Geographical indicators of mortality provide one of the most important means of assessing the health of populations and are particularly effective in identifying inequalities in health. Geographical mortality indicators have regularly been produced by the Office for National Statistics, but not normally for areas smaller than local authorities. In order to allow variations in mortality within local authorities to be examined, in 2006 ONS published Standardised Mortality Ratios (SMRs) for wards in England and Wales, based on deaths in 1999–2003. For mortality indicators for small populations, based on small numbers of deaths, there is however a risk that results will be unstable, making geographical patterns hard to interpret. To examine whether this problem could be overcome, methods for smoothing SMRs in time and space were considered, with conclusions published in a methodology report in 2007. This article presents results from that work, illustrating the geographical patterns in mortality that emerge following smoothing of the ward-level SMRs.

Introduction

The Office for National Statistics (ONS) and its predecessor organisations have long reported on geographical differences in mortality. Although analyses have regularly been produced for regions and local authority administrative areas, they have not been routinely produced for smaller areas. When, in 2001, ONS reported on the large inequalities in life expectancy at birth that exist between local authorities in the UK, it was noted that the analysis was subject to a number of limitations. As local authorities vary substantially in size, an analysis at that geographical level could not examine variations in mortality within large authorities such as Birmingham and Manchester. It was also noted that there are known to be substantial variations in mortality at small area level within most local authorities that cannot be captured by authority level analysis.

In order to address the need to examine variations in mortality within local authorities, in April 2006 ONS published Standardised Mortality Ratios (SMRs) for wards in England and Wales, based on deaths under age 85 in 1999–2003. (Ward-level figures for life expectancy at birth for the same period were also published in June 2006.) The results demonstrated that big variations in mortality could exist within local authorities. In Liverpool, for example, a large authority with an overall high level of mortality, SMRs for wards ranged from 84 to 204. Even though mortality data were aggregated over a five-year period, many of the published results were however still based on rather small numbers of deaths. This leads to a risk that the SMRs may be unstable, with results illustrating chance variations in numbers of deaths between wards, rather than real underlying patterns of mortality.

To examine this potential problem some research was carried out to consider basic methods for smoothing the ward-level SMRs in time and space.
Smoothing

Abrupt variations in data, whether in a time series or between geographical areas, may make it hard to detect meaningful underlying patterns. Such variations may be due to real, underlying changes; to noise (caused by measurement or sampling error or random variation); or to a mixture of these. Smoothing is the application of procedures to remove noise from data. This can be done over time, across space, or a combination of the two. The objective of smoothing methods is to enhance the visibility of underlying trends in noisy data.

With ward-level SMRs, noise can arise from random mortality – numbers of deaths that cannot be predicted and which do not correlate with an underlying component. The aim of smoothing SMRs is therefore to reduce or eliminate this noise, to better uncover the underlying pattern.

The magnitude of noise is related to both population size and underlying mortality rates but smoothing can help to stabilise rates based on small numbers of deaths. Time smoothing can be used to reduce abrupt changes in mortality from year to year to reveal underlying local variation. The SMRs were also considered amenable to spatial smoothing as there is a high probability that underlying patterns of mortality may well cross small area boundaries. Spatial smoothing can therefore provide indications of possible patterns that might otherwise be difficult to detect. Data that have been smoothed can be used to produce maps from which geographical patterns previously hidden by noise can be recovered. Ideally, smoothing will obtain the best estimate of underlying mortality by reducing noise but still retain useful information about local variation. While noise is reduced as much as possible, substantial local differences should still be evident if the smoothing procedure is effective. A smooth estimate of underlying mortality does not necessarily mean a better estimate. It is certainly possible to over-smooth. For example, the smoothest estimate for each ward is the national mortality rate. While this is certainly very stable, it has the unwanted side effect of removing all local variation from the data.

Data and methods

A note on the calculation and interpretation of SMRs can be found in Box One. Ward-level results were calculated using deaths registered in England and Wales from 1999–2003. Published figures were based on five aggregated years of data to try to provide a reasonable number of deaths for each ward. The two years either side of 2001 were selected, as population estimates for wards were only available for 2001 and 2002. Only records where the age at death was less than 85 were selected as it is known that some wards have particularly large proportions of their total population in nursing homes. As age-specific mortality in nursing homes is higher than in the general population it may appear that death rates in these areas are unexpectedly high. Deaths at age 85 and above were therefore excluded from the calculations to partly ameliorate this effect. Deaths were assigned to 2001 Census Standard Table wards based on the place of usual residence of the deceased.

The ward populations used were 2001 experimental population estimates for census wards. Due to the small populations of the City of London and Isles of Scilly, population estimates were not produced for the individual wards within these areas, but were calculated for the two local authorities as a whole.

The SMRs were standardised using age-specific rates for England and Wales from 1999–2003. These were based on deaths registered in 1999–2003 and mid-year population estimates from 1999–2003. By aggregating mortality data for five years, the SMRs published by ONS had already, in effect, been smoothed over time. In order to consider other mechanisms for time smoothing the data, we also used SMRs calculated for the single years 1999–2003, and results for three periods where deaths were aggregated over three years: 1999–2001, 2000–02, and 2001–03. All of the SMRs, whether for five, three or single years, were calculated using only the ward population estimates for 2001 however.

Using these SMRs, a selection of simple time and space smoothing techniques were defined and applied to the ward-level results. The objective was to establish whether spatial smoothing methods could provide more stable estimates of underlying patterns of mortality from the published ward-level SMRs, and to identify which approaches were most suitable for application.

A range of simple techniques for smoothing in space were tested, by replacing the individual value for each target ward by a weighted average of itself and its neighbours. Neighbours were defined as first order (immediate) and second order (neighbours of first order neighbours) and with two types of weights: equal (where all wards under consideration have equal influence) and tapering over space (where the contribution of neighbouring wards tails off as we move farther away from the target ward).

The number of neighbours per ward ranged from 0 (for one area: Isles of Scilly) to 19 first order neighbours and 43 second order neighbours. The average number of first order neighbours per ward was 5.9 and the average number of second order neighbours was 14.3.

The best performing spatial smoother in this study used weights that differentiated between first and second order neighbours, with slightly

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**Box One**

**Standardised Mortality Ratios (SMRs)**

SMRs are a means of measuring mortality which takes into account the age structure of the population being considered. They are calculated by using a standard set of age-specific death rates (such as results for England and Wales) which are used to calculate how many deaths would be expected in a particular population, given its size and age structure. This gives a total number of ‘expected’ deaths. This figure is then compared with the actual number of ‘observed’ deaths which did take place. For example, given national death rates the number of deaths in a particular ward might be expected to be 80 but only 40 were observed. The SMR is then the ratio of the observed to expected or 40 divided by 80. For presentational purposes the ratios are normally multiplied by 100. The formula is therefore:

\[
\text{SMR} = \frac{\text{Observed}}{\text{Expected}} \times 100
\]

An SMR could therefore be defined as the ratio of the observed number of deaths in a ward to the number expected if the ward had the same age-specific rates as England and Wales.

As national death rates were used as the standard for the results, the SMR for England and Wales is 100. The results for wards therefore allow their mortality experience to be compared with the national average. If an SMR is less than 100 that means the number of deaths for a ward was less than would have been expected. Conversely if an SMR is greater than 100 the number of deaths was greater than expected.
higher weight for the first order neighbours relative to the second order ones. The techniques chosen, and methods used in the analysis, are described in detail in a report published as part of the National Statistics Methodological Series. The report includes evaluations of the performance of the simple smoothing solutions defined, identifies the most suitable simple smoothing solution for the SMR data under analysis and indicates the direction for future work in relation to smoothing SMRs.

The published ward SMRs were for both sexes combined, and males and females separately (standardised with sex-specific mortality rates). The smoothing study however used examples only for all persons, and it is these results which are illustrated here.

**Results**

The 8,797 wards for which SMRs were calculated had an average population in 2001 of just over 5,800 for those aged under 85. Population size differed considerably across England and Wales, from just under 1,000 in some of the smallest wards in Wales, to over 35,000 in the largest ward in Birmingham. This variation was reflected in the annual number of deaths. In 2001 the mean number of deaths under age 85 per ward was 41. Three wards however had only one death in this year, while one ward in Birmingham had 241.

SMRs based on data for a single year would, for some wards, therefore be based on very small numbers of deaths, with the risk of inherent instability. This was evident when SMRs for the five single years from 1999–2003 were examined. Standard deviations for the SMRs, which quantify variability by measuring the dispersion of values from the mean, differed considerably between wards. Standard deviations ranged from 1 to 74. (If all SMRs had been the same in each of the five years the standard deviation would have been zero and increasing results indicate greater variability.) Thus while a small number of wards had SMRs which were similar across all years, others, such as one ward in Northampton, had SMRs which ranged between 59 and 208. Just over three-quarters of wards had a standard deviation which was greater than 10.

Using results for a single year would therefore produce geographical patterns from which it would be hard to discern underlying patterns of mortality. This can be seen in Map 1 where SMRs based only on deaths in 2001 are illustrated. The map presents the SMRs grouped into six categories, each containing an equal numbers of wards. (In the map’s legend, ranges for the categories appear to overlap as they have been rounded to whole numbers.) Although some patterns are apparent in the map, because of the variability of the SMRs for single years, it is hard to judge whether these are real, reflecting genuine underlying differences in mortality between areas, or whether they are spurious, a result of random variation in numbers of deaths.

Map 2 illustrates the SMRs which were published by ONS, with data aggregated for 1999–2003 — results which have in effect been smoothed in time. While Map 1 contains 1,466 wards in each category, in Map 2 there are more wards in the middle ranges and fewer wards in the highest and lowest categories (1,272 wards in the highest range of SMRs and only 732 wards in the lowest range). Map 2 does still show some sharp variations in mortality between wards, but patterns are easier to see than in Map 1. Despite the time-smoothed results being more stable than those for single years, the mortality patterns in Maps 1 and 2 do appear similar in some areas, and it may be surprising that there is not greater contrast between the two. This may be partly related to the division of results into sixths and, in particular, to the width of the upper and lower bands used. Some wards had big differences between SMRs for 1999 and 1999–2003, for example, one ward had an SMR of 226 for 1999 but only 126 for 1999–2003. The latter result still placed this ward in the sixth of areas with the highest SMRs however, and so it is shaded the same in both Maps 1 and 2.

Using the best performing spatial smoother in our study, the time-smoothed SMRs illustrated in Map 2 were also smoothed in space. The advantages of this spatial smoothing can clearly be seen in Map 3, especially when it is compared with Map 2. Patterns of mortality, which cross ward boundaries, are far easier to discern and it is simple to see, for example, the areas of high mortality around urban areas in the north east and north west, and across south Wales and parts of inner London. Compared with Map 2, there is a further concentration of wards in the central ranges. In Map 3 only 109 wards had an SMR in the lowest range and 769 had an SMR in the highest range. In contrast the middle two ranges (SMRs of 83–93 and 93–105) had 2,511 and 2,114 wards, respectively.

**Discussion**

The results shown here illustrate the potential benefit of smoothing ward-level SMRs across time and space, by reducing noise and thereby revealing underlying patterns of mortality.

Although our initial findings are promising, there are some challenges and problems raised by smoothing. Different smoothing techniques will produce different results when applied to the same data. Within a given technique, the outcome of smoothing is also closely linked to the choice of smoothing parameters (time span, area covered, specific weights): the larger the degree of smoothing, the smaller the variance of the smoothed value (by reducing the size of random errors) and the larger the bias (the amount that the smoothed value is different from the raw value). Reduction in variance at the cost of increased bias in the smoothed value is the fundamental trade-off in all smoothing methods. Some data users may be concerned about the differences between raw and smoothed values (which may be large), although the potential benefits of smoothing may outweigh these concerns.

Although the smoothed SMRs we produced do illustrate the added benefit provided by smoothing in space, the spatial smoothers that we considered were very simple, based on contiguity between neighbouring wards. These were selected as this was the first project by ONS to examine spatial smoothing and simple methods were thought appropriate to best convey the essence of the technique. They also provided results which could be used in an exploratory way by allowing the visualisation of underlying geographical patterns of mortality. Further work is needed however to compare the performance of these simple methods with more sophisticated techniques. Bayesian inference methods, in particular, have been advocated as smoothing solutions when mapping the risk of disease or mortality. The investigation of such methods would help to ensure best practice for the publication of smoothed mortality indicators for small areas in the future.

Our study showed however that the time-smoothed estimates, calculated using five years of mortality data, performed well in our evaluation. The published SMRs for 1999–2003 therefore still retain an inherent value.
Map 3
Time and spatially-smoothed SMRs for all persons aged under 85, 1999 to 2003, England and Wales

SMRs
- 122 to 341
- 105 to 122
- 93 to 105
- 83 to 93
- 70 to 83
- 9 to 70

London inset
Acknowledgements

The study to investigate smoothing methods for ward-level SMRs was conducted by the Spatial Analysis Centre at ONS. This work was led by Martin Ralphs and Anca Carrington, assisted by colleagues within the ONS Methodology Directorate.

Key findings

- Ward-level SMRs based on mortality data for a single year can be highly variable. Resulting geographical patterns may be a result of random variation in the number of deaths, rather than reflecting genuine underlying differences in mortality rates between areas.
- Time smoothing SMRs, by basing figures on five years of mortality data, produces more stable results.
- Spatially smoothing the time-smoothed results adds further benefit, producing patterns of mortality which are easier to discern when mapped.
- Work is needed to investigate further smoothing techniques if ONS is to publish smoothed mortality indicators for small areas in the future.

References