had an overdispersed distribution (hence Poisson models were not appropriate) (Hilbe 2007). Models were adjusted for the age group and sex structure of the population and for area-level socioeconomic deprivation. Socioeconomic deprivation was operationalised as quintiles of the Scottish Index of Multiple Deprivation (SIMD 2009). Modelling was conducted using the Stata/IC 11.0 software.

These models demonstrated that the Undesirable and Hazardous Environment domains were associated with health risks in the expected direction: risks were often highest for data zones with the highest domain scores and dose-response trends were observed. For the Salutogenic Environments domain, however, the models revealed the opposite relationship with health than was expected: significantly reduced risks were found for the data zones with the *least* salutogenic environments. In other words, populations *deprived* of Salutogenic Environments experienced *better* health. Due to this unexpected finding it was concluded that the Salutogenic Environments domain, as constructed here, was not a suitable measure of health-relevant environmental deprivation for South Lanarkshire and hence was excluded from the index.

5. Constructing the index

The three Hazardous Environments domain indicators (air pollution, noise pollution and traffic environment) and the two Undesirable Environments domain indicators (undesirable land uses and crime rates) were combined to form a single index. Factor analysis has been used in earlier index development work to extract a single underlying factor for domains such as health and education (e.g., Scottish Government 2009). The technique is based on the premise that the indicators that are most highly correlated with the domain will also be highly correlated with each other.

Given the overlapping nature of the Hazardous and Undesirable Environment domains (e.g., unsafe traffic environments and industrial facilities could influence health both directly and indirectly) and the small number of indicators, a single factor analysis of the five indicators was conducted. The indicators were first ranked and transformed to a normal distribution. The analysis identified a single factor that explained the underlying variance better than the original indicators themselves (i.e., had an eigenvalue > 1). The factor analysis had a Condition Index of 2.2, demonstrating an absence of multi-collinearity among the indicators. The ranked and transformed indicators were multiplied by the loadings (weights) for the first factor and summed to produce an index score for each data zone. This index, the South Lanarkshire Index of Multiple Environmental Deprivation (SLIMED), was normally distributed, ranged from -4.0 (least environmental deprivation) to +4.2 (greatest environmental deprivation) and had a mean value of 0. The data zones were partitioned into quintiles to represent levels of increasing multiple environmental deprivation.

Analyses

The contribution of multiple environmental deprivation to ill health across the region was assessed using regression modelling, as described above. Firstly, models were constructed to assess whether the health of each data zone's population was independently related to its level of environmental deprivation, after accounting for other important factors (age, sex and area-level socioeconomic deprivation).

The excess ill health in South Lanarkshire that could potentially be attributed to environmental deprivation was then estimated. A baseline 'expected' count of ill persons was calculated for each data zone by applying the age, sex and SIMD deprivation-specific rate for the least environmentally deprived data zones (SLIMED quintile 1). Comparing this against the actual count of ill persons provided a prediction of the excess ill health attributable to environmental deprivation after accounting for the influences of age, sex and socioeconomic deprivation.

Finally, the contribution of multiple environmental deprivation to health inequalities across South Lanarkshire was investigated. The socioeconomic health inequalities within populations exposed to the same level of environmental deprivation (SLIMED quintile) were identified. If environmental deprivation contributed to health inequalities within South Lanarkshire wider health inequalities between more and less socially deprived populations would be expected in data zones with higher levels of multiple environmental deprivation. Interaction models were used as a formal test of whether the association between socioeconomic deprivation and health varied by neighbourhood multiple environmental deprivation.

Results

Levels of multiple environmental deprivation in South Lanarkshire tended to be greater in urban areas than in rural areas (Figure 2; Table 2). Environmental deprivation was particularly concentrated in the towns of Hamilton, Rutherglen and Cambuslang (see inset, Figure 2): of the ten most environmentally deprived data zones six were in Hamilton and four were in Rutherglen. Overall, 78% of the South Lanarkshire population lived in urban areas, and 92% of the population exposed to the greatest environmental deprivation (SLIMED quintile 5) were urban dwellers. The majority (62%) of the rural population lived in data zones classified as having low levels of multiple environmental deprivation (SLIMED quintiles 1 and 2). However, the SLIMED index provided more than a proxy for urban/rural differences, as some rural data zones were in the highest SLIMED quintile and some urban areas were in the least environmentally deprived quintile (Table 2). Compared with SLIMED, socioeconomic deprivation (SIMD) was more evenly distributed between urban and rural areas: urban areas accounted for 83% of the least deprived population and 84% of the most deprived population.

[Figure 2 and Table 2]

Self-reported health and respiratory disease hospital admission counts were correlated (correlation coefficient = 0.54). Their relationships with environmental deprivation are presented in Figure 3. The incidence rate ratios (IRRs) indicate the risk for each SLIMED quintile relative to the least environmentally deprived population (SLIMED quintile 1, IRR = 1.0), after accounting for confounders. The results suggested that multiple environmental deprivation had an independent association with self-reported health: residents of data zones with medium to high levels of environmental deprivation (SLIMED quintiles 3, 4 and 5) had a significantly greater risk of reporting that their health was not good. The increased risks were modest, ranging between 7 and 9% relative to SLIMED quintile 1.

Environmental deprivation was not associated with hospital admissions for respiratory disease (Figure 3). The graph suggests slightly elevated risks with increased environmental deprivation, with people in the most environmentally deprived data zones having the highest risks, but the wide confidence intervals render this non-significant.

[Figure 3]

The excess ill health that could have potentially been attributable to environmental deprivation was calculated for self-reported "not good" health (Table 3). After age group, sex and socioeconomic deprivation had been accounted for there were an additional 5044 people reporting "not good" health at the 2001 census. This 'excess' ill health was most prevalent in the most socially deprived data zones (n = 2981, or 29.3% of the self-reported ill health in SIMD quintile 5), and at higher levels of environmental deprivation (n = 3371, or 21% of the self-reported ill health in SLIMED quintiles 4 and 5).

[Table 3]

Socioeconomic inequalities were found for both health metrics across the region: those in socially deprived neighbourhoods had significantly worse self-reported health and respiratory disease hospital admission risks than those in more affluent areas. The modifying effect of environmental deprivation on these inequalities differed, however (Figure 4). For self-reported "not good" health the socioeconomic gradients widened at higher levels of environmental deprivation. This was not an artefact of within-quintile variation in deprivation, as within the most deprived data zones (SIMD quintile 5) mean SIMD scores did not differ significantly between the SLIMED levels. An interaction model (incorporating a continuous*continuous interaction term) revealed that the relationship between socioeconomic deprivation and "not good" health was significantly and positively modified by exposure to SLIMED (p = 0.004). Hence, the socioeconomic gradient in health from the least to the most deprived steepened significantly with increasing SLIMED level. For respiratory disease hospital admissions, however, no such pattern was observed (Figure 4), and an interaction model revealed no significant interaction effect (p = 0.36).

[Figure 4]

Discussion

Multiple environmental deprivation has a negative relationship with population health across the UK (Pearce et al. 2010) but whether such associations also occur at the regional scale had not previously been investigated. In order to address this question a regionally-specific measure of multiple environmental deprivation was developed for neighbourhoods across South Lanarkshire, Scotland. The index was tested against two health outcomes selected because of the potential role of environmental quality in their aetiology. Environmental deprivation was associated with increased rates of self-reported ill health, and wider social inequalities of the same, but with not respiratory disease hospital admissions. The regional focus of the SLIMED index conferred it with advantages over the national-level work and demonstrated the value of developing a purpose-built index. SLIMED highlighted local areas of particularly high environmental deprivation and had a greater potential for detecting fine resolution variation in environmental quality than the UK-wide MEDIx index.

The study revealed that populations exposed to environmental deprivation reported a burden of ill health over and above that commensurate with their demographic profile. Significantly poorer health was reported at medium to high levels of environmental deprivation (after accounting for age, sex and socioeconomic differences between the populations). Although the risk increases were modest they indicated substantial population-level effects: over 5000 more people than expected (28,000 expected based on age, sex and socioeconomic deprivation) reported that their general health was “not good”. This result is corroborated by studies that have found worse self-reported health in poor quality environments (Vrijheid 2000; Charafeddine and Boden 2008; Bowling et al. 2006). Multiple environmental deprivation at the UK level has also been associated with worse self-reported health (the authors’ unpublished results, available on request). As self-reported health is a strong predictor of subsequent mortality (Burström and Fredlund 2001) this finding suggests that environmental deprivation plays a role in population health variations across South Lanarkshire.

In contrast there was little evidence that hospital admissions for respiratory disease were influenced by environmental deprivation. This result was unexpected given the well-established link between respiratory disease and air pollution (Schwartz 1994), although it may be explained by the other components of the index (e.g., undesirable land uses, crime rates, noise) having no obvious direct role in the development of this health outcome.

Environmental deprivation was also found to make a significant but modest contribution to socioeconomic inequalities in self-reported health in South Lanarkshire: social gradients widened with increasing environmental deprivation. Nonetheless, the socioeconomic gradient in health substantially exceeded any gradient due to multiple environmental deprivation, indicating that the majority of the inequality could not be explained by differential exposure to physical environments. These results are consistent with UK-level findings (the authors' unpublished results) that reducing levels of environmental deprivation was only likely to make a small contribution to reducing socioeconomic inequalities in health. The modest effect on health inequalities is perhaps unsurprising given the relatively stringent environmental regulations that have been implemented in the UK. The UK benefits from a relatively benign physical environment with few obvious hazards to health. Again, no such effect was found for respiratory disease hospital admissions.

An unexpected finding was that the Salutogenic Environments domain was related to worse rather than better health in South Lanarkshire. It is unlikely that living near green space, paths, public transport and key services causes poor health, and it is more likely that confounding, data inadequacy or measurement issues were responsible for the result. The Salutogenic and Hazardous Environments domains were negatively correlated, because some salutogenic features and hazardous environments were strongly related to the urban environment (e.g., public transport, accessibility of key services, urban green space, air pollution and noise). The finding was therefore likely to reflect the association between hazardous environments and poor health, which is stronger than that generally found between salutogenic environments and good health. With future improvements of the comparatively sparse evidence base regarding health-promoting environmental characteristics the development of aggregate measures of salutogenic environments should be revisited.

Other limitations of the work must also be acknowledged. First, the accuracy of the SLIMED index was contingent on the quality of the data sets utilised. Issues regarding data availability (e.g., noise) and spatial coverage (e.g., green space) were unavoidable, and future work would benefit from acquiring improved measures of these indicators. Second, the choice of the data zone geography was informed by the availability of health and environment datasets, but for planning purposes a finer resolution focus might be more suitable.

Third, the index was constructed by means of an unweighted combination of the individual indicators, although it was recognised that some environmental characteristics were likely to have more serious implications for health or might have the potential to influence health via a number of pathways (e.g., an industrial facility might cause air pollution, noise pollution and psychosocial stress). The decision not to weight the indicators was taken because of the absence of evidence with which to quantify their relative health risks or causal pathways. As the risks associated with each indicator will vary according to the health outcome, the decision was taken to create an index of relevance for general health rather than a different weighting scheme for each health outcome of interest. Nonetheless, the indicators of environmental deprivation were carefully selected and recognised index construction methods were adhered to (Scottish Government 2009). Consequently SLIMED represents a methodological step forward in the field of environmental health research.

Fourth, the index captured environmental deprivation at a single point in time for each data zone, and then related this to residents' health. As with other cross-sectional area-level studies this approach was subject to potential exposure misclassification at spatial and temporal scales. The analyses did not account for physical environmental conditions experienced outside of each individual's data zone of residence, or for conditions experienced at other times through the lifecourse. The latter point will be especially relevant for older residents, whose health will partly represent the accumulation of past environmental exposures as well as present-day conditions. It could also help explain the absence of a relationship between environmental deprivation and hospital admissions for respiratory disease, as this condition may have been acquired or developed in different environments to those prevailing at the time of admission. The methodological approach also meant that the study provided evidence for an association between environmental deprivation and self-reported general health rather than a causal link. Fifth, the analyses were adjusted for key area-level risk factors but could not be adjusted for important individual-level factors such as smoking behaviour, as these data were unavailable.

The SLIMED index could have implications for improving policymaking and resource allocation at the local government level. The regional focus of this approach maximises the policy relevance of the resulting index, giving it the potential to directly inform decision making regarding services such as planning and transportation. The index could be used to identify neighbourhoods in which environmental conditions might engender poor general health, and where conditions could be improved. The index also allows areas blighted by both environmental and socioeconomic deprivation to be identified: 41 data zones (10%) were in the top quintiles of both SLIMED and SIMD09, of which 19 were in Hamilton and 14 were in Greater Glasgow.

In conclusion, this study has contributed to recent efforts (Pearce et al. 2010; Shortt et al. 2010) to broaden the more traditional single-factor focus of environmental epidemiology research. By refining the authors' earlier national-level focus the research revealed that simultaneous exposure to a range of adverse environmental factors may also have implications for population health at regional scales. The feasibility of measuring multiple environmental deprivation at a regional level and employing the index in epidemiological investigation was demonstrated. The resulting index, SLIMED, allowed relationships with health to be investigated at a finer resolution and with a more localised perspective than existing measures had allowed. The analyses successfully disentangled neighbourhood-level socioeconomic and environmental influences on health, and revealed that environmental deprivation makes a significant independent contribution to self-reported ill health in the region. Socioeconomic inequalities in self-reported health were also widest in the most environmentally deprived areas, suggesting a health-damaging interaction between poor environmental and socioeconomic conditions. The study furthered understanding of the role of multiple, suboptimal physical conditions in health and health inequalities, and created opportunities for further exploration of this important topic.

References

Babisch, W. 2000. Traffic noise and cardiovascular disease: epidemiological review and synthesis. *Noise and Health* 2 (8):9-32.

Bell, M. L., F. Dominici, and J. M. Samet. 2005. A meta-analysis of time-series studies of ozone and mortality with comparison to the national morbidity, mortality, and air pollution study. *Epidemiology* 16 (4):436-45.

Bowling, Ann, Julie Barber, Richard Morris, and Shah Ebrahim. 2006. Do perceptions of neighbourhood environment influence health? Baseline findings from a British survey of aging. *Journal of Epidemiology and Community Health* 60 (6):476-483.

Boyle, P. J., D. Exeter, and R. Flowerdew. 2004. The role of population change in widening the mortality gap in Scotland. *Area* 36.2:164-173.

Brulle, R.J., and D.N. Pellow. 2006. Environmental justice: human health and environmental inequalities. *Annual Review of Public Health* 27:103-124.

Burström, B., and P. Fredlund. 2001. Self rated health: Is it as good a predictor of subsequent mortality among adults in lower as well as in higher social classes? *Journal of Epidemiology and Community Health* 55:836-840.

Carstairs, V., and R. Morris. 1989. Deprivation: explaining differences in mortality between Scotland and England and Wales. *British Medical Journal* 299:886-889.

Carter, S., M. Williams, J. Paterson, and L. Iusitini. 2009. Do perceptions of neighbourhood problems contribute to maternal health? Findings from the Pacific Islands Families study. *Health & Place* 15 (2):622-630.

Charafeddine, R., and L. I. Boden. 2008. Does income inequality modify the association between air pollution and health? *Environmental Research* 106 (1):81-88.

de Vries, S., R. A. Verheij, P. P. Groenewegen, and P. Spreeuwenberg. 2003. Natural environments - Healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning A* 35 (10):1717-1731.

Ellaway, Anne, S. Macintyre, and X. Bonnefoy. 2005. Graffiti, greenery, and obesity in adults: secondary analysis of European cross sectional survey. *British Medical Journal* 331:611-612.

Ellen, I.G., T. Mijanovich, and K.N. Dillman. 2001. Neighbourhood effects on health exploring the links and assessing the evidence. *Journal of Urban Affairs* 23:391-408.

Evans, G. W., and E. Kantrowitz. 2002. Socioeconomic status and health: the potential role of environmental risk exposure. *Annual Review of Public Health* 23:303-31.

Gee, G.C., and D.T.D.T Takeuchi. 2004. Traffic stress, vehicular burden and well-being: A multilevel analysis. *Social Science & Medicine* 59:405-414.
Health Council of the Netherlands, and RMNO. 2004. *Nature and health: the influence of nature on social, psychological and physical well-being*. The Hague: Health Council of the Netherlands and RMNO, Publication no. 2004/09.
Hilbe, J.M. 2007. *Negative Binomial Regression*. Cambridge: Cambridge University Press.
Ito, K., S. F. De Leon, and M. Lippmann. 2005. Associations between ozone and daily mortality: analysis and meta-analysis. *Epidemiology* 16 (4):446-57.
Kaczynski, A.T., and K.A. Henderson. 2007. Environmental correlates of physical activity: a review of evidence about parks and recreation. *Leisure Sciences* 29:315-354.
Kaplan, R. , and S. Kaplan. 1989. *The experience of nature. A psychological perspective*. Cambridge: Cambridge University Press.
Lee, Duncan, Claire Ferguson, and Richard Mitchell. 2009. Air pollution and health in Scotland: a multicity study. *Biostatistics* 10 (3):409-423.
Levy, J. I., J. K. Hammitt, and J. D. Spengler. 2000. Estimating the mortality impacts of particulate matter: what can be learned from between-study variability? *Environmental Health Perspectives* 108 (2):109-17.
Maas, J., R.A. Verheij, P. P. Groenewegen, S. de Vries, and P. Spreeuwenberg. 2006. Green space, urbanity, and health: how strong is the relation? *Journal of Epidemiology and Community Health* 60:587-592.
Maas, Jolanda, Robert A. Verheij, Sjerp de Vries, Peter Spreeuwenberg, Francois G. Schellevis, and Peter P. Groenewegen. 2009. Morbidity is related to a green living environment. *Journal of Epidemiology & Community Health*.
Macintyre, S., A. Ellaway, and S. Cummins. 2002. Place effects on health: how can we conceptualise, operationalise and measure them? *Social Science & Medicine* 55 (1):125-139.
Mair, Christina, Ana V. Diez Roux, and Jeffrey D. Morenoff. 2010. Neighborhood stressors and social support as predictors of depressive symptoms in the Chicago Community Adult Health Study. *Health & Place* In Press, Corrected Proof.
Mann, S L, M E Wadsworth, and J R Colley. 1992. Accumulation of factors influencing respiratory illness in members of a national birth cohort and their offspring. *Journal of Epidemiology and Community Health* 46 (3):286-292.
McCarthy, P., D. Byrne, S. Harrisson, and J. Keithley. 1985. Respiratory conditions: effects of housing and other factors. *Journal of Epidemiology and Community Health* 39:15-19.
McLoone, P., and F. A. Boddy. 1994. Deprivation and mortality in Scotland, 1981 and 1991. *British Medical Journal* 309 (6967):1465-1470.
Mitchell, R., and F. Popham. 2007. Greenspace, urbanity and health: Relationships in England. *Journal of Epidemiology and Community Health* 61 (8):681-683.
———. 2008. Effect of exposure to natural environment on health inequalities: an observational population study. *The Lancet* 372:1655-1660.
Noble, M., H. Barnes, G. Wright, D. McLennan, D. Avenell, A. Whitworth, and B. Roberts. 2009. The South African Index of Multiple Deprivation 2001 at Datazone Level Pretoria: Department of Social Development.

Owen, N., N. Humpel, E. Leslie, A. Bauman, and J.F. Sallis. 2004. Understanding environmental influences on walking: review and research agenda. *American Journal of Preventive Medicine* 27 (1):67-76.

Pearce, J., E.A. Richardson, R. Mitchell, and N.K. Shortt. 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* 35 (4):522-539.

Poortinga, W. 2006. Perceptions of the environment, physical activity, and obesity. *Social Science & Medicine* 63 (11):2835-2846.

Poortinga, Wouter, Frank D. Dunstan, and David L. Fone. 2008. Neighbourhood deprivation and self-rated health: The role of perceptions of the neighbourhood and of housing problems. *Health & Place* 14 (3):562-575.

Richardson, E.A., R.J. Mitchell, N.K. Shortt, J. Pearce, and T.P. Dawson. 2009. Evidence-based selection of environmental factors and datasets for measuring multiple environmental deprivation in epidemiological research. *Environmental Health* 8 (Suppl. 1):S18.

———. 2010. Developing summary measures of health-related multiple physical environmental deprivation for epidemiological research *Environment and Planning A* 42 (7):1650-1668.

Schwartz, J. 1994. Air pollution and daily mortality: a review and meta analysis. *Environmental Research* 64 (1):36-52.

Scottish Government. 2009. Scottish Index of Multiple Deprivation 2009: General Report. Edinburgh: Office of the Chief Statistician, Scottish Government.

———. 2009. Scottish Index of Multiple Deprivation 2009: Technical Report. Edinburgh: Office of the Chief Statistician, Scottish Government.

Shortt, N.K., E.A. Richardson, R. Mitchell, and J. Pearce. 2010. Re-engaging with the physical environment: a health-related environmental classification of the UK. *Area*.

Shusterman, D., J. Lipscomb, R. Neutra, and K. Satin. 1991. Symptom prevalence and odor-worry interaction near hazardous waste sites. *Environmental Health Perspectives* 94:25-30.

Sol, V.M., P.E.M. Lammers, H. Aiking, J. de Boer, and J.F. Feenstra. 1995. Integrated environmental index for application in land-use zoning. *Environmental Management* 19 (3):457-467.

Sooman, A., and S. Macintyre. 1995. Health and perceptions of the local environment in socially contrasting neighbourhoods in Glasgow. *Health and Place* 1:15-26.

South Lanarkshire Community Planning Partnership. 2008. Stronger together for health improvement 3: Joint action for health improvement in South Lanarkshire 2008-2011. Hamilton: Social Work Resources.

Stieb, D. M., S. Judek, and R. T. Burnett. 2002. Meta-analysis of time-series studies of air pollution and mortality: effects of gases and particles and the influence of cause of death, age, and season. *Journal of the Air & Waste Management Association* 52 (4):470-84.

Sugiyama, T., E. Leslie, Billie Giles-Corti, and N. Owen. 2008. Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? *Journal of Epidemiology and Community Health* 62 (5):e9.

The Scottish Government. 2009. Scottish Index of Multiple Deprivation: 2009 General Report. Edinburgh: The Scottish Government.

Trost, S., N. Owen, A. Bauman, J.F. Sallis, and W. Brown. 2002. Correlates of adults' participation in physical activity: review and update *Medicine and Science in Sports and Exercise* 34 (12):1996-2001.

van Kempen, E.E.M.M., H. Kruize, H.C. Boshuizen, C.B. Ameling, B.A.M. Staatsen, and A.E.M. de Hollander. 2002. The association between noise exposure and blood pressure and ischaemic heart disease: a meta-analysis. *Environmental Health Perspectives* 110 (3):307-317.

Vrijheid, M. 2000. Health effects of residence near hazardous waste landfill sites: A review of epidemiologic literature. *Environmental Health Perspectives* 108 (Suppl. 1):101-112.

Weich, S., L. Twigg, G. Holt, G. Lewis, and K. Jones. 2003. Contextual risk factors for the common mental disorders in Britain: a multilevel investigation of the effects of place. *Journal of Epidemiology and Community Health* 57 (8):616-621.

Welsh Assembly Government. 2009. Welsh Index of Multiple Deprivation 2008: Technical Report. Cardiff: Welsh Assembly Government.

World Health Organization. 2004. Health aspects of air pollution: results from the WHO project "Systematic review of health aspects of air pollution in Europe". Geneva: World Health Organization.

Table 1. Data sets used to measure the indicators of environmental deprivation.

Indicator	Data zone level measure of exposure	Dataset		
		Data source	Dataset details	Additional processing required
HAZARDOUS ENVIRONMENTS				
Air pollution	Annual average concentration PM_{10} ($\mu g.m^{-3}$, population-weighted, 2002 to 2004)	SNS (using data from UK Air Quality Archive and OS Address Point layer)	Individual addresses linked to gridded air pollutant data (1 km^2 grid) and averaged.	None
Noise	% data zone area (population-weighted) within 100 m of a major road or rail route (2009)	OS	Polyline shapefile detailing major roads (motorways, A- and B-roads) and railway lines in 2009.	Intersected 100 m buffer around transport routes with OAs to give % OA area within buffer. Weighted % by OA population (2001) to calculate DZ average %.
Traffic environment	Per capita rate of pedestrian and cyclist road accidents over 10 years (1999 to 2008)	SG Transport Directorate	STATS 19 road accident data for 1999 to 2008 (including year, grid reference and type of road user)	Extracted pedestrian and cyclist accidents for each DZ to calculate accident rate.

Indicator	Data zone level measure of exposure	Dataset		
		Data source	Dataset details	Additional processing required
UNDESIRABLE ENVIRONMENTS				
Undesirable land uses	% data zone area (population-weighted) within 100 m of any of the following four land uses:			
	1. industrial facilities	SEPA	Coordinates of SPRI sites (2002 - 2008)	Intersected 100 m buffer around undesirable land uses with OAs to give % OA area within buffer. Weighted % by OA population (2001) to calculate DZ average %.
	2. mineral extraction areas	SL Council	Polygon shapefile (2009)	
	3. derelict land	SL Council	Polygon shapefile (2009)	
	4. contaminated land	SL Council	Polygon shapefile (2001)	
Crime	Per capita rate of SIMD crimes (2007 - 2008)	SNS (using data from the police force and GROS)	Rate of neighbourhood crimes: violent crime, burglary, vandalism, minor assault and drugs offences (SIMD Crime domain, 2007 to 2008)	None

Indicator	Data zone level measure of exposure	Dataset		
		Data source	Dataset details	Additional processing required
SALUTOGENIC ENVIRONMENTS				
Green space (urban)	% coverage by “Priority” or “Green Network” urban green spaces (population-weighted)	SL Council	Polygon shapefile of green space identified as a “Priority Green Space Land Use” or as “Green Network” (2006)	% OA area designated priority/ green network green space was weighted using OA population (2001) to calculate DZ average %.
Public transport	Density of bus stops (no. per ha, population-weighted)	Strathclyde Partnership for Transport (SPT)	Grid references of SPT bus stops in South Lanarkshire (2009)	OA bus stop density (no. per ha) weighted using OA population (2001) to calculate DZ average %.
Paths	% data zone area (population-weighted) within 100 m of any of:			
	1. Foot paths	SL Council	Polyline shapefile of designated Core Paths and Wider Network paths (2009)	Intersected 100 m buffer around paths with OAs to give % OA area within buffer.
	2. Cycle paths	(a) SL Council and (b) SusTrans	Polyline shapefiles of (a) regional and (b) national cycle paths (2009)	Weighted % by OA population (2001) to calculate DZ average %.

Indicator	Data zone level measure of exposure	Dataset		
		Data source	Dataset details	Additional processing required
Access	SIMD 2009 Geographic Access domain: the average time taken to reach key services by private car/public transport	SNS (using data from the OS, GROS, Experian, Traveline and CACI)	A factor analysis of 8 travel time indicators (5 drive time and 3 public transport time, 2009) was used to create the domain score	None

Abbreviations

DZ	Data zone
GROS	General Register Office for Scotland
ha	hectare (= 0.01 km^2)
OA	Output Area
OS	Ordnance Survey
PM_{10}	Particulate matter with a median diameter < 10 μm
SEPA	Scottish Environmental Protection Agency
SG	Scottish Government
SIMD	Scottish Index of Multiple Deprivation
SL	South Lanarkshire
SNS	Scottish Neighbourhood Statistics
SPRI	Scottish Pollutant Release Inventory
SPT	Strathclyde Partnership for Transport

Table 2. Population distribution between the SLIMED quintiles, by Urban-Rural classification.

Scottish Urban-Rural classification 2007/08	Population count (+ *% SL population*) by SLIMED quintile					
	1 (least deprived)	2	3	4	5 (most deprived)	Total
1 (large urban areas)	1985	6647	16861	24408	19501	69402
	0.6	*2.1*	*5.4*	*7.9*	*6.3*	*22.4*
2 (other urban areas)	40509	33750	30996	28369	38620	172244
	13.1	*10.9*	*10.0*	*9.2*	*12.5*	*55.7*
3 (accessible small towns)	5467	8268	4296	6395	4663	29089
	1.8	*2.7*	*1.4*	*2.1*	*1.5*	*9.4*
5 (accessible rural)	11098	12160	8600	3693	738	36289
	3.6	*3.9*	*2.8*	*1.2*	*0.2*	*11.7*
6 (remote rural)	760	0	1038	678	0	2476
	0.2	*0.0*	*0.3*	*0.2*	*0.0*	*0.8*
Total	59819	60825	61791	63543	63522	309500

Table 3. Excess ill health potentially attributable to environmental deprivation in South Lanarkshire.

Data zone grouping	actual (n)	predicted* (n)	potentially attributable to environmental deprivation	
			count	% of actual
SIMD09 quintile				
1 (most affluent)	3345	3307	38	1.1
2	4910	4520	390	7.9
3	6263	5391	872	13.9
4	8361	7597	764	9.1
5 (most deprived)	10162	7181	2981	29.3
Total	*33041*	*27997*	*5044*	*15.3*
SLIMED quintile				
1 (least environmental deprivation)	4352	4352	0	0
2	5749	5194	555	9.6
3	6770	5652	1118	16.5
4	7444	5975	1469	19.7
5 (most environmental deprivation)	8726	6824	1902	21.8
Total	*33041*	*27997*	*5044*	*15.3*

* applying age, sex and deprivation-specific rates for SLIMED quintile 1 to the whole population.

FIGURES

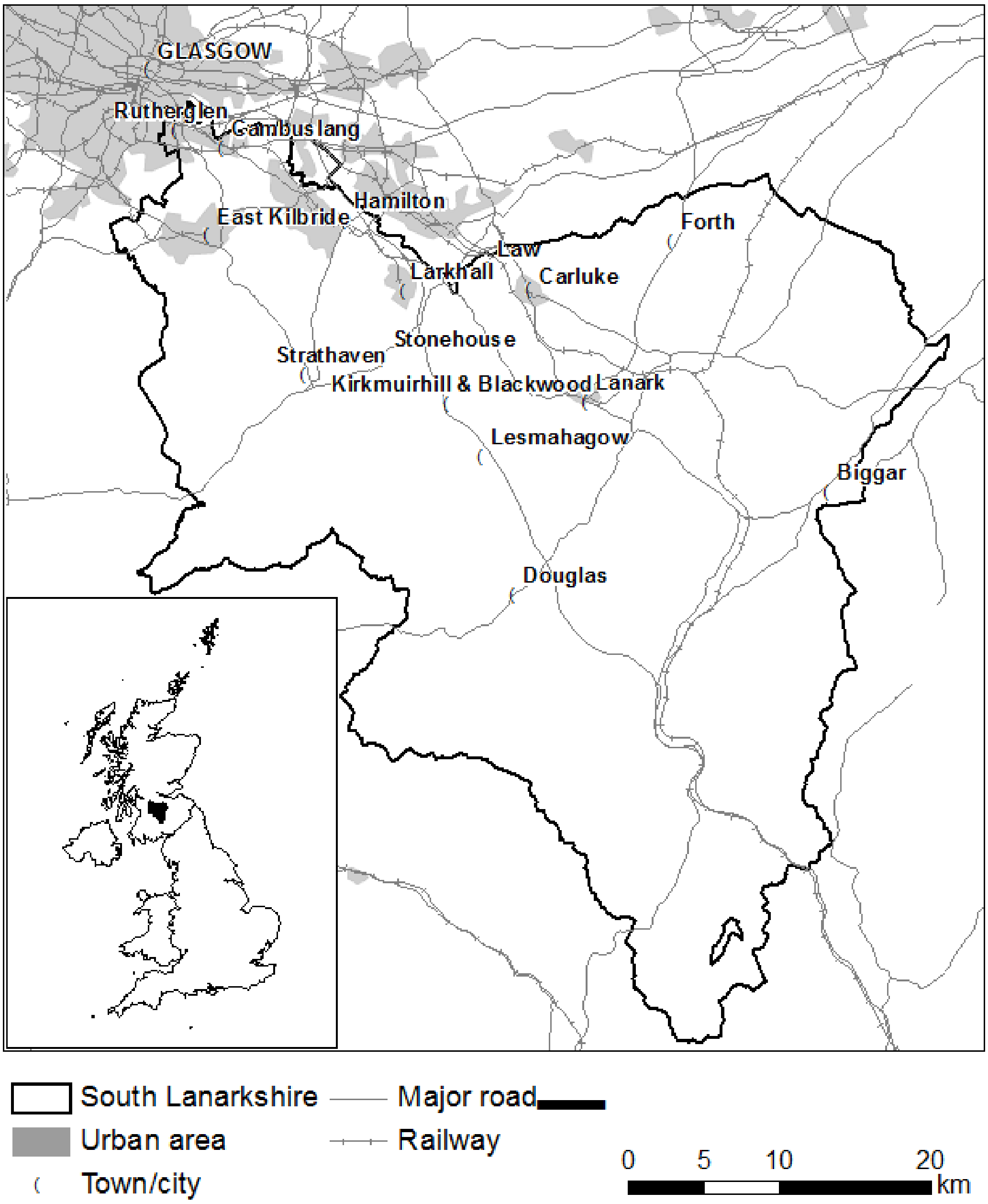


Figure 1. South Lanarkshire local authority. Inset shows location of South Lanarkshire in the UK. Mapping is Ordnance Survey © Crown copyright and database right 2010. All rights reserved. An Ordnance Survey/EDINA supplied service.

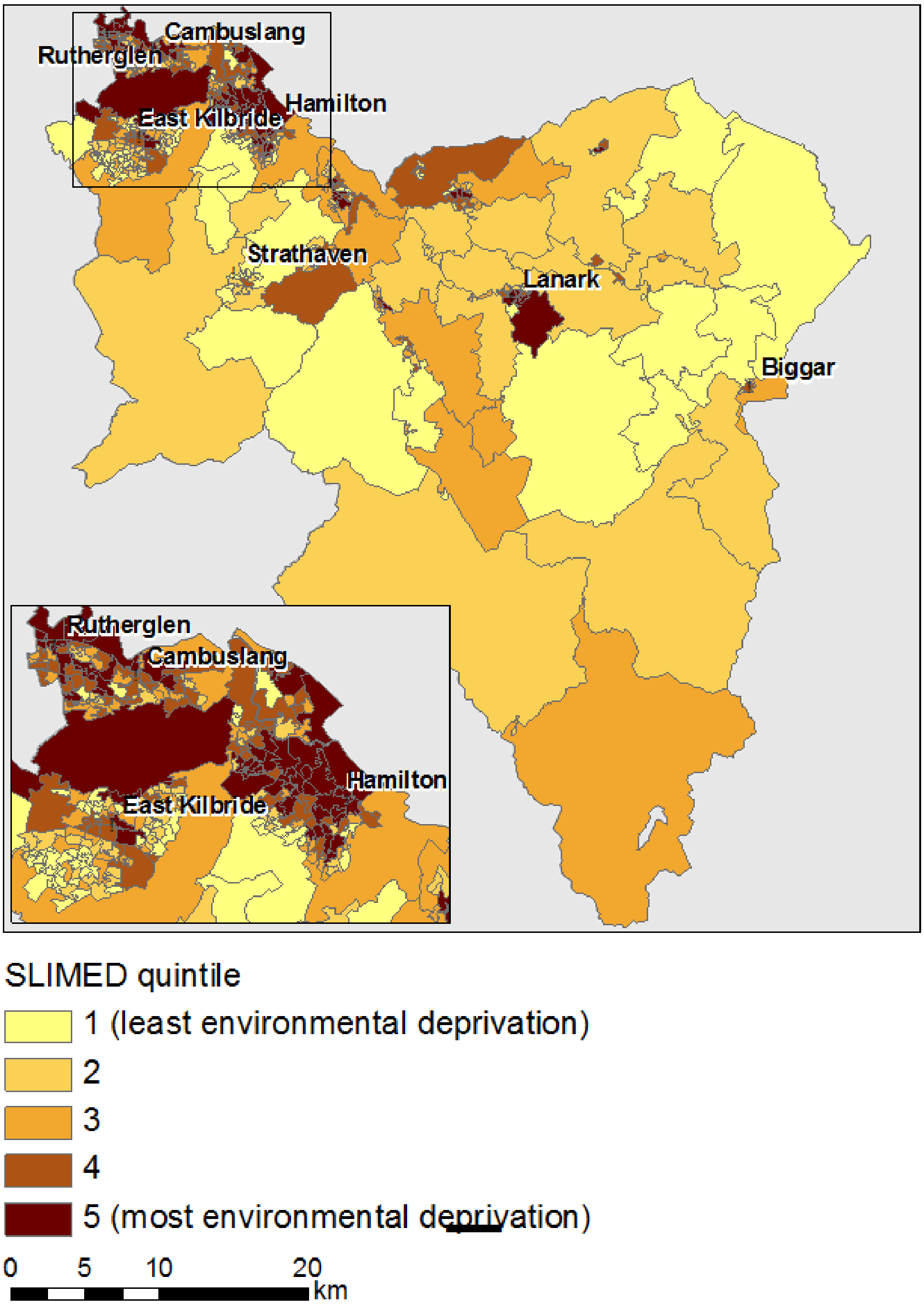
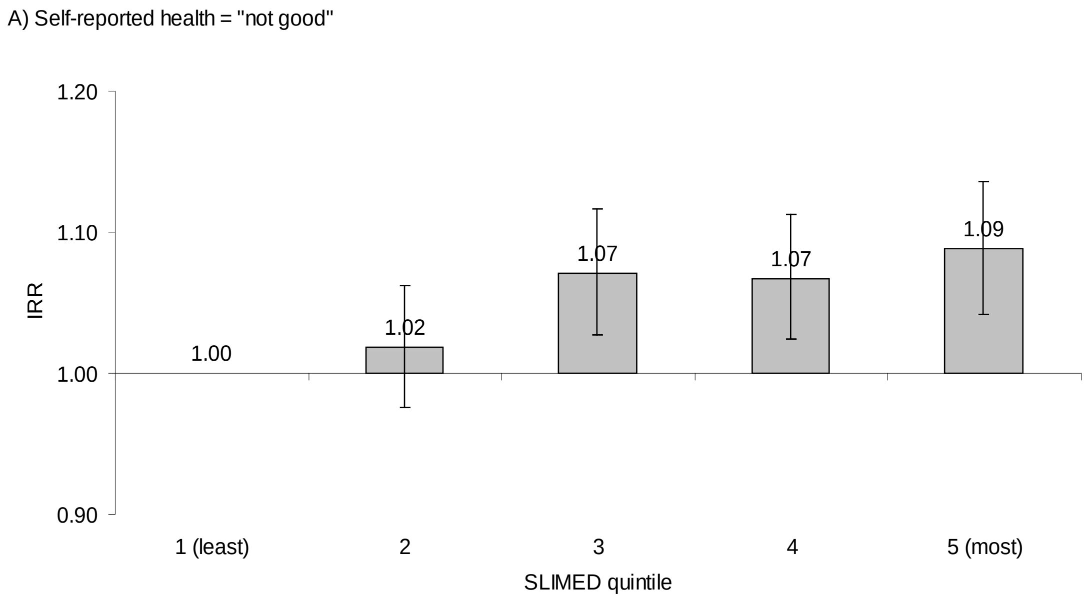


Figure 2. Distribution of the South Lanarkshire Index of Multiple Environmental Deprivation (SLIMED). Mapping is Ordnance Survey © Crown copyright and database right 2010. All rights reserved. An Ordnance Survey/EDINA supplied service.



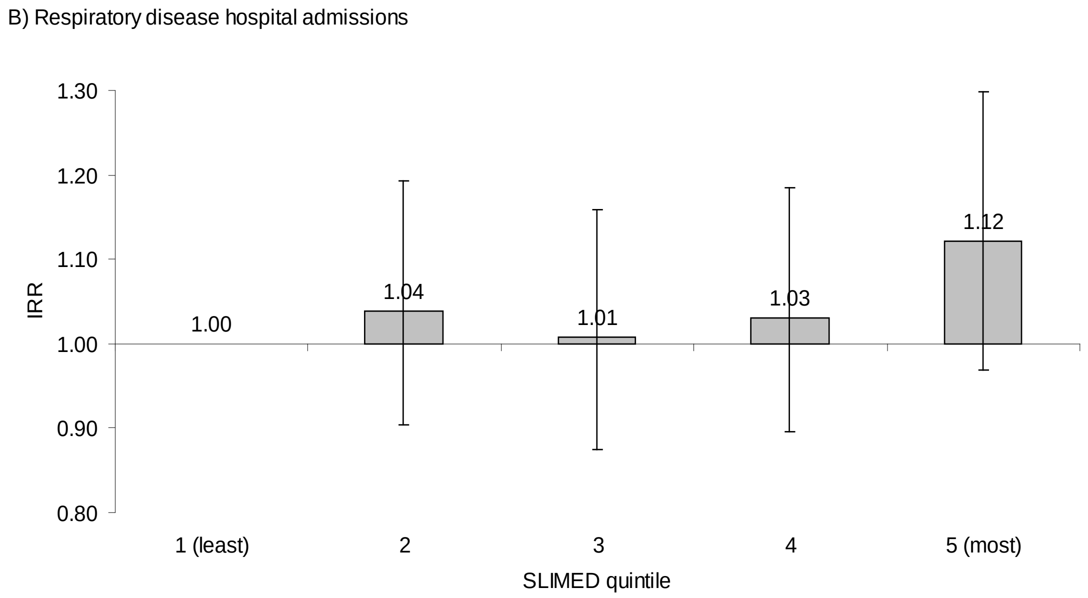


Figure 3. Relative risk of A) self-reported not-good health and B) respiratory disease hospital admissions for populations at each level of multiple environmental deprivation (SLIMED quintile), after adjustment for age group, sex and SIMD 2009 deprivation quintile. Incidence rate ratios (IRRs) are given relative to SLIMED quintile 1, the least environmentally deprived data zones (IRR = 1.0). Bars indicate 95% confidence intervals.

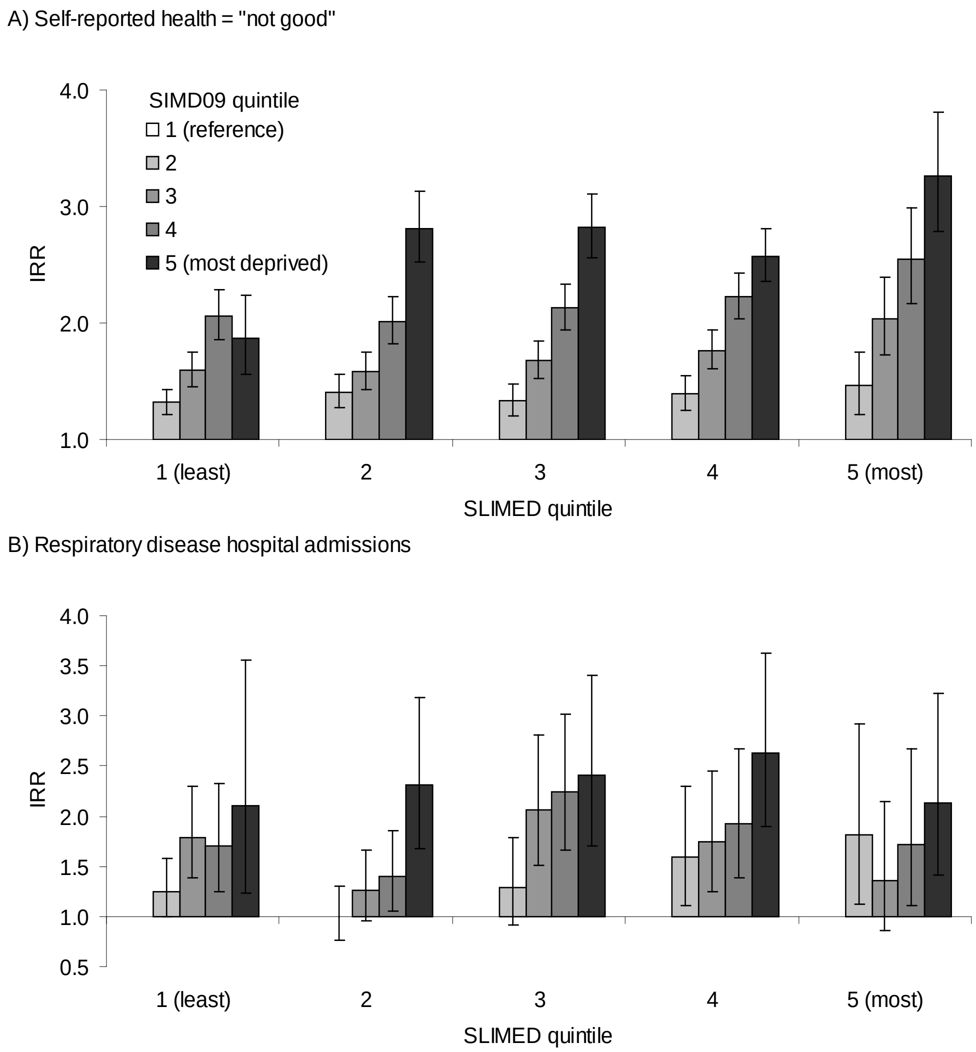


Figure 4. Socioeconomic inequalities in A) self-reported not-good health and B) respiratory disease hospital admissions at each level of environmental deprivation (SLIMED quintiles). Incidence rate ratios (IRRs) were adjusted for age group and sex, and are given relative to SIMD 2009 quintile 1, the most affluent data zones at each level (IRR = 1.0). Bars indicate 95% confidence intervals.