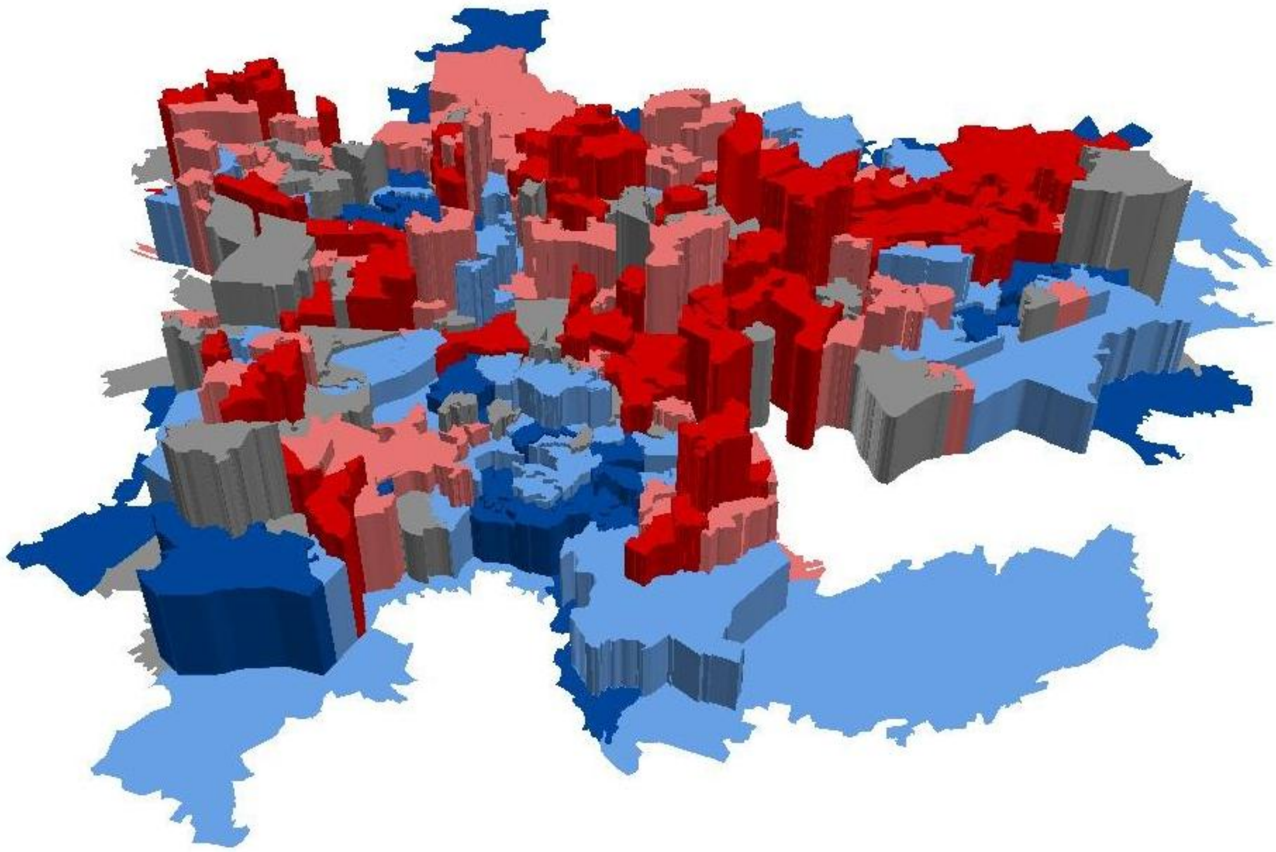

Investigating the impact of the spatial distribution of deprivation on health outcomes

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Executive summary

Scotland has some of the poorest health in Western Europe and has a health profile that has more in common with Eastern European countries than the more developed West. Poorer health has been linked to high levels of deprivation and given Scotland's deprivation profile, it might be thought that this is the explanation for Scotland's poor health. However, research has shown that even after adjusting for differences in deprivation levels, there is still considerable 'excess' mortality in Scotland compared with England. A large proportion of this excess is found in the West of Scotland and in Glasgow in particular. A recent study has shown that when Glasgow is compared with similar post-industrial cities in England (Liverpool and Manchester) with similar deprivation profiles there is considerable excess mortality in Glasgow. Considerable effort is now being made into trying to identify the causes of this so-called 'Glasgow Effect'. One possible explanation is that the health of the population of Glasgow may be affected by a different *spatial patterning of deprivation* to that in the two English cities: that is, the way in which deprived and affluent areas are distributed across the city may be different in Glasgow than in Liverpool and Manchester, and may, through particular causal pathways, adversely affect the health of Glasgow's population. This study sought to explore whether or not this may be the case.

The specific research questions were:

Is the spatial patterning of deprivation in Glasgow different to that found in Liverpool and Manchester?

Does the distribution of deprivation in the three cities have an impact on all-cause mortality, premature mortality, and disease-specific mortality?

Does the addition of neighbourhood contextual variables impact on all-cause mortality and influence the relationship between the neighbourhood and the surrounding areas?

At what scale, if any, are these effects observed?

To what extent are differences in the distribution of deprivation responsible for differences in health outcomes in the three cities?

To answer these questions deprivation was mapped and tested for differences in patterning across the three cities. This showed that while deprived neighbourhoods in all cities were likely to be close to similarly deprived areas, Glasgow's neighbourhoods were more dispersed than Liverpool and Manchester. Another difference was that deprived neighbourhoods in Liverpool and Manchester were more likely to be situated nearer to the city centre than was the case in Glasgow.

Statistical modelling was undertaken to test these relationships more formally, and to assess the impact of any differences in the geographical distribution of deprivation on mortality. Neighbourhood deprivation (along with the percentage of people living in nursing homes) was found to be the most important independent variable in explaining variations in mortality rates between neighbourhoods. Deprivation in the surrounding neighbourhoods had only a small influence on mortality rates, and this relationship was similar in all three cities: this, therefore, is not an explanation for the 'Glasgow Effect'.

The relationship between neighbourhood deprivation and mortality was different in all three cities, with mortality still significantly higher in Glasgow compared with Liverpool and Manchester after all statistical adjustments. Models which examined premature mortality (<65 years) had similar results, with neighbourhood deprivation the most significant single variable in explaining differences between neighbourhood mortality rates. Again surrounding deprivation only had a small effect on neighbourhood mortality rates. In all the models tested, the excess mortality (or gap) between Glasgow and the other cities widened as deprivation rose, showing that differences between the cities were at their greatest at the highest levels of deprivation.

We can conclude that while the spatial patterning of deprivation may have a small influence on mortality rates in the neighbourhood, the influence is similar in all three cities and does not provide us with any explanation for differences in the mortality rates that we see in Glasgow compared with the two English cities. The most significant explanatory variable for differences in mortality rates in neighbourhoods is deprivation, although the relationship between deprivation and mortality rates is different in the three cities.

1. Introduction

1.1 Overview

Scotland's poor health status relative to other Western European countries is well known. Historically, this has been attributed to higher levels of material deprivation, at least in comparison with other parts of the UK[1-4]. However, in recent years a number of studies have shown that even when differences in deprivation have been accounted for (be they measures of *area* deprivation or *individual* socioeconomic status), there still remains an 'excess' level of poor health in Scotland that is, in effect, unexplained[5-8].

This 'excess' has been shown to be ubiquitous: that is, all parts of Scotland have poorer health (higher rates of mortality) than the rest of the UK, even allowing for differences in deprivation levels[5]. However, the excess has been shown to be greatest in the West Central Scotland conurbation which has Glasgow at its core. Research published in 2010 showed that Glasgow has almost identical deprivation profiles to the similar post-industrial English cities of Liverpool and Manchester. Despite this, premature deaths in Glasgow are 30% higher than in the English cities, with numbers of deaths at all ages around 15% higher[9].

A number of different hypotheses have been put forward to explain this discrepancy[10]. Included in these is the idea that the health of the population of Glasgow may be affected by a different *spatial patterning of deprivation* than exists in the two English cities: that is, the way in which deprived and affluent areas are distributed across the city may be different in Glasgow than in Liverpool and Manchester, and may, through particular causal pathways, adversely affect the health of Glasgow's population. This study sought to explore whether or not this may be the case.

1.2 Health and the patterning of deprivation

There is a large body of research on the effects of 'place' (e.g. the neighbourhood one lives in) on individuals' health. This relates not just to obvious 'direct' effects (from air pollution, traffic accidents, housing quality and so on), but also to more 'indirect' effects (e.g. relating to the existence of social networks, availability of quality green spaces, the general quality of the environment). Studies have shown independent effects of neighbourhood on both the physical[11] and mental (for example see Truong & Ma, 2006[12]) health of those living there, that is to say, over and above that explained by the characteristics of the individuals themselves (for example socioeconomic status). The spatial patterning of deprivation within and across areas is one such potential indirect influence.

In seeking to understand the influence of place on health, the role of poverty and deprivation is crucial. Deprivation causes poor health through a variety of different causal pathways, and thus poorer areas generally exhibit worse health than less deprived localities. However, there is an emerging body of evidence which suggests that the health of an area is influenced not just by its own level of deprivation, but also by the levels of deprivation in neighbouring areas.

This makes intuitive sense: previous studies of neighbourhood effects on health have treated the concept of neighbourhood in quite simplistic terms – as if the characteristics of a place can be captured by measuring these at a single scale or level. In effect, neighbourhood units were treated as ‘islands’ divorced from their surroundings. Yet we might expect that the wider spatial context in which a neighbourhood lies might also be an important influence on individuals.

In relation to this, two possible, but opposing, mechanisms have been suggested as potentially influential. The first is that increasing segregation of the poorest into the most deprived neighbourhoods is damaging to the health of those resident in these areas. Authors such as Dorling have argued that the UK has become more segregated in recent decades, with the poorest and most affluent members of society increasingly living apart in different neighbourhoods[13]. A deprived neighbourhood which is surrounded by a concentration of other deprived neighbourhoods might have different health behaviours and outcomes than one which is surrounded by, or adjacent to, more affluent neighbourhoods. Health is adversely affected by damaging behaviours and there is strong evidence that smoking, lack of exercise, poor diet and other problematic behaviours are more prevalent in more deprived areas. Geographical concentration of deprived neighbourhoods might serve to strengthen and deepen these poor health behaviours and cultures. In contrast, those living in deprived neighbourhoods which are surrounded by more affluent areas may have more positive influences on their health behaviours resulting in better outcomes.

Thus, it is argued that there are potential negative effects of the *concentration* of deprivation. However, an alternative hypothesis, although also highlighting the importance of the spatial patterning of deprivation, suggests negative effects of more *mixed* levels of deprivation and affluence. This focuses on the work of Wilkinson and others[14,15] which proposed that high levels of inequality and social comparisons lead to poorer health and social outcomes. In other words people feel the effects of poverty most where differences are greatest, and feel less ‘othered’[a] where economic differences are smaller; and thus problems of stress associated with social status would be lower in homogeneous areas. Wilkinson argues that these effects operate at the level of whole societies (countries, or states in large countries such as the USA) rather than neighbourhood. However, others have suggested similar local effects may operate in urban settings[17].

[a] Othering is a process that identifies those that are thought to be different from oneself or the mainstream[16].

Thus, in different ways, spatial patterning of deprivation may influence health; and there is increasing evidence of this from a number of studies. For example, Sridharan and colleagues used Scottish postcode sectors to examine the impact of spatial patterning of deprivation on levels of mortality in the neighbourhoods: they showed deprivation levels in surrounding areas to be significantly associated with levels of mortality in the sectors themselves[18]. Similar general findings were obtained in separate studies by Cox[19] and Zhang[20], although the methodologies and spatial scales used in the analyses differed. Indeed, the issues of scale and neighbourhood definition are crucial to these analyses; and a weakness of Sridharan *et al*.'s study (acknowledged by the authors) was the use of postcode sectors: these are relatively large in size with average populations of 5,000 in Scotland (5,500 in Glasgow) and cannot reasonably be thought of as a unit of neighbourhood. Other studies have varied in how they have defined neighbourhoods, usually driven by the geographical level of available data, and often using large spatial units of analysis on the basis of convenience and availability (as in the use of political wards and parliamentary constituencies), or in order to maintain consistent boundaries over time (as in the use of 'tracts'[b]).

This issue is particularly relevant to the current study, as is the work of Rae, who set out an approach to measuring deprivation which allows the spatial concentration of deprivation to be considered[21]. This approach, which uses concentric contiguous rings of neighbourhoods, combines spatial statistical approaches with a deprivation index. The same author has also used this approach to show that deprivation in England is highly concentrated, and that this concentration is persistent over time[22].

Thus, a number of studies have shown the impact of the spatial patterning of deprivation on health. The research reported here sets out to examine whether the spatial patterning of deprivation in the cities of Glasgow, Liverpool, and Manchester is different, and whether any differences contribute in some way to the excess mortality observed in Glasgow compared with Liverpool and Manchester.

1.3 Research questions

As outlined above, this project set out to:

- determine the extent to which the distribution and patterning of deprivation is different within Glasgow, Liverpool and Manchester
- assess the extent to which any differences may in part impact on the higher rates of mortality seen in Glasgow.

[b] Census tracts are geographical areas which were constructed to provide data with consistent boundaries over different census time periods. However, they vary considerably in scale and population size.

Specifically, the research questions were as follows:

1. Is the spatial patterning of deprivation in Glasgow different to that found in Liverpool and Manchester?

2. Does the distribution of deprivation in the three cities have an impact on all-cause mortality?

3. Does the distribution of deprivation in the three cities have particular influence on certain types of mortality?

4. Does the addition of neighbourhood contextual variables impact on all-cause mortality and influence the relationship between the neighbourhood and the surrounding areas?

5. Are differences in these impacts more apparent using different geographical scales?

6. Overall, to what extent are differences in the distribution of deprivation responsible for differences in health outcomes in the three cities?

2. Methods

In this section a description is provided of the health and deprivation data used, the geographical scale of the analysis, statistical measures applied and modelling approach.

2.1 Neighbourhood and neighbourhood scale

Neighbourhood in Liverpool and Manchester has been measured at the Lower Super Output Area (LSOA) level. LSOAs are designed for the presentation of 'neighbourhood' statistics by the government. These areas are designed to be relatively homogenous in terms of levels of deprivation. The average population of an LSOA is around 1,500 people. There are a total of 291 LSOAs in Liverpool and 259 in Manchester. The relatively small size of LSOAs, compared with other geographies such as electoral wards, makes it more likely that they represent the geographical scale at which people are most likely to interact on a daily basis, and these areas, therefore, are a better representation of a neighbourhood than other, larger, spatial units.

In Scotland LSOAs are not used. The equivalent measure used for reporting official neighbourhood statistics is datazones. Datazones have an average population size of approximately 750 people and are thus half the size of the English LSOAs. To enable analyses of the three cities using the same spatial scale, the project used a set of previously created merged datazones for Glasgow of a similar size to LSOAs. In all, 350 areas were established with an average population size of 1,650[c][9]; a further 131 areas were created in the surrounding rings around the city for the purposes of this project.

2.2 Mortality and population data

Mortality and population data were provided by the Glasgow Centre for Population Health (GCPH). These were used in the original study of mortality and deprivation in the three cities[9], and were originally obtained from the National Records of Scotland (formerly, the General Register Office for Scotland) for Glasgow, and from the Office of National Statistics (ONS) for the English cities. Data were provided by five year age band, gender and for a range of causes for the period 2003-2007 for each LSOA and merged datazone. Directly age and sex standardised mortality[d] rates were calculated for each small area in the three cities.

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[c] Walsh *et al*.[9] used geographical information systems to merge neighbouring datazones to create areas which were similar in income deprivation but also in size to English LSOAs.

[d] Standardised to the European population.

2.3 Income deprivation

Both Scotland and England have sophisticated measures of deprivation in the form of the Scottish Index of Multiple Deprivation (SIMD) in Scotland[23] and the Indices of Multiple Deprivation (IMD) in England[24]. However, as there are differences in content and weighting between the two indices, they are not directly comparable.

To address this, in the study a measure of 'income deprivation' has been used: this is measured as the proportion of the population in receipt of key income-related benefits in 2005 as well as children dependent on adult recipients of those benefits. Data on income deprivation for Glasgow were derived from the SIMD and for England were obtained from the Department of Work and Pensions (DWP)[e].

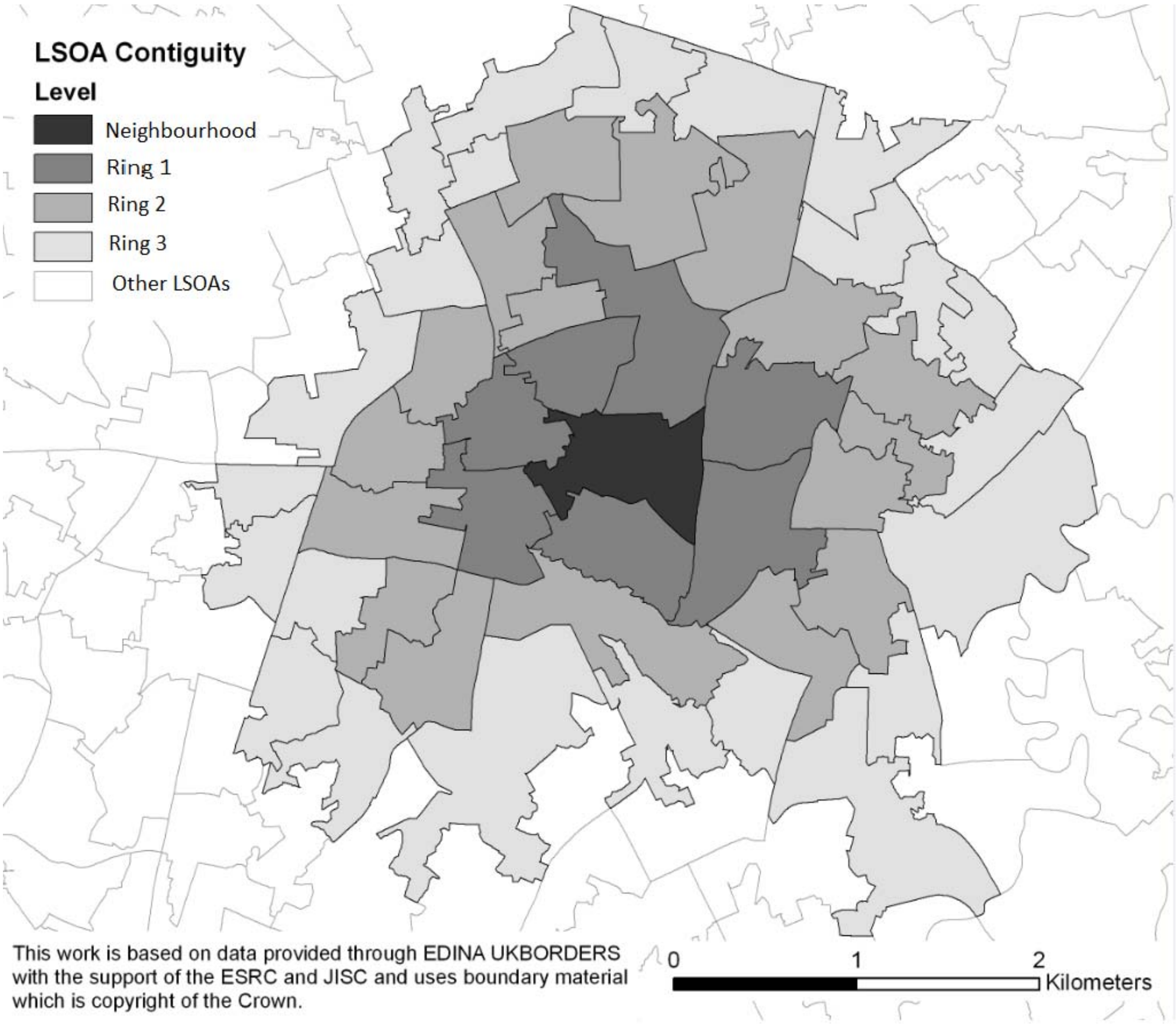
For spatial analyses, population-weighted income deprivation deciles were used. Thus, each small area (LSOA/merged datazone) was assigned to a decile (from 1 to 10, where 1 = least deprived and 10 = most deprived), based on its level of deprivation.

2.4 Different geographical scales

Effects at three different scales are presented in this paper: the neighbourhood scale as described above (i.e. LSOAs and merged datazones (in Glasgow)), and two further scales as defined by Rae (2009)[21]. The second scale is the first contiguous ring of LSOAs (Ring 1) around a neighbourhood, and the third scale the second contiguous ring round the first ring (Ring 2) – see Figure 1 for a graphical illustration.

[e] This measure of deprivation is highly correlated with the national (SIMD, IMD) deprivation indices in these cities (correlation coefficients of 0.98 for Glasgow and 0.97 Liverpool/Manchester).

Figure 1. Adjacency-based neighbourhoods: different levels of contiguity.



Reproduced with the kind permission of Alasdair Rae, Department of Town and Regional Planning, University of Sheffield (see Rae 2009[21]). Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

2.5 Measuring the pattern of deprivation

There are few formal methods for assessing or measuring spatial patterning, although this is an area that academics are starting to explore[25,26]. The most obvious and simple way of doing this is through the use of Geographic Information System (GIS) software to map, and compare, levels of neighbourhood deprivation in the three cities.

As well as mapping levels of deprivation, a number of statistics were also calculated to examine patterns across the three cities more objectively.

Six statistics were used to measure different aspects of the distribution and patterning of deprivation:

1. Mean income deprivation in the surrounding contiguous LSOAs (Ring 1);
2. Median income deprivation in the surrounding contiguous LSOAs (Ring 1);
3. Highest income deprivation in the surrounding contiguous LSOAs (Ring 1);
4. Lowest income deprivation in the surrounding contiguous LSOAs (Ring 1);
5. Mean distance from areas to city centre
6. Moran's I test.

These are all described in more detail below.

Mean income deprivation in Ring 1
The mean income deprivation of all the LSOAs/merged datazones contiguous to each neighbourhood (Ring 1) was calculated.

As with many of the statistics, this was calculated and analysed by each of the ten deprivation deciles in each city. In this case, such analyses allow us to assess differences in *surrounding* deprivation levels between and within the cities. This allows us an assessment of whether deprived neighbourhoods are more likely to be surrounded by other similarly deprived neighbourhoods and whether the likelihood is stronger in particular cities.

Median income deprivation in Ring 1
One weakness of the calculation of mean deprivation in Ring 1 (above) is that the statistic can be unduly influenced by the presence of one particularly affluent or deprived area in the 'ring'. Calculating the median rather than the mean makes the statistic less at risk of 'leverage' from one area.

Highest deprivation in Ring 1
While not an indication of the wider deprivation levels of the surrounding neighbourhoods this statistic does indicate whether or not an area is in close contact with another area of high deprivation.

Lowest deprivation in Ring 1
As above but concentrating on whether neighbourhoods are in contact with less deprived neighbourhoods.

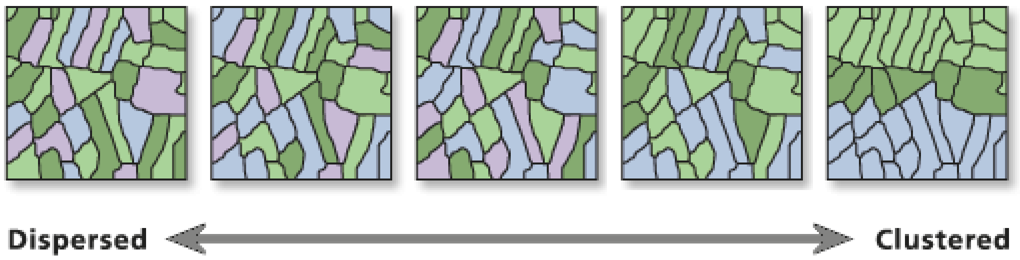
Mean distance to city centre
A fifth statistic used to compare the three cities is the average distance of areas from the city centre. While there is no research to suggest that being closer or further away from the city centre has implications for poorer health, deprived areas which are on the periphery of a city may suffer from increased segregation from the rest of the city as well as poorer access to centralised services, especially if transport links

are poor. The distance to the city centre was calculated for all neighbourhoods in each city, using the Euclidian distance (i.e. as the crow flies) from the centre[f] of the neighbourhood to the city hall. The distance to the centre was standardised by dividing the mean distance by the overall mean distance to centre for all areas in the city, creating a standardised ratio.

Moran's I test

The Moran's I test is a test of 'spatial autocorrelation' and thus measures the likelihood that areas in close proximity are similar to each other, based on a particular characteristic (in this case deprivation). The score runs from -1 to +1. A score of -1 means that areas are perfectly dispersed, while a score of +1 indicates that areas are perfectly clustered or completely segregated. A score of 0 indicates a random spatial pattern. Figure 2 provides a visual illustration of this. Moran's I test is not only important for assessing how likely areas are to be near similar areas, but also for assessing the extent that modelling accounts for any spatial differences on mortality rates.

Figure 2. Example of differently dispersed/clustered neighbourhoods.



2.6 Mapping of mortality and deprivation

Three dimensional maps showing mortality rates and deprivation were created to examine the univariate relationship between the two variables within each of the three cities.

Neighbourhood deprivation was mapped in colour (blue to red with increasing levels of income deprivation) with mortality rates represented by elevation (increasing elevation with higher mortality rates). The maps were created using Arc GIS software.

[f] This is defined as the centroid i.e. the geometric centre of the area (LSOA/merged datazone), using GIS software.

2.7 Modelling

Linear regression models were used to examine the relationship between mortality and deprivation across the three cities. In each case the outcome (or dependent) variable was the standardised mortality rate of each small area. A number of different predictor (or independent) variables were included in the models to quantify their influence, for example: level of deprivation, city, percentage of nursing homes in an area (as the latter can affect mortality rates at this small spatial scale), and measures of surrounding deprivation (for Rings 1 and 2). In a later model, other 'neighbourhood' variables known to be related to mortality (e.g. housing tenure, educational attainment) were additionally included. Nonlinearity was tested and nonlinear variables were transformed to reflect the more appropriate relationship with mortality and to improve the model. Table 1 shows the full list of all such independent variables in the modelling analyses including a number of interaction terms.

Table 1. Independent variables used in modelling.

	Independent variables
	City
Neighbourhood†	% Income deprivation
	Square root of % income deprivation
	% Income deprivation*% income deprivation interaction
	% Income deprived*city interaction
	% Social renting
	% Private renting
	%Owner occupied
	% Turnover of people in and out of the neighbourhood (measure of churn)
	% Household type (% lone parents)
	% No qualifications
	% Degree qualifications
	% Population in communal establishment
	% Population with no car available
Spatial terms	Median % income deprived in Ring 1
	Median % income deprived in Ring 1* city interaction
	Minimum % income deprived in Ring 1 Minimum % income deprived in Ring 1* city interaction
	Maximum % income deprived in Ring 1 Maximum % income deprived in Ring1* city interaction
	Median % income deprived in Ring 2 Median % income deprived in Ring 2* city interaction
	Minimum % income deprived in Ring 2 Minimum % income deprived in Ring 2* city interaction
	Maximum % income deprived in Ring 2 Maximum % income deprived in Ring 2* city interaction

† All neighbourhood variables except income deprivation were provided by the 2001 Census. Note that these were only included in the final all-cause, all-age mortality model – see Results section.

Variables which were not significant were removed from model unless their presence was essential to account for spatial autocorrelation (discussed above). Neighbourhoods with unusually high values and which were exerting too much influence were removed from the model. Further details of the statistical processes employed in the modelling analyses are included in Box 1.

Box 1. Statistical note.

Generalised least squares regression was used to examine the relationship between mortality and deprivation in the three cities. The logs of standardised all-cause mortality (all ages), premature mortality (age 65 or less) and different specific causes of mortality were used as the dependent variables in the models. Independent variables were entered into the model in stages to ascertain the impact of each variable. To ascertain the relationship between deprivation and mortality in the three cities, interaction terms between deprivation and city were also added to the model. Testing for non-linear relationships in the models was also carried out and transformations made, where necessary. Non-significant variables were removed from the model except where their presence was required to account for spatial autocorrelation.

To ascertain the impact of surrounding deprivation on the neighbourhood and to account for and measure any spatial autocorrelation, a number of different spatial terms were added to the model (see Table 1). All models were tested for remaining spatial autocorrelation by submitting the residuals from the models to a Moran’s I test, a significant result indicating that there remained an unexplained spatial relationship with mortality. Without accounting for all significant spatial autocorrelation it is not possible to make valid comparisons between the three cities. Correlations between the independent variables were examined to avoid multi-co-linearity.

Cases with undue influence and outliers were identified and removed from the data before models were finalised. Two statistical tests, Studentised Residual and Cooks Distance, were used as the means of testing for outliers. Furthermore, these were used to verify whether or not any outliers were distorting the regression equation. Using Studentised Residuals, any variable with an absolute value (i.e. positive or negative) more than 3 can be considered as an outlier. A Cooks Distance measurement of greater than 1 indicates that the outlier is having an overall influence on the model and could be deleted[27]. This was done to ensure no single case with an extreme value was distorting the balance of the model. Outliers were also checked using the residual diagnostics in the MLwiN 2.24 software programme. Modelling was carried out using MLwiN 2.24.

3. Results

In this section, results on the patterning of deprivation in the three cities will be discussed first. Results on regression modelling are then laid out in the following order:

- all-cause mortality (all ages)
- premature mortality
- cause-specific mortality
- all-cause mortality with neighbourhood context variables.

3.1 Measuring the pattern of deprivation

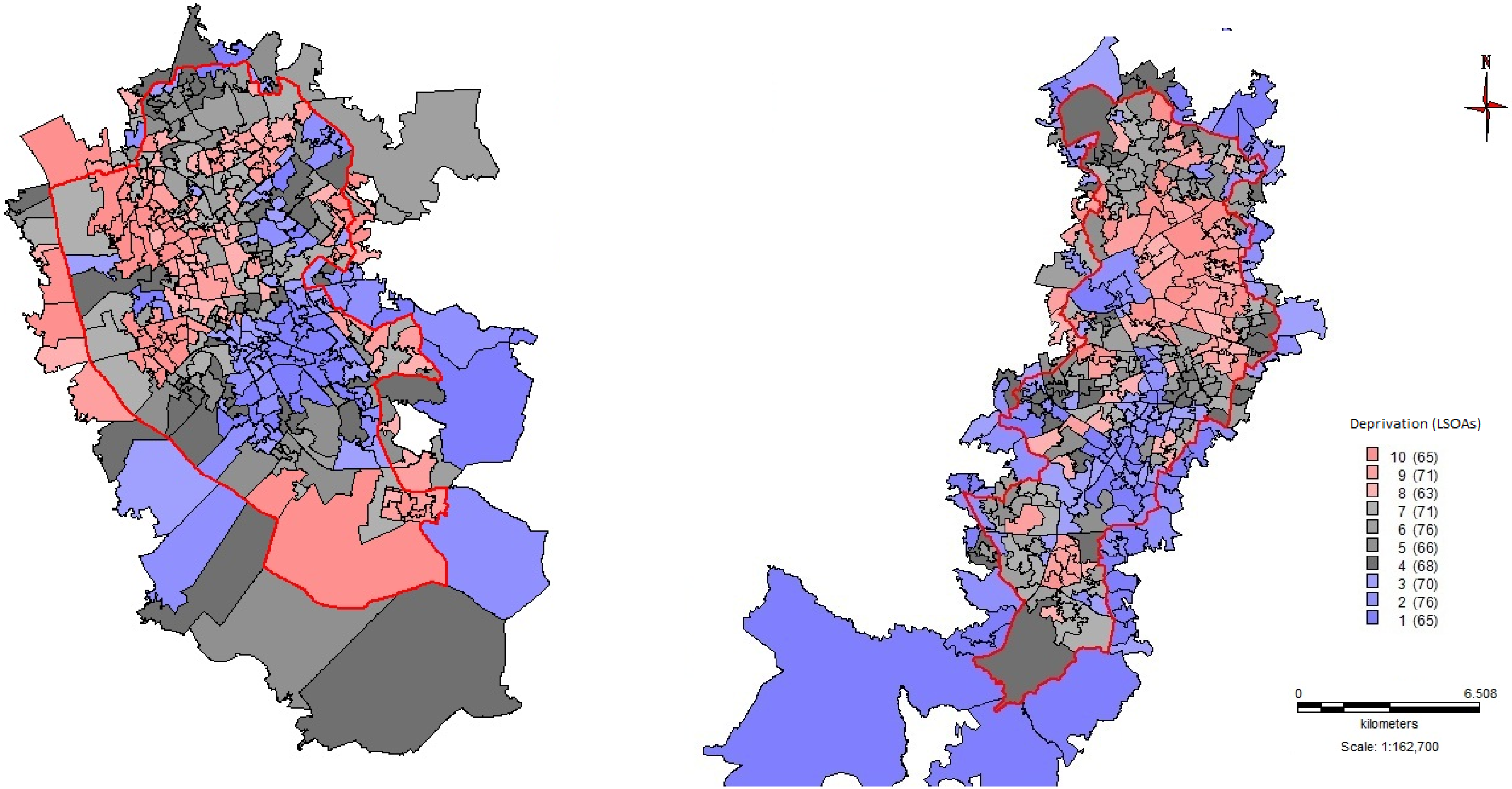
If the spatial patterning of deprivation is similar in each of the three cities, then it is unlikely that this is an explanation for the differences in the mortality rate found between the cities. Therefore the first step in this research was to compare patterns between the three cities. This was done through creation, and visual comparison, of maps of deprivation, and through analyses of the statistics described in the previous section.

3.1.1 Mapping of deprivation in the three cities

Figures 3 and 4 show maps of the patterning of deprivation across the three cities. Each LSOA/merged datazone is shaded according to the deprivation decile it has been assigned to (10 being most deprived, 1 being the least deprived). This is the case both for the small areas within each city's boundary, and for the areas outwith the boundaries.

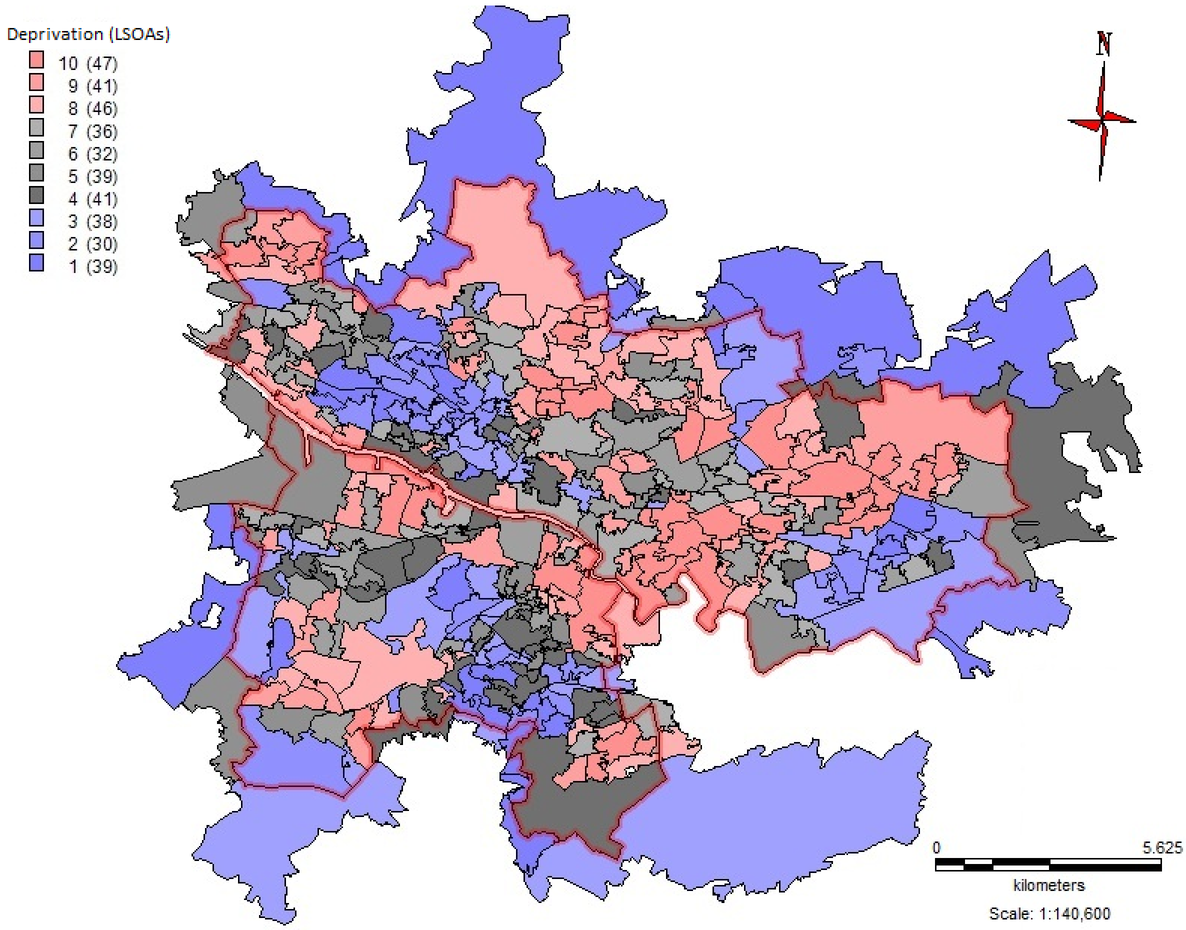
There is a certain subjectivity in visually examining maps for differences but it does allow easy identification of any obvious or large differences between the cities. The first thing that strikes the viewer is that the three cities have very different shapes. We should also be aware that these boundaries are 'man-made' and that the 'real' city boundaries – relating to work and the economy – for all three cities are wider than the council areas we are using. That said, there are still differences we can detect between the three cities. Deprivation in both Liverpool and Manchester is more focused near the centre of the city (Figure 3). In Glasgow the opposite is the case with deprivation more widely dispersed across the city (Figure 4). That is not to say that deprivation is evenly distributed throughout Glasgow. On the contrary there are five or six blocks of deprivation throughout the city, some of which are relatively near the city centre. This immediately suggests that it is unlikely that the spatial concentration of deprived neighbourhoods into large areas of deprivation is the explanation for the differences in mortality rates found in the three cities (i.e. as there is evidence of clustering in all three cities). However, a more objective assessment of the patterning of deprivation can be provided through statistical analyses. These are described in the following sections.

Figure 3. Income deprivation Liverpool (left) and Manchester (right) [ranked within three cities].



Notes: City Council boundary is represented by the red line. Decile 10 is the most deprived decile and decile 1 is the least deprived. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

Figure 4. Income deprivation in Glasgow (ranked within three cities).



Notes: City Council boundary is represented by the red line. Decile 10 is the most deprived decile and decile 1 is the least deprived. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

3.1.2 Statistical measuring of patterns of deprivation

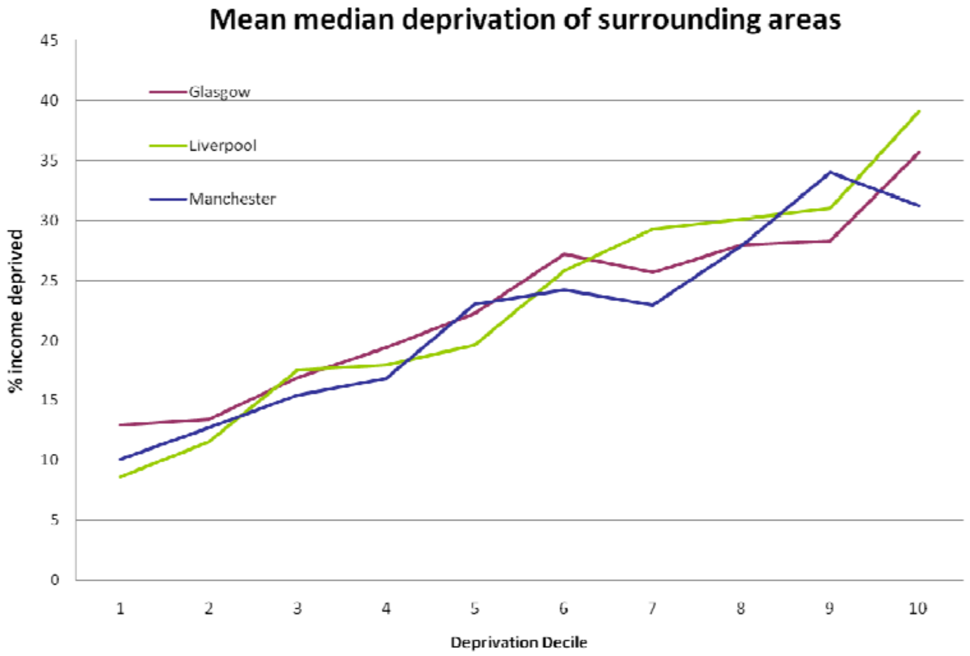
Surrounding deprivation

Figures 5-7 present analyses of the median, highest and lowest levels of deprivation in the surrounding areas by deprivation decile of the neighbourhood.

Although the statistics in Figures 5-7 are similar, they each show something a little different. The graph of the mean median surrounding deprivation (Figure 5) illustrates the average surrounding deprivation in each deprivation decile. If neighbourhoods were totally randomly distributed then the line would be flat at the average income deprivation level. The closer the angle of the line is to 45 degrees the more likely it is that neighbourhoods will be beside areas which are similar. This graph shows, for example, that areas in the least deprived decile in Glasgow are on average more likely to be surrounded by areas with higher levels of deprivation, than the least deprived areas of Liverpool and Manchester. Areas in the most deprived decile in Liverpool tend to be surrounded by areas with higher levels of deprivation than the areas surrounding the most deprived areas of the other two cities, but especially Manchester. However, overall the differences are very slight.

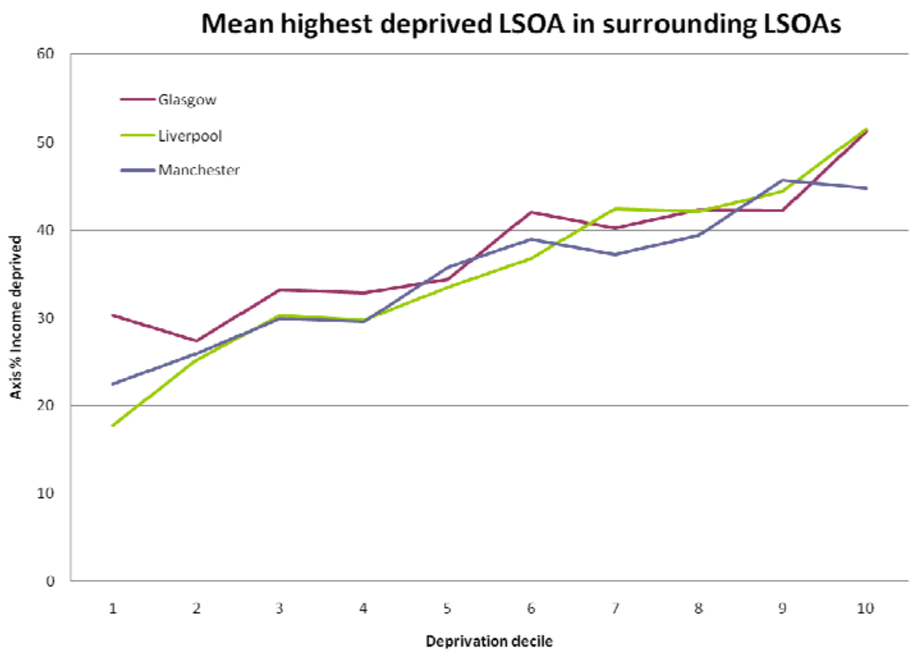
The graph showing the highest level of deprivation in the surrounding 'ring' (Figure 6) is similar but gives an indication of whether neighbourhoods are beside more deprived areas (and whether that differs across the cities), while the graph of the lowest level of surrounding deprivation (Figure 7) gives an indication of differences in the likelihood that neighbourhoods are beside more affluent areas. In all three of the graphs the lines for the three cities have similar gradients indicating that neighbourhoods in each city are likely to be located beside neighbourhoods with similar deprivation. There is generally little difference between the three cities in this regard.

Figure 5. Mean of median deprivation of surrounding areas by deprivation deciles (ranked within three cities).



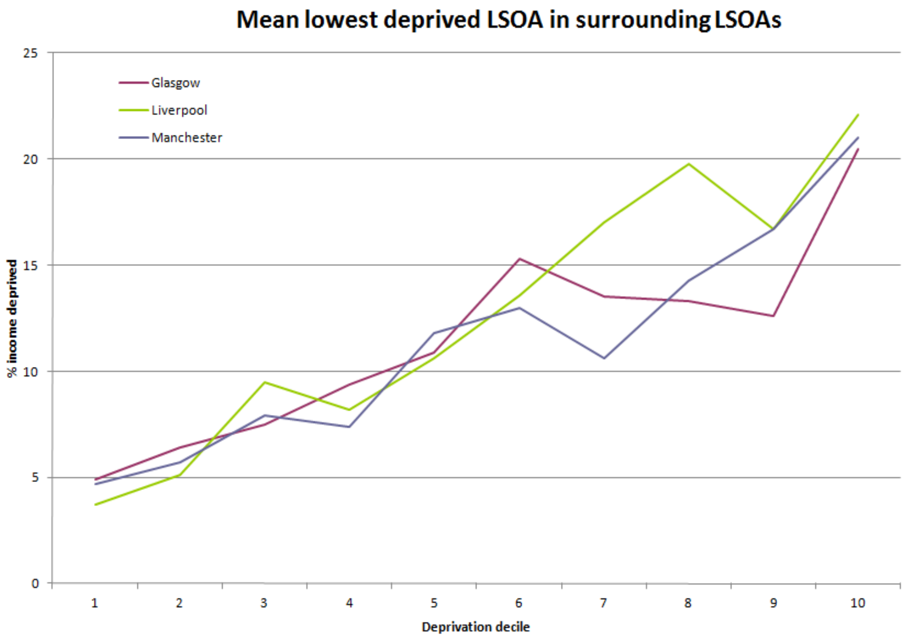
Deprivation deciles ranked from 1 (least deprived) to 10 (most deprived).

Figure 6. Mean highest deprivation of surrounding areas by deprivation deciles (ranked within three cities).



Deprivation deciles ranked from 1 (least deprived) to 10 (most deprived).

Figure 7. Mean lowest deprivation of surrounding areas by deprivation deciles (ranked within three cities).



Deprivation deciles ranked from 1 (least deprived) to 10 (most deprived).

Distance to city centre

Table 2 shows, for each of the three cities, the mean distance from the LSOAs/merged datazones to the city centre. This shows that, in all cities, areas within the most affluent deciles (deciles 1-3) are more likely to be further from the city centre than the other neighbourhoods. In Manchester and Liverpool, areas within the most deprived deciles (deciles 8-10) are more likely to be closer to the centre than the rest of the neighbourhoods in those cities; in Glasgow, however, the more deprived areas are, on average, further away from the centre than areas within the other deciles.

Overall, distances to the centre in Glasgow are lower in absolute terms compared with both Liverpool and Manchester, reflecting the different shapes of the three cities. However, in relative terms, Glasgow's deprived areas are more likely to be further away from the centre than other neighbourhoods in the city (compared with Liverpool and Manchester): this is reflected in the Standardised Ratio in Table 2.

Table 2. Mean distance to city centre.

Distance to centre for most deprived LSOAs (Deciles 8-10)				
		Mean	City mean	Standardised ratio
Glasgow	Rest	4,870	4,936	0.99
	Deprived	5,046	4,936	1.02
Liverpool	Rest	6,131	5,792	1.06
	Deprived	5,173	5,792	0.89
Manchester	Rest	5,753	5,522	1.04
	Deprived	4,922	5,522	0.89
Distance to centre for most affluent LSOAs (Deciles 1-3)				
		Mean	City mean	Standardised ratio
Glasgow	Rest	4,902	4,936	0.99
	Affluent	5,045	4,936	1.02
Liverpool	Rest	5,497	5,792	0.95
	Affluent	6,655	5,792	1.15
Manchester	Rest	5,467	5,522	0.99
	Affluent	5,683	5,522	1.03

Notes: Distance measured in metres. Standardised ratios calculated to adjust for different size of cities.

It is not unusual for many of the most affluent neighbourhoods in cities to be positioned on the peripheries, and this appears to be the case in all three cities. However, Glasgow is different in that much of the deprivation is also located on the periphery of the city.

Moran's I test

Another way of examining the likelihood that neighbourhoods of similar deprivation are close to each other is by using the Moran's I test. This checks for spatial autocorrelation: that is, whether areas which are in close proximity are more likely to be like each other in terms of (in these analyses) levels of deprivation. As outlined earlier, a test value close to zero indicates that neighbourhoods are no more likely to be close to similar neighbourhoods (in terms of deprivation) than dissimilar neighbourhoods, that is, the distribution of deprivation among nearby neighbourhoods is random.

Table 3 shows that the test for the distribution of deprivation in all three cities produces a significant result, indicating that neighbourhoods are likely to be near areas with similar levels of deprivation: in other words there are clusters of similar areas in all three cities. Although the results are significant in all the cities, Glasgow has the smallest I test score, indicating that of the three cities, its areas are more dispersed in terms of deprivation. This reinforces the initial impressions gained from the maps presented in Figures 3 and 4.

Table 3. Moran's I test of deprivation.

	I	sd(I)	Z	P
Glasgow	0.077	0.004	18.334	0.000
Liverpool	0.146	0.005	30.683	0.000
Manchester	0.117	0.006	20.896	0.000

Notes: Higher values of the Moran's I test indicate a higher likelihood of nearby areas having similar levels of the characteristic measured (in this case deprivation).

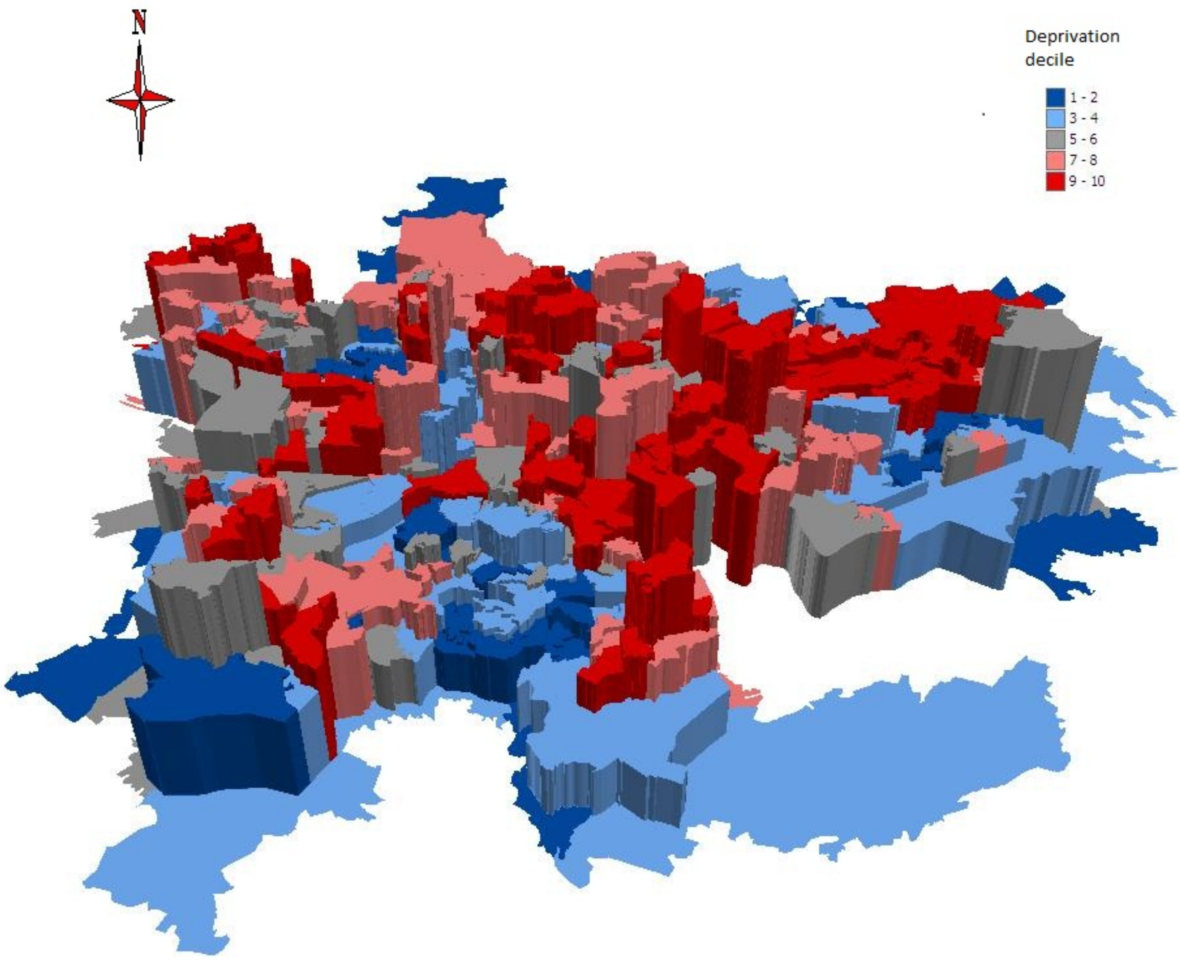
In summary, while deprived neighbourhoods in all the cities are likely to be close to similarly deprived areas, there do appear to be some differences in the patterning between the three cities, and possibly in a way that we would not have predicted. Glasgow's neighbourhoods appear to be less spatially concentrated in terms of deprivation than those in Liverpool or Manchester, where deprived areas tend to be more clustered. Glasgow's deprivation, while still clustered in blocks of deprived neighbourhoods, is more dispersed around the city.

3.2 Distribution of deprived neighbourhoods and mortality

3.2.1 Mapping of deprivation and mortality
As a first stage in examining the spatial relationship between deprivation and mortality in the three cities, maps of deprivation and mortality rates at the neighbourhood (LSOA/merged datazone) level were created. These were produced for deaths at all ages, and also for deaths under the age of 65 (premature mortality). Deprivation is represented by colour and mortality rates by elevation.

What is apparent from examining the maps of all-cause and all-age mortality is the variance in mortality rates between neighbourhoods with similar levels of deprivation in all of the cities (Figures 8-10).

Figure 8. Deprivation and mortality rates at all ages for all causes (rates expressed as elevation) in Glasgow, 2003-2007.



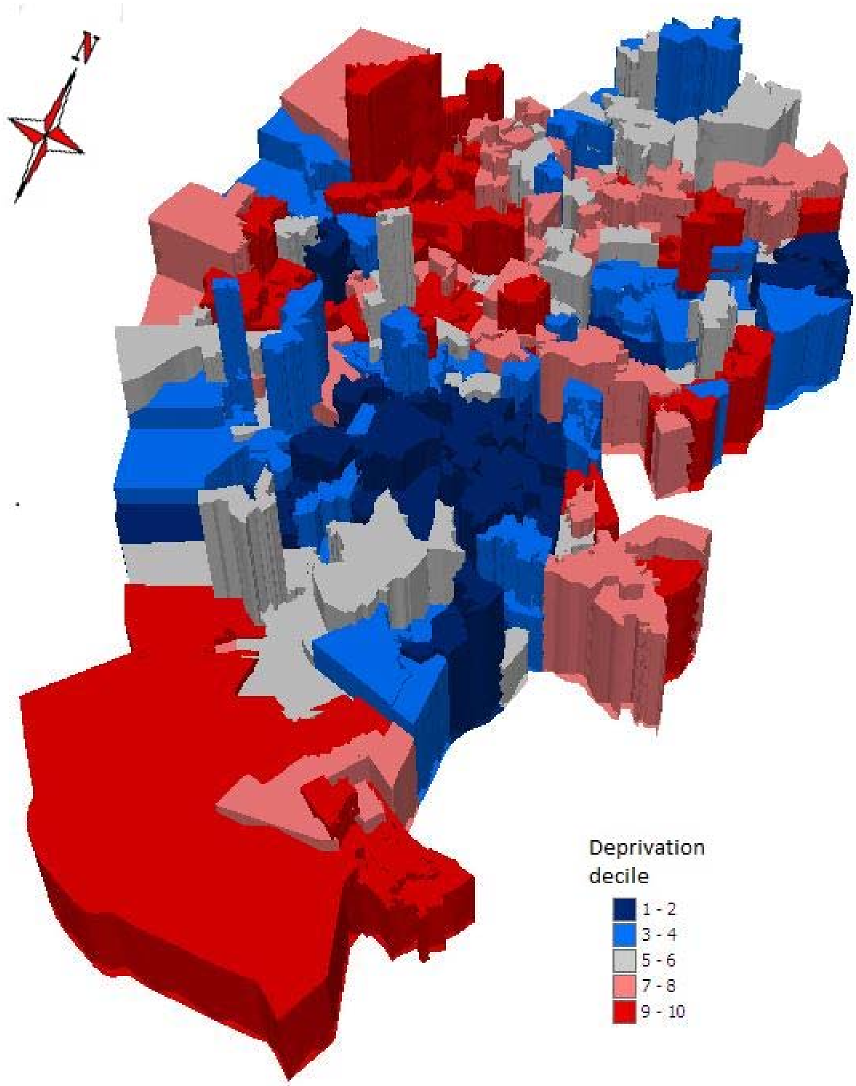
Note: It is not advisable to add a scale bar to 3D maps because different parts of the map have different scales. However, the map has an approximate scale of 1:140,000. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

So, for instance, some deprived areas have high mortality rates while other deprived areas have lower mortality rates. The same applies across the deprivation scale. In all three cities, there are some affluent areas with unexpectedly high rates of mortality, especially in Liverpool and Manchester: some of the ‘peaks’ in mortality rate in these two cities seems out of proportion to other neighbourhoods. For instance, in Manchester there is one LSOA where mortality rates are much higher than anywhere else in the city.

These rather exaggerated peaks are a result of two things. First, there is a concentration of mortality in areas which have a high proportion of people living in either residential or nursing homes. Second, at this small geographical level, even after smoothing mortality rates by combining five years of data, numbers are still small enough that an abnormal year for mortality can have a large effect on the rate. This said, the pattern of mortality rates in relation to deprivation in Glasgow appears to be much more consistent than in the other two cities, with mortality rates generally higher in the more deprived areas. This is less clear in Liverpool and Manchester where the pattern of high mortality is less obviously associated with deprivation.

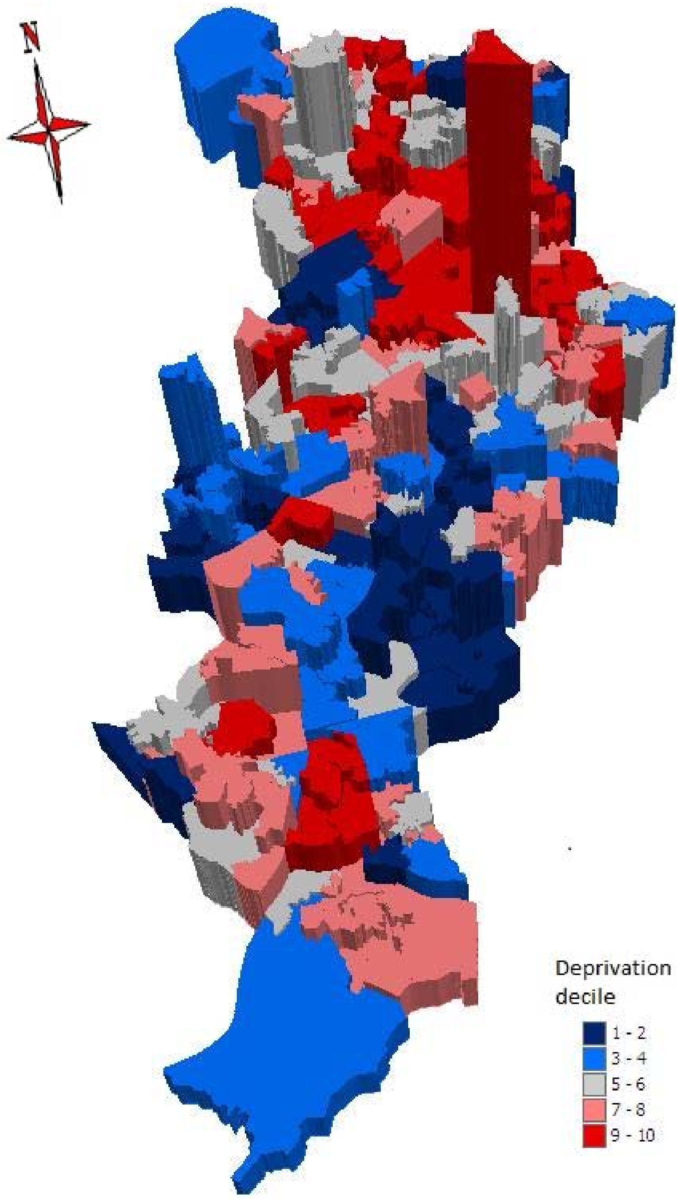
As a result of the skewing effect produced by nursing and residential homes, the percentage of people who live in these homes was included as a variable in the regression models to control for their influence.

Figure 9. Deprivation and mortality rates (at all ages for all causes) in Liverpool, 2003-2007.



Note: It is not advisable to add a scale bar to 3D maps because different parts of the map have different scales. However, the map has an approximate scale of 1:160,000. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

Figure 10. Deprivation and mortality rates (at all ages for all causes) in Manchester, 2003-07.

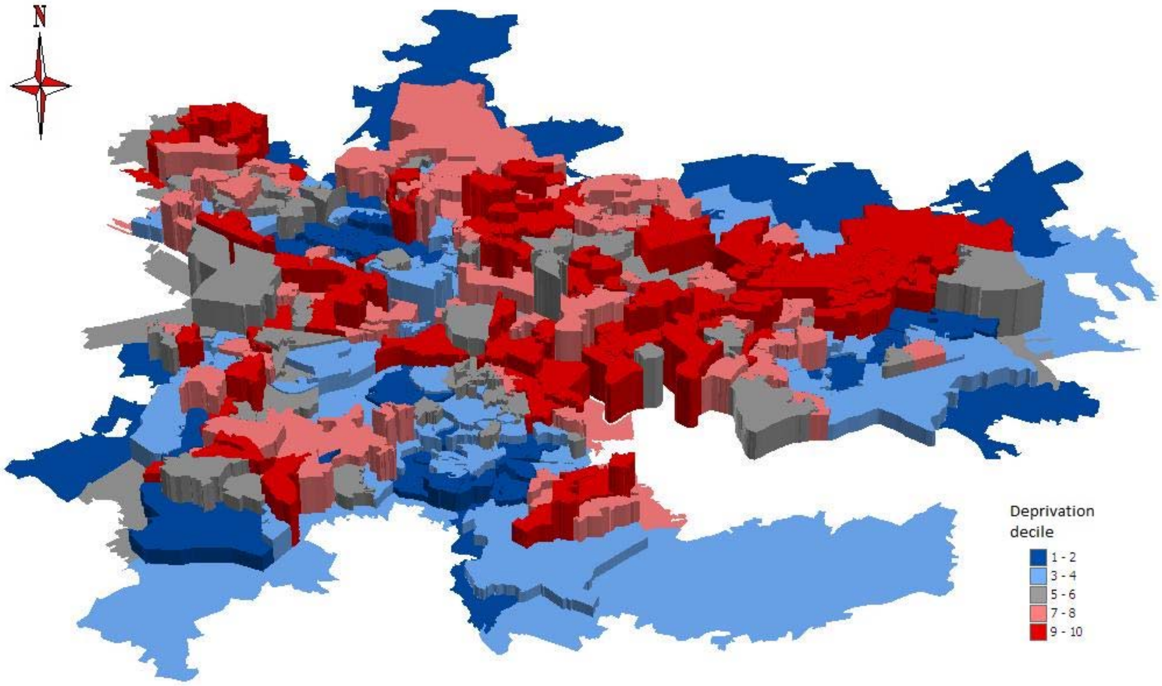


Note: It is not advisable to add a scale bar to 3D maps because different parts of the map have different scales. However, the map has an approximate scale of 1:160,000. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

Figures 11-13 show similar maps, but for premature mortality (deaths under 65 years of age) rather than deaths at all ages. As rates of premature deaths in general are low, mortality in these maps have elevation magnified by multiplying mortality rates by 2.

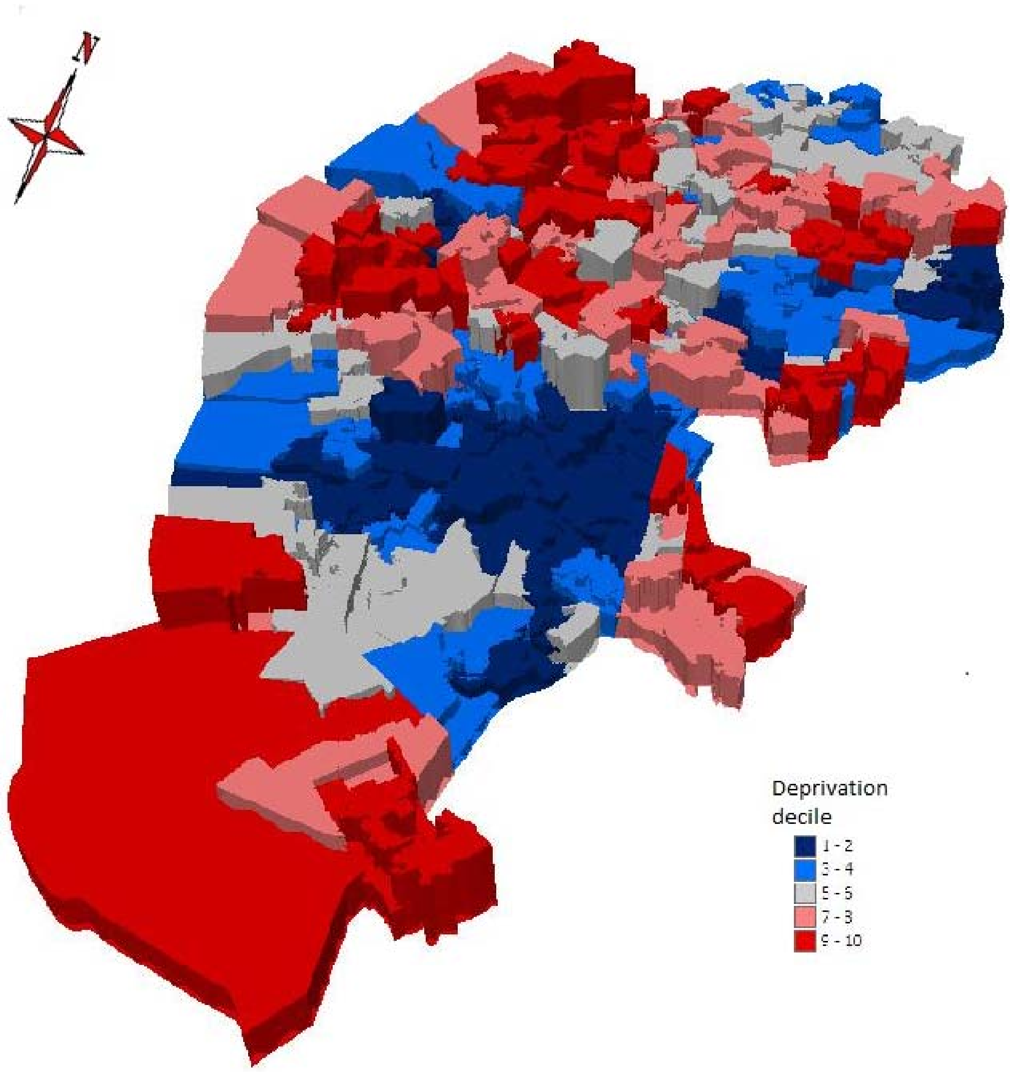
In these maps, the link between deprivation and mortality rate appears much clearer in all three cities.

Figure 11. Deprivation and premature mortality (all causes, <65) in Glasgow, 2003-07.



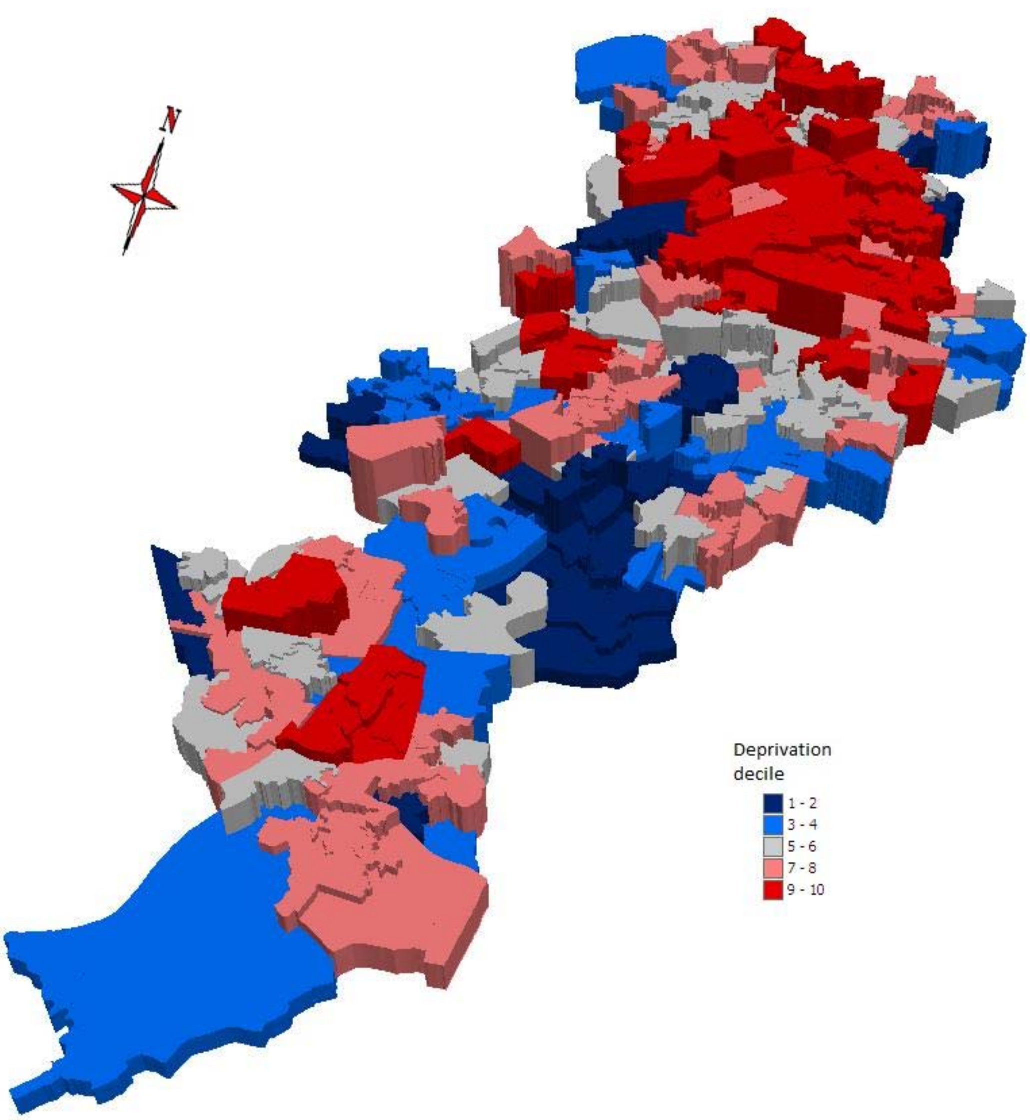
Note: It is not advisable to add a scale bar to 3D maps because different parts of the map have different scales. However, the map has an approximate scale of 1:140,000. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

Figure 12. Deprivation and premature mortality (all causes, <65) in Liverpool, 2003-07.



Note: It is not advisable to add a scale bar to 3D maps because different parts of the map have different scales. However, the map has an approximate scale of 1:160,000. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

Figure 13. Deprivation and premature mortality (all causes, <65) in Manchester, 2003-07.



Note: It is not advisable to add a scale bar to 3D maps because different parts of the map have different scales. However, the map has an approximate scale of 1:150,000. Maps are based on data provided with the support of the ESRC use boundary material which is copyright of the Crown, Post Office and the EDLINE consortium.

3.3 Modelling of deprivation and mortality

The next section reports on the linear regression modelling. Four different models are described:

- all-cause mortality (including all ages)
- premature mortality (under 65 years of age) for all causes
- cause-specific mortality (all ages) (deaths from cancer and circulatory diseases)
- all-cause mortality (including all ages) with neighbourhood context included.

The methodology is explained in full in the Methods section (see Box 1). Additional statistical details relating to some of the results of the models are included in Box 2 overleaf.

The modelling sought to explore the relationship between mortality and neighbourhood in the cities, with a particular focus on the influence of differences in the spatial patterning of deprivation across the cities.

The model for all-cause mortality (all ages) explains a large amount of the neighbourhood variance in mortality rates, accounting for nearly 60%: this suggests that the variables included in the model are important in explaining neighbourhood mortality rates. The strongest associations with mortality rates[g] are income deprivation and the percentage of the population in each neighbourhood who are resident in nursing homes or residential homes; however, income deprivation has by far the strongest relationship (Figure 14 and Table 4). The effect of income deprivation in the model is captured through two measures: the percentage income deprived and the square root of that term[h].

To see the overall effect of deprivation, we need to look at Figure 15 which shows the combined effect of both terms (the percentage income deprived and the square root of that term). The mortality rate rises as income deprivation increases, albeit at a decreasing rate.

The results also show that Liverpool and Manchester both have significantly lower mortality rates than Glasgow even after adjusting for all the variables in the model. Finally, deprivation in the surrounding ring is not significant, although its inclusion in the model is required to account for all the spatial correlation in mortality rates.

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[g] In fact, log of mortality rates. See Methods section.

[h] The square root of deprivation is included in the model to allow deprivation to have a nonlinear relationship with mortality.

Overall, this suggests that the spatial concentration of deprived neighbourhoods does not account for a large proportion of the excess mortality that has been observed between Glasgow and the other two cities.

Further details of issues relating to the running of, and results from, the models are included in Box 2.

Box 2. Statistical note.

In the model the variables and interaction terms for Ring 1 and Ring 2 do not appear significant. However, while the model does not highlight these as significant, without their inclusion in the model there is significant unaccounted autocorrelation. This suggests that while not significant in the model, surrounding deprivation has some small influence on the mortality rates in the neighbourhood. As the rings were added sequentially, Ring 1 without Ring 2 was significant although the effect of surrounding deprivation was small. When this model was tested for spatial correlation the overall model was significant using the Moran's I test but the residuals for Glasgow were not, suggesting that all spatial dependency in Glasgow had been accounted for by the model. All remaining autocorrelation disappears when you add in Ring 2. This suggests that while the model is not indicating a significant effect of surrounding neighbourhoods, the more sensitive Moran's I test shows evidence that areas which are close to the neighbourhood (Ring 1 and Ring 2) have an influence on neighbourhood mortality rate. However, we should be clear that this effect is very small when compared with the strong association between mortality and neighbourhood deprivation. The coefficients in Table 4 show that the factors most strongly associated with mortality are neighbourhood deprivation and the percentage of people resident in nursing homes. Importantly both Liverpool and Manchester have lower levels of mortality even after adjusting for neighbourhood deprivation, and surrounding deprivation at two different scales. It should also be noted that 11 outliers have been excluded from this model and that some of these neighbourhoods, while atypical, have very high mortality rates. On investigation there are a number of reasons that appear to make these areas atypical, for instance one neighbourhood in Glasgow near the city centre has high premature mortality but is known to be a focus for drug addicts. Other areas have some form of hostel nearby which leads to a concentration of vulnerable individuals living in the neighbourhood.

Table 4. All-cause mortality model coefficients.

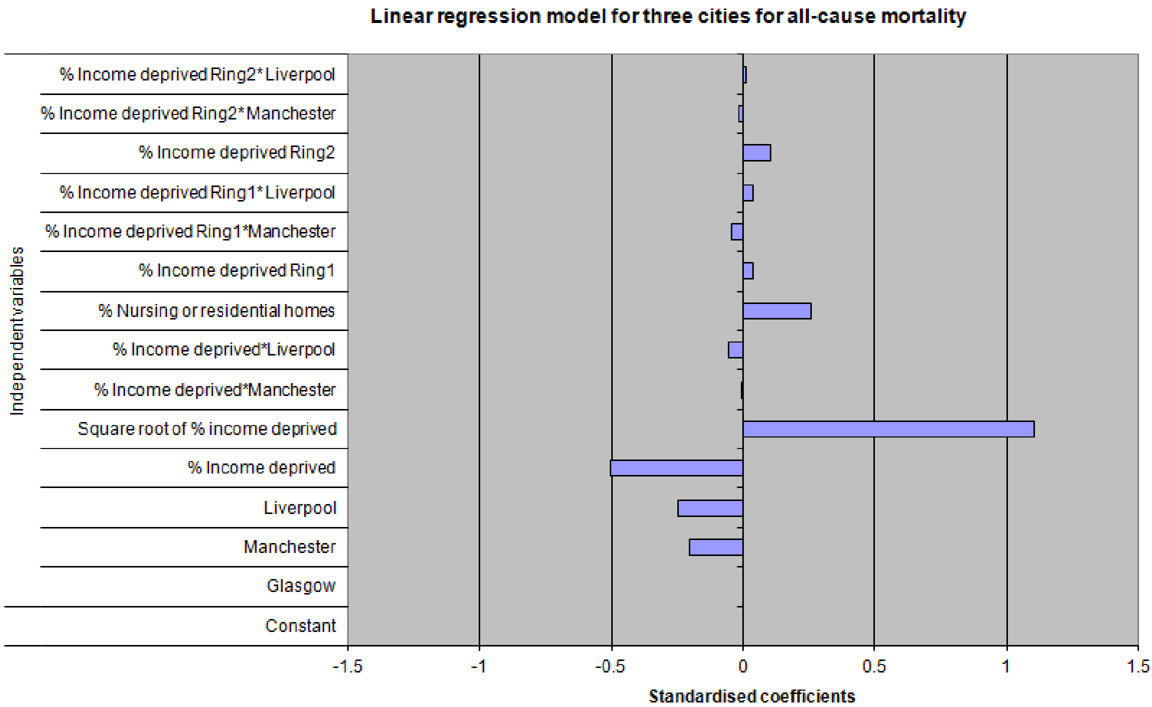
	Unstandardised coefficients‡	Standardised coefficients¥	Significance
(Constant)	**5.740**		**0.000**
Glasgow			
Manchester	**-0.140**	**-0.203**	**0.000**
Liverpool	**-0.166**	**-0.248**	**0.000**
% Deprived	**-0.011**	**-0.504**	**0.000**
Square root % deprived	**0.235**	**1.107**	**0.000**
% Deprived*Manchester interaction	0.000	-0.001	0.987
% Deprived*Liverpool interaction	-0.002	-0.053	0.205
% Nursing/residential homes	**5.130**	**0.258**	**0.000**
Median deprivation Ring 1	0.001	0.04	0.535
Median deprivation Ring 1*Manchester interaction	-0.003	-0.046	0.342
Median deprivation Ring 1*Liverpool interaction	0.002	0.04	0.499
Median deprivation Ring 2	0.003	0.105	0.106
Median deprivation Ring 2*Manchester interaction	-0.001	-0.017	0.714
Median deprivation Ring 2*Liverpool interaction	0.001	0.014	0.801

Adjusted R-Squared value = 0.590; All significant results in bold (P<0.05).

‡ Coefficients from the model showing association with mortality in relation to the unit measured.
¥ Standardised coefficients allow direct comparison of associations between variables in the model.

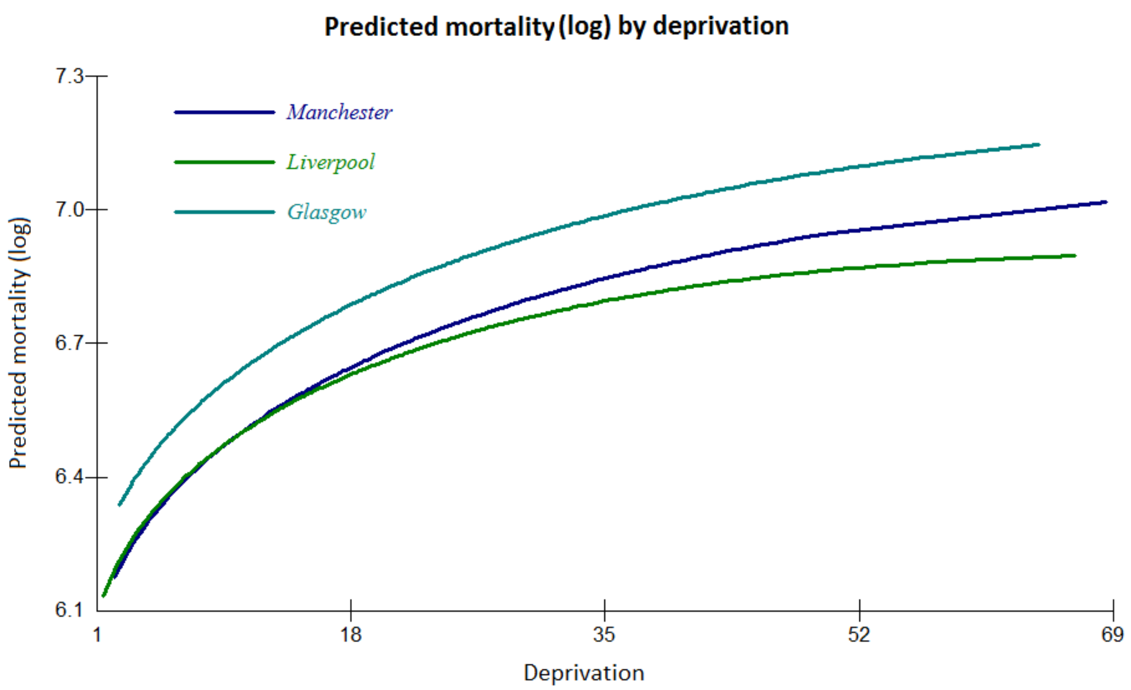
Further results from the model are shown graphically in Figures 14-15. Figure 14 allows us to compare the size of the effects for each of the independent variables with each other. This emphasises the impact of deprivation, the cities themselves and the location of nursing and residential homes on mortality rates. However, because of the large number of interaction terms it is difficult to assess the relationship some of the variables have with each other from Figure 14. Figure 15 allows us to look at the relationship between mortality rates and neighbourhood deprivation for each of the cities. The graph shows the log of standardised mortality rate predicted by the model for neighbourhood deprivation. We can see that the relationship between mortality rates and deprivation is different in each of the cities. The higher mortality rates in Glasgow are reflected across the deprivation scale. Liverpool and Manchester have similar mortality at lower levels of deprivation but as deprivation rises there is a divergence between the two cities, with the mortality rates flattening off earlier in Liverpool than in Manchester.

Figure 14. Standardised coefficients for all-cause model.



Standardised coefficients allow direct comparison of associations between variables in the model.

Figure 15. Predicted log of mortality rates by deprivation for all-cause model.



3.3.1 Premature mortality model

The same modelling process was undertaken to examine the influence of all variables, including the spatial patterning of deprivation, on rates of premature mortality (deaths under 65 years).

The results of the models are remarkably similar to those found for all-cause mortality (all ages). Again, the independent variables with the largest effects on mortality rates are deprivation in the neighbourhood, the presence of nursing and residential homes, and the cities variables. None of the other variables had a significant relationship with mortality (Table 5[i]).

Thus, differences in spatial patterning of deprivation are not a major influence on higher rates of premature death in Glasgow.

Table 5. Premature mortality (<65) model coefficients.

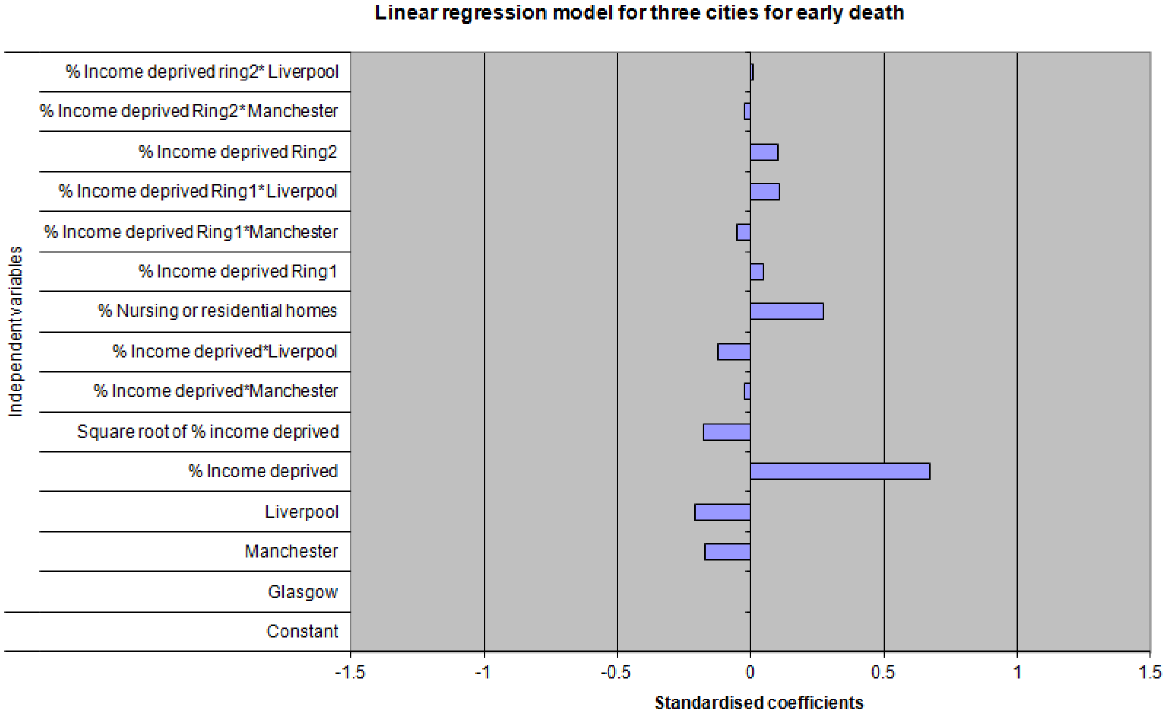
	Unstandardised coefficients[‡]	Standardised coefficients[¥]	Significance
(Constant)	**5.530**		**0.000**
Glasgow			
Manchester	**-0.130**	**-0.176**	**0.000**
Liverpool	**-0.142**	**-0.199**	**0.000**
% Deprived	**-0.016**	**-0.668**	**0.000**
Square root % deprived	**0.282**	**1.24**	**0.000**
% Deprived*Manchester interaction	0.000	-0.004	0.910
% Deprived*Liverpool interaction	**-0.004**	**-0.107**	**0.016**
% Nursing/residential homes	**5.447**	**0.257**	**0.000**
Median deprivation Ring 1	0.001	0.043	0.534
Median deprivation Ring 1*Manchester interaction	0.000	-0.004	0.939
Median deprivation Ring 1*Liverpool interaction	0.005	0.096	0.127
Median deprivation Ring 2	0.003	0.089	0.203
Median deprivation Ring 2*Manchester interaction	-0.005	-0.069	0.158
Median deprivation Ring 2*Liverpool interaction	0.000	0.006	0.920

Adjusted R-Squared value = 0.613; All significant results in bold (P<0.05).

[‡] Coefficients from the model showing association with mortality in relation to the unit measured.
[¥] Standardised coefficients allow direct comparison of associations between variables in the model.

[i] Note also that as in the all-cause mortality model, spatial autocorrelation is only accounted for once both Ring 1 and Ring 2 deprivation have been added to the model.

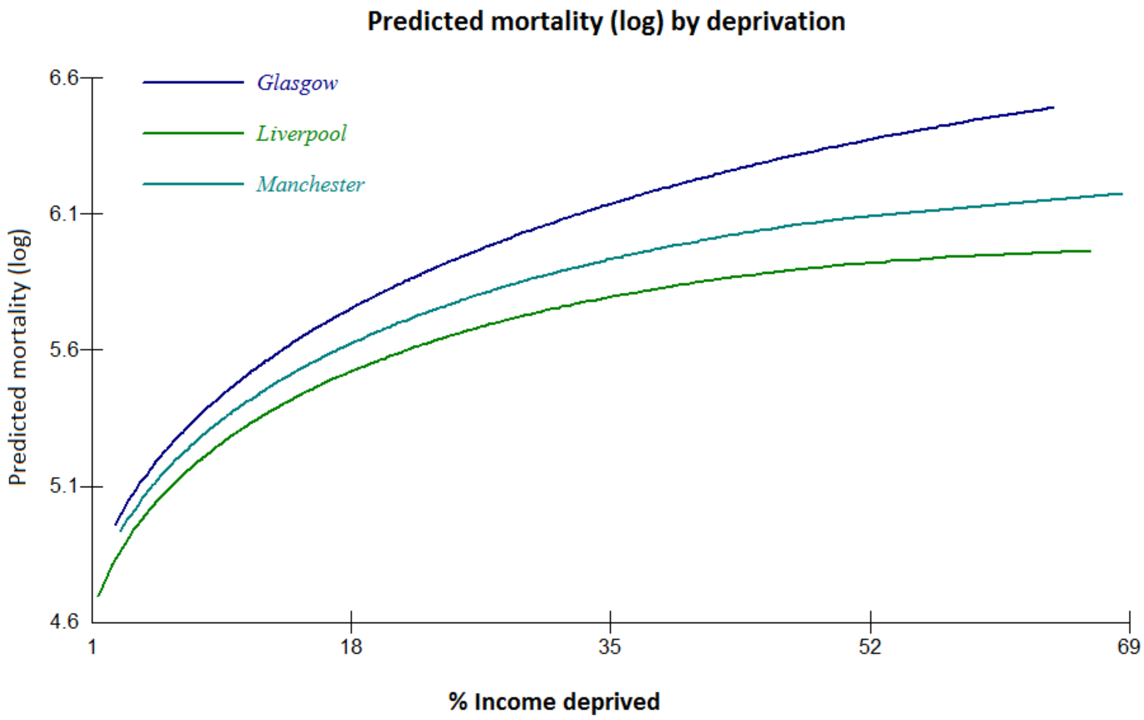
Figure 16. Standardised coefficients for premature mortality model.



Standardised coefficients allow direct comparison of associations between variables in the model.

Examination of the results of the models highlights a number of further factors. First, the relationship between deprivation and premature mortality in the cities differs from that in the all-cause mortality model. While premature mortality is higher in Glasgow at all levels of deprivation, the gap between Glasgow and the other cities widens as deprivation rises, showing that differences between the cities are at their greatest at the highest levels of deprivation (Figure 17).

Figure 17. Predicted log of mortality rates by deprivation for all premature deaths model.



In the premature mortality model, as in the all-cause (all ages) model, surrounding deprivation is not a significant factor though it is required to account for all the spatial autocorrelation in mortality rates. We should be very clear, however, that the impact of surrounding deprivation on health outcomes is small compared with the impact of deprivation in neighbourhoods themselves.

3.3.2 Cause-specific mortality

It is possible that the effect of deprivation in the surrounding neighbourhoods on neighbourhood mortality rates varies by cause. Indeed we know from the previous research on the three cities that mortality rates for different causes vary considerably across the three urban settings, with the 'excess' mortality in Glasgow greatest for deaths from alcohol, drugs and suicide, with smaller relative differences for causes such as cancer and cardiovascular disease[9].

The following section shows the results for models for different causes of mortality. It was not possible to break down cause of death into single groups, i.e. deaths as a result of drugs, deaths from cancer and so on: this was because the numbers of deaths in each group were too small to carry out any meaningful analysis at the required small geographical scale. Rather it was decided to look at two broad groups of cause of death: deaths from cancers and circulatory diseases; and deaths from drugs and alcohol. The first group of deaths represents deaths from common chronic diseases while the second group might be seen as representative of damaging or self-destructive behaviours. The second group represents causes which have been shown not only to be responsible for a large amount of the excess premature mortality seen in Glasgow compared with Liverpool and Manchester, but also to be driving the widening inequalities in mortality in younger ages in Scotland[28]. Unfortunately, despite combining causes and using data for a five year period, the numbers of deaths in the drug and alcohol group were still very small, with many LSOAs/merged datazones having no deaths recorded for this cause, and even where deaths had occurred, numbers were typically no more than one. This made the modelling for these causes very unstable and unreliable – the results, therefore, are presented only in the Appendices.

Cancers and circulatory diseases[j]

The results of the modelling for cancers and circulatory diseases are interesting. There is little evidence, as in the previous analyses, that surrounding deprivation has a strong impact on mortality rates in the neighbourhood at either the level of Ring 1 or Ring 2 (Table 6); and although there are significant differences between Glasgow and Liverpool in the relationship between deprivation and mortality in Ring 2, the effect is small. Deprivation, in nearly all the Ring variables in the model, is not significant (although it requires inclusion in the model to account for spatial autocorrelation). As in the all-cause mortality model, the most significant associations with mortality from cancers and circulatory diseases are between city comparisons, neighbourhood deprivation, and the presence of nursing homes.

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[j] Cancers and Circulatory diseases were defined as ICD 10 codes: All cancers (malignant neoplasms) – C00-C97; Circulatory system – I00-I99.

Table 6. Model coefficients for deaths from malignant neoplasms and circulatory diseases.

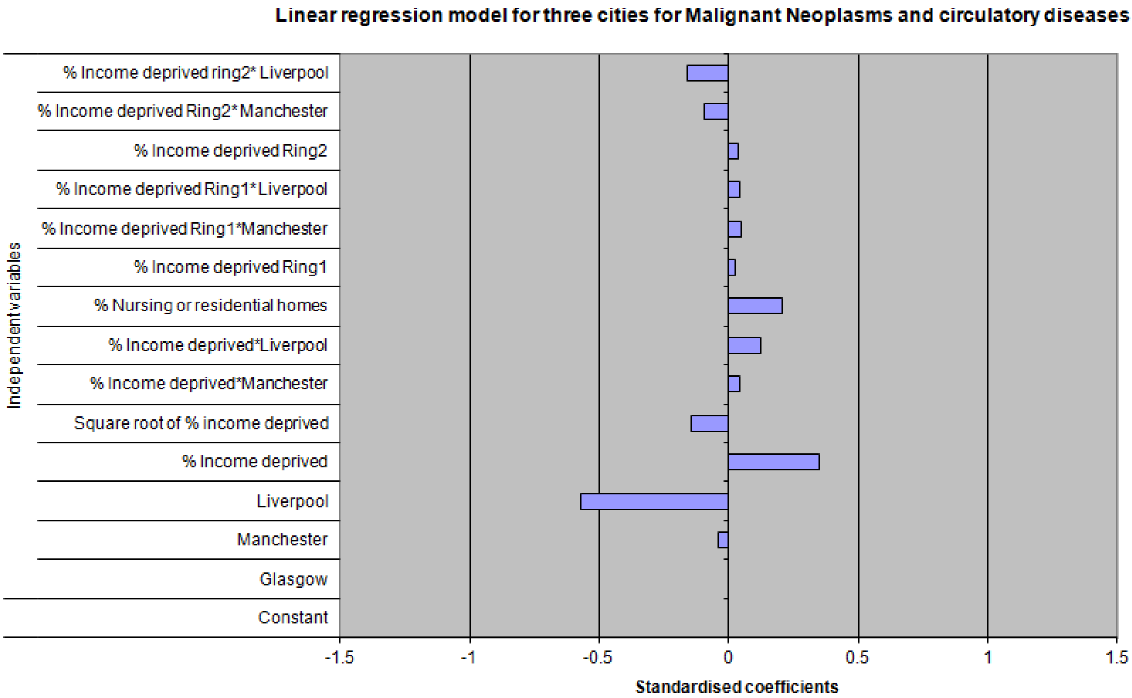
	Coefficients(a)				
	Unstandardised coefficients		Standardised coefficients		
	B	Std. Error	Beta	T	Sig.
(Constant)	**6.336**	**0.027**		**236.471**	**0.000**
Glasgow					
Manchester	-0.053	0.037	-0.041	-1.445	0.149
Liverpool	**-0.715**	**0.035**	**-0.57**	**-20.198**	**0.000**
% Deprived	**0.015**	**0.002**	**0.349**	**6.967**	**0.000**
Square root % deprived	**0.000**	**0**	**-0.147**	**-5.145**	**0.000**
% Deprived*Manchester interaction	0.004	0.003	0.041	1.024	0.306
% Deprived*Liverpool interaction	**0.009**	**0.003**	**0.126**	**2.775**	**0.006**
% Nursing/residential homes	**7.756**	**0.911**	**0.204**	**8.513**	**0.000**
Median deprivation Ring 1	0.001	0.004	0.028	0.39	0.696
Median deprivation Ring 1*Manchester interaction	0.005	0.006	0.045	0.844	0.399
Median deprivation Ring 1*Liverpool interaction	0.004	0.006	0.042	0.652	0.515
Median deprivation Ring 2	0.002	0.004	0.034	0.479	0.632
Median deprivation Ring 2*Manchester interaction	-0.011	0.006	-0.094	-1.885	0.060
Median deprivation Ring 2*Liverpool interaction	**-0.016**	**0.006**	**-0.162**	**-2.7**	**0.007**

Adjusted R-Squared value = 0.499; All significant results in bold (P<0.05).

Figure 18 shows that once we adjust for all other factors (including the effect of surrounding deprivation levels), Liverpool has a significantly lower mortality rate than both Glasgow and Manchester[k]. Further results are included in Appendix 1.

[k] Figure 18 also shows that the interaction between city and deprivation in Ring 1 is not significantly associated with neighbourhood mortality: however, in Ring 2 both Liverpool and Manchester have lower mortality with increasing deprivation compared to Glasgow.

Figure 18. Standardised coefficients for malignant neoplasms and circulatory diseases.



3.3.3 Mortality models with neighbourhood factors

Having examined the relationship between deprivation and mortality in the three cities at different scales, this analysis was taken further to look at the impact on these relationships of neighbourhood context. A number of neighbourhood variables were considered for inclusion in the model (see Table 1 in the Methods section). Neighbourhood variables were checked for correlations to ensure that no multi-collinearity was introduced into the model. High correlations were found between the following variables[l]:

- Percentage of social renters and income deprived (R = 0.877)
- Percentage of owner occupiers and income deprived (R = -0.814)
- Percentage with no qualifications and income deprived (R = 0.715)
- Percentage of private renters and turnover (gross)[m] (R = 0.788)
- Percentage of lone parents and with no access to a car (R = 0.781).

Variables which were highly correlated with income deprivation were dropped from the model. Turnover was chosen as having more relevance than private renting, and the percentage of people with no access to a car was chosen in preference to the

[l] All neighbourhood variables are collected at the LSOA level and all but income deprivation are derived from the 2001 Census.

[m] Gross turnover is a measure of migration and counts in and out migration from within Scotland. It is a measure of neighbourhood stability.

percentage of lone parents as it had the lowest level of correlation with income deprivation. Variables were added to the existing all-cause model.

The final set of contextual variables added to the models were: percentage population turnover; percentage of degree standard education; percentage population in communal establishment; percentage of households who have no car.

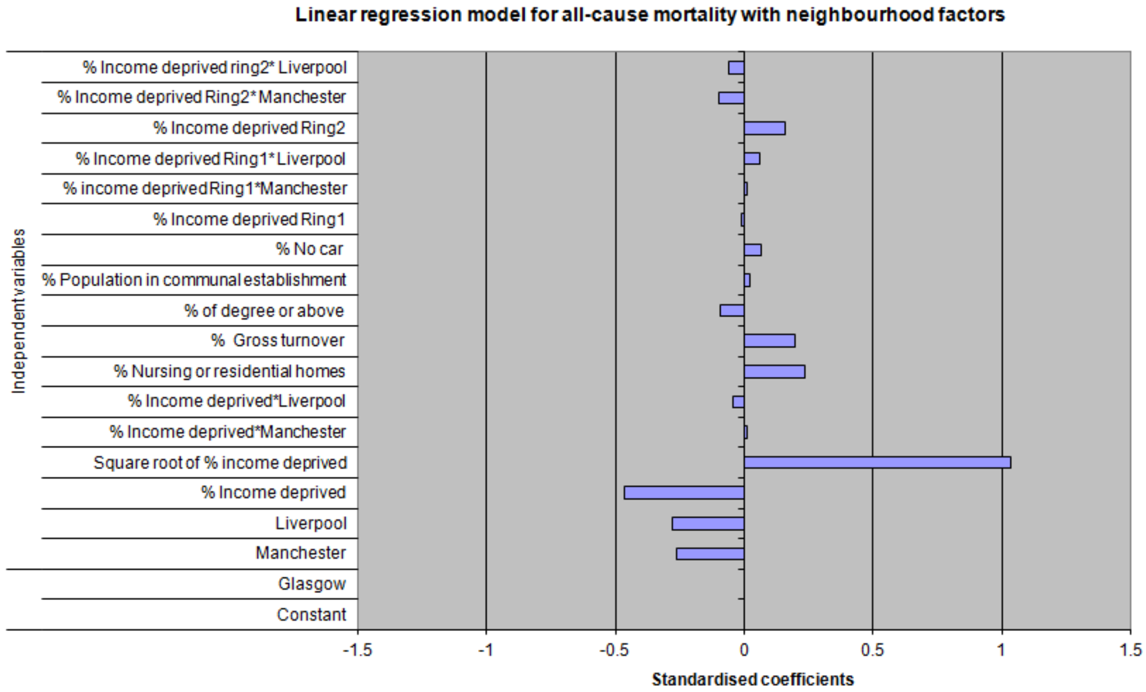
Adding the neighbourhood variables to the model increased the model's explanatory power by a small amount, explaining 62% of the variance in mortality across the three cities compared with 59% in the model without the neighbourhood variables. City, deprivation, and nursing homes still have highly significant associations with mortality (Table 7, Figure 19). Of the neighbourhood variables entered into the model, percentage turnover and the percentage of people with a degree are both significantly associated with mortality rates. Higher levels of education are associated with lower levels of mortality, while higher levels of turnover are associated with higher levels of mortality. Adding the neighbourhood variables also has an impact on the significance of deprivation in the surrounding rings: not in Ring 1 but in Ring 2. Deprivation in Ring 2 has a significant impact on the mortality rates in the neighbourhood and there is a significant difference between Glasgow and Manchester with deprivation in Ring 2 having a greater impact on neighbourhood mortality rates in Glasgow compared with Manchester. However, overall the effects of surrounding rings of deprivation are small.

Table 7. Model coefficients for all-cause mortality and neighbourhood variables.

	Coefficients(a)				
	Unstandardised coefficients		Standardised coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	**5.742**	**0.137**		**41.976**	**0.000**
Glasgow					
Manchester	**-0.180**	**0.025**	**-0.26**	**-7.276**	**0.000**
Liverpool	**-0.188**	**0.024**	**-0.28**	**-7.812**	**0.000**
% Deprived	**-0.011**	**0.003**	**-0.467**	**-3.394**	**0.001**
Square root % deprived	**0.221**	**0.03**	**1.037**	**7.402**	**0.000**
% Deprived*Manchester interaction	0.000	0.002	0.011	0.28	0.780
% Deprived*Liverpool interaction	-0.002	0.002	-0.042	-0.943	0.346
% Nursing/residential homes	**4.773**	**0.443**	**0.238**	**10.778**	**0.000**
% Turnover	**0.003**	**0.001**	**0.195**	**6.089**	**0.000**
% Of degree or above	**-0.002**	**0.001**	**-0.092**	**-2.852**	**0.004**
% Population in communal establishment	0.001	0.001	0.024	0.814	0.416
% No car	0.001	0.001	0.064	1.407	0.160
Median deprivation Ring 1	0.000	0.002	-0.013	-0.214	0.830
Median deprivation Ring 1*Manchester interaction	0.001	0.003	0.009	0.181	0.856
Median deprivation Ring 1*Liverpool interaction	0.003	0.003	0.058	1.024	0.306
Median deprivation Ring 2	**0.005**	**0.002**	**0.16**	**2.531**	**0.012**
Median deprivation Ring 2*Manchester interaction	**-0.006**	**0.003**	**-0.098**	**-2.203**	**0.028**
Median deprivation Ring 2*Liverpool interaction	-0.003	0.003	-0.06	-1.126	0.261

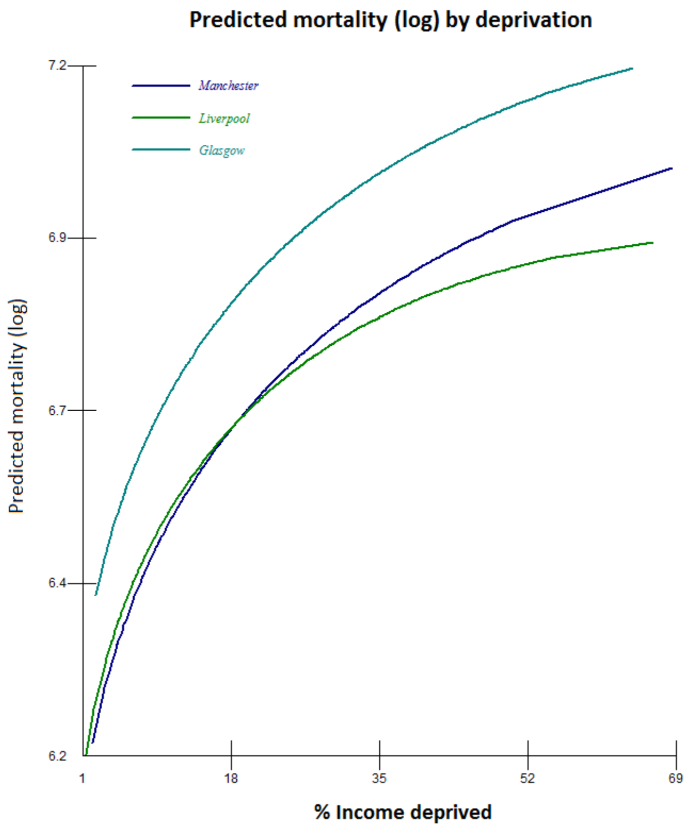
Adjusted R-Squared value = 0.616. All significant results in bold ($P<0.05$).

Figure 19. Standardised coefficients for all-cause mortality with neighbourhood factors.



The relationship between deprivation and mortality in the neighbourhood can be seen in Figure 20. The impact of deprivation on mortality rates is again higher in Glasgow across the deprivation spectrum compared with Liverpool and Manchester.

Figure 20. Predicted log of mortality rates by deprivation for all-cause model including neighbourhood factors.



4. Discussion

This research has sought to examine whether the patterning of deprivation is in part an explanation for the excess mortality that Glasgow experiences compared with the similarly deprived post-industrial cities of Liverpool and Manchester.

There are differences between the three cities in the patterning of deprivation. Deprivation in Glasgow appears to be more dispersed than in Liverpool and Manchester. The statistics we have used suggest that in all three cities deprived neighbourhoods are statistically more likely to be near neighbourhoods with similar deprivation levels. However, the Moran's I test suggests that this is less pronounced in Glasgow, which reinforces the visual impression provided by the maps of deprivation. Another difference in the patterning of deprivation in Glasgow compared with Liverpool and Manchester, is that deprived areas in Glasgow are more likely to be further from the centre of the city, than similarly deprived areas in Liverpool and Manchester.

In building models at different scales we examined whether the patterning of deprivation is in part responsible for the differences found in the mortality rates between Glasgow and the other two cities. The results suggest that the relationship between deprivation and mortality in each of the cities is different, though the clear picture in all cases is that higher levels of deprivation are associated with higher levels of mortality. Deprivation in the surrounding neighbourhoods is not significant in most of the models for both Ring 1 and Ring 2. However its inclusion in the model is required to account for the spatial autocorrelation found in mortality rates, which suggests that surrounding deprivation has *some* influence on the mortality rates in a neighbourhood. The effect is however very small compared with the effect of deprivation in the neighbourhood. Though this effect on neighbourhood mortality is small, if we are to understand and compare the impact of neighbourhood deprivation on mortality rates in the three cities, we still need to account for the wider deprivation in the surrounding area, otherwise our conclusions may be biased. We can clearly say that the influence of surrounding neighbourhoods on mortality is not a contributor to the 'Glasgow Effect', and if anything the impact in Glasgow is weaker than in the other two cities.

The amount of the variance that is explained by the all-cause model is high (nearly 60%) for a model which examines neighbourhood variance in three different cities. This is a sign of the robustness of the model. The premature deaths model is remarkably similar to the all-cause (all ages) model explaining just over 61% of the variance. The strength of the relationship between surrounding deprivation and mortality rates for those less than 65 years of age is also similar: weak but important for accounting for the spatial autocorrelation. The relationship between deprivation and mortality in the three cities is, however, different. In the all-cause model Glasgow has higher levels of mortality across the deprivation scale. The level of difference between the three cities widens as deprivation increases.

We might expect deaths from different causes to have a different relationship with neighbourhood deprivation, surrounding deprivation, and with neighbourhood context more broadly, and we have examined this relationship in models which have concentrated on specific causes of death. The main issue is that death for many causes is a relatively uncommon outcome, especially at the level of small neighbourhoods. We have been able to consider the relationship between neighbourhood deprivation and deaths from all malignant neoplasms and circulatory diseases, two of the most common causes of death; however, for less common events such as deaths as a result of drugs or alcohol, this is much more problematic. The modelling of deaths as a result of drugs or alcohol is much less stable, producing models which have low explanatory power but which are also much more unreliable and vulnerable to random difference. However if in future a broader grouping of self-destructive behaviours could be created – adding suicides, violent deaths, and so on, then this model might be more robust.

However, the analysis of the malignant neoplasms and circulatory group allows us to consider the relationship between deprivation at all three scales and mortality from these particular causes. The model explains less of the variance in mortality rates in this group than in the all-cause model (50% compared with 60% respectively). The predicted mortality in this model has a similar relationship with deprivation in Glasgow and Manchester and this is different in Liverpool where mortality is lower across the whole spectrum of deprivation. Deprivation in the surrounding areas is only significantly associated with neighbourhood in Ring 2. Again, Liverpool has a significantly different relationship to that in Glasgow. Deprivation in the outer ring in Liverpool has a weaker effect compared with Glasgow. It may seem strange for Ring 2 to have a more significant effect than Ring 1: this is discussed further below.

When a number of neighbourhood variables are added to the all-cause model there is an improvement in the model with a small increase in the variance explained. Two of the neighbourhood variables (population turnover and percentage of population educated to degree level or higher) have a significant effect. The relationship between predicted mortality and income deprivation in the neighbourhood is similar to the original model. However, the relationship between mortality in the neighbourhood and Ring 2 becomes stronger: so increasing deprivation in Ring 2 is significantly associated with higher mortality rates. The relationship in Manchester is less strong than that in Glasgow.

It is interesting to think about why we might find a significant relationship for Ring 2 but not Ring 1. First, we should acknowledge that the effect on mortality of deprivation in both Ring 1 and Ring 2 is very small compared with the overall effect of deprivation in the neighbourhood. Second, while Rings 1 and 2 often are not shown in the models as being significant they are required to account for what are otherwise significant levels of spatial autocorrelation, which suggests that this test is more sensitive to these differences than the significance testing in the regression modelling. The presence of deprivation in Ring 2 may be an indication that the level of concentration of deprived neighbourhoods has reached a tipping point and has begun to have an impact on mortality rates in the core neighbourhood. The presence of deprivation in a neighbourhood, in Ring 1 and in Ring 2, may be an indication of a greater depth of deprivation. It is not possible to disentangle this effect in this study and using the methods used here. However, it is useful to reiterate that any effect we see is very small compared with neighbourhood deprivation and certainly not in any meaningful way an explanation for the 'Glasgow Effect'.

Previous research has identified that the deprivation in surrounding areas does have an impact on mortality rates in the neighbourhood. These studies have used data from larger geographical units i.e. electoral wards. This is the first study to look at this question with geographical units more closely aligned with neighbourhood as we might imagine it. This research has also shown that deprivation in surrounding areas has an impact on mortality rates in the neighbourhood. It has examined at what scale this is important and found that even in Ring 2 there is some influence on mortality rates.

While spatial patterning of deprived neighbourhoods has a small impact on mortality rates in the neighbourhood this does not appear to be responsible in any significant way for the differences in mortality rates found between the three cities, or for the so-called the 'Glasgow Effect'. The models show that Glasgow has a higher level of mortality than the other two cities and that this difference remains even after adjusting for deprivation in two scales of surrounding neighbourhood (Ring 1 and Ring 2).

Other research has also examined whether neighbourhood mortality rates are influenced by differences in deprivation between the neighbourhood and surrounding neighbourhoods[19]. Recent research published in 2011 has shown that where differences are greatest there may be a negative effect on mortality rates[20]. This has not been investigated here but further work in this area may help to provide us with a better understanding of the impact on mortality of large differences in deprivation between neighbourhoods.

As death is a relatively rare outcome at the level of LSOA it makes detecting differences at this level difficult. We have combined five years of mortality data to allow us to examine the relationships between the spatial patterning of deprivation and health outcomes. However, the use of mortality data in this way has certain limitations in relation to examining the effect on specific causes of death. Future work is also needed to examine the relationship between health behaviours and the spatial patterning of deprivation to understand more fully whether certain patterns of deprivation are associated with poorer health behaviours.

5. Conclusions

While there are subtle differences in the patterning of deprivation in Glasgow compared with both Liverpool and Manchester these are relatively small. Glasgow's deprived population is more dispersed than its equivalents in the other two cities and Glasgow has more deprivation on the fringes of the city. However, deprivation in Glasgow is still quite concentrated and deprived areas tend to be beside other deprived areas in all three cities. Surrounding deprivation is significantly associated with higher levels of mortality in all three cities but the effect is very small. This is true for all causes of death, deaths from cancer and coronary heart disease, and for premature deaths.

The analysis of the spatial patterning of deprivation in the three cities suggests that this is not an explanation for the 'Glasgow Effect'. In each of the cities, as deprivation rises so does the mortality rate, which is what we would expect. However the specific relationship between deprivation and mortality in each of the cities is different, both for all-cause mortality and for premature mortality. When surrounding deprivation is added to the model it has a small effect on outcome in the neighbourhood in all three cities but the effect does not explain why the mortality rate is greater in Glasgow compared with the other two cities.

This research confirms the results of other studies which have examined the influence of deprivation in surrounding areas on mortality in a given neighbourhood[18-20]. It has been able to do this at a much lower geographical level than other studies. It has also been able to consider the effect on different causes of death as well as for different neighbourhood contexts, none of which has been examined before. However, while deprivation in nearby areas can be seen to have a detrimental effect on mortality in a given neighbourhood, and this is apparent in all three cities, the effect is small. The research allows us to say with considerable certainty that the patterning of deprivation in Glasgow is not a significant explanation for the excess mortality found in this city compared with the other two cities in the study.

While this research has been able to examine patterns of deprivation and the effects on mortality it has not specifically examined the effect on areas where the difference is at its greatest. Researchers did model minimum levels of deprivation in the surrounding areas but since this statistic is correlated strongly with the median deprivation in the surrounding area it is not possible to have both in the model. The models were similar to the models which have used median deprivation but had less explanatory power and so have not been reported here. It might be possible using different statistical techniques to examine whether outcomes are different in neighbourhoods where differences in deprivation are greatest but it has not been possible to explore this in any detail in this research.

Another limitation of this study is the use of mortality rates as an outcome measure. As mortality can be a result of any number of influences over a person's life, and it is an event that occurs infrequently at a neighbourhood level, this makes it an insensitive outcome measure and harder to detect effects. It may be that using a different and more sensitive health outcome measure, for example behaviours that have been shown to lead to poorer outcomes, we might see stronger effects of surrounding neighbourhoods.

While the results from this research clearly indicate that the spatial patterning of deprivation is not a significant explanatory factor for the 'Glasgow Effect', further research is needed to examine the impact of patterning using more sensitive outcomes. Research is also needed to examine whether large differences between adjoining neighbourhoods have an independent association with mortality.

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Appendix 1

Different mortality cause models – drugs and alcohol

While the analysis for deaths that are a result of drugs and alcohol have been shown here, we need to be very clear that these models are not stable because of the small numbers of drug and alcohol deaths over the five year period considered. The model has considerably lower explanatory power with only just over 30% of the variance explained. The only significant factors in the model are deprivation and city. The model shows no significant effect on mortality from deprivation in the surrounding rings (Appendix Table 1).

Appendix Table 1. Model coefficients for drugs and alcohol model.

	Coefficients(a)				
	Unstandardised coefficients		Standardised coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	4.213	0.04		105.934	0.000
Glasgow					
Manchester	-0.676	0.053	-0.441	-12.656	0.000
Liverpool	-0.371	0.058	-0.233	-6.441	0.000
% Deprived	0.022	0.003	0.418	6.765	0.000
Square root % deprived	0.000	0	0.001	0.018	0.986
% Deprived*Manchester interaction	-0.008	0.005	-0.08	-1.557	0.120
% Deprived*Liverpool interaction	-0.013	0.005	-0.133	-2.323	0.020
% Nursing/residential homes	0.844	1.326	0.019	0.636	0.525
Median deprivation Ring 1	0.001	0.006	0.012	0.147	0.883
Median deprivation Ring 1*Manchester interaction	-0.006	0.009	-0.047	-0.702	0.483
Median deprivation Ring 1*Liverpool interaction	0.001	0.009	0.009	0.121	0.904
Median deprivation Ring 2	0.002	0.007	0.03	0.347	0.729
Median deprivation Ring 2*Manchester interaction	0.008	0.009	0.061	0.964	0.335
Median deprivation Ring 2*Liverpool interaction	0.005	0.009	0.041	0.561	0.575

Adjusted R-Squared value = 0.317.

Further statistics relating to this model are available from the authors on request.

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