Connected Health Cities – End of Project Report

Workforce Development:

Dealing with spatial misalignment to model the relationship between deprivation and life expectancy in Liverpool:

A model-based geostatistical approach

Contents:

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Abstract:

Life expectancy at birth (LEB), one of the main indicators of human longevity, has often been used to characterise the health status of a population.

Understanding its relationships with deprivation is key to develop policies and evaluate interventions that are aimed at reducing health inequalities.

However, methodological challenges in the analysis of LEB data arise from the fact that different Government agencies often provide spatially aggregated information on LEB and the index of multiple deprivation (IMD) at different spatial scales.

Our objective is to develop a geostatistical framework that, unlike existing methods of inference, allows us to carry out spatially continuous prediction while dealing with spatial misalignment of the areal-level data.

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Introduction:

Over the last decades, access to better healthcare and education has led to a surge in human longevity, especially in high-income countries[1].

Life expectancy at birth (LEB), one of the main indicators of human longevity, has often been used to characterise the health status of a population[2].

Measuring deprivation is also important in order to describe health inequalities within a population and to better understand variation in health outcomes[3].

Previous studies have shown that the LEB is strongly affected by deprivation[4] and that differences in LEB between most and least deprived individuals are larger among men than women[5].

However, methodological challenges arise from the fact that different Government agencies often release spatially aggregated information on LEB and other socio-demographic variables, including deprivation, at different spatial scales.

For example, in the UK, the Life Events and Population Sources Division of the Office for National Statistics releases information on LEB by Middle Super Output Area (MSOA) while the index of multiple deprivation (IMD), published by the Ministry of Housing, Communities and Local Government, is available at a higher spatial resolution by Lower Super Output Area (LSOA).

In the recent paper by Buck[6], the authors investigate the association between LEB and IMD in England using a linear regression modelling framework. Their analysis is carried out at MSOA-level by taking the population-weighted average IMD based on the LSOAs falling in each of the corresponding MSOAs while assuming independent and identically distributed Gaussian residuals.

This modelling approach ignores two important aspects: the within-MSOA variation which could result in a biased estimate for the regression coefficient associated with IMD; the residual spatial correlation in LEB, which affects the standard errors of the regression coefficient estimates. Furthermore, the technique used by Buck[6] can only be reliably applied when spatial units at different scales are nested within each other.

In this paper, our objectives are:

1) to develop a model-based geostatistical approach that allows the joint analysis of LEB and IMD data when these are available as spatially aggregated indices over misaligned partitions of the study area

2) to carry out spatially continuous inference on LEB using spatially aggregated data.

Liverpool has been ranked as the most deprived local authority area in England in 2004, 2007 and 2010, and as the 4th most deprived in 2015.

In 2018, LEB for both men and women was lower than the overall average in England. Understanding the relationship between deprivation and life expectancy within a single conurbation helps to develop policies and evaluate interventions that are aimed at reducing health inequalities.

To address the aforementioned limitations of existing methods of inference, we develop a geostatistical framework that avoids the re-aggregation of IMD at MSOA- level.

Instead, we jointly model LEB and IMD as aggregated outcomes of a spatially continuous stochastic process. More specifically, we model the spatial correlation across MSOAs for LEB and across LSOAs for IMD using inter-point distances based on a regular grid covering the whole of the study area.

One of the main advantages of this approach is that it allows to carry out spatial prediction at any desired spatial scale, regardless of the format of the analysed data.

The methodology presented in this paper can also be used to model any spatially aggregated health outcome and estimate its association with risk factors that may be available at a range of spatial scales.

Methods:

We developed a model-based geostatistical approach for the joint analysis of LEB and IMD, when these are available over different partitions of the study region.

We model the spatial correlation in LEB and IMD across the areal units using inter-point distances based on a regular grid covering the whole of the study area.

The advantages and strengths of the new methodology are illustrated through an analysis of LEB and IMD data from the Liverpool City Council.

Index of Multiple Deprivation (IMD)

IMD is a measure of relative deprivation and can thus be used to rank neighbourhoods. It combines seven distinct domains of deprivation: income; employment; education; skills and training; health deprivation and disability; crime, barriers to housing and services; and living environment. IMD data are made available either as scores, deciles or ranks. In this study, we used the IMD score released in 2015.

Life expectancy at birth (LEB)

Our outcome variable is the LEB released by the (ONS). The ONS estimates LEB using life tables that are constructed by applying the Chiang method[7] to mortality data collected over five consecutive years, starting from 2009.

The proposed modelling framework

We developed a novel model-based geostatistical framework for the joint analysis of LEB and IMD and carry out spatially continuous prediction.

The details of the methods can be found in our paper published in International Journal of Health Geographics, titled "Dealing with spatial misalignment to model the relationship between deprivation and life expectancy in Liverpool: A model-based geostatistical approach".

At the time of writing the report, the paper has been accepted but not yet appeared online.

Results:

We found that the effect of IMD on LEB is stronger in males than in females, explaining about 63.35% of the spatial variation in LEB in the former group and 38.92% in the latter.

We also estimate that LEB is about 8.5 years lower between the most and least deprived area of Liverpool for men, and 7.1 years for women.

Finally, we find that LEB, both in males and females, is at least 80% likely to be above the England wide average only in some areas falling in the electoral wards of Childwall, Woolton and Church.

Table 1: Point estimates and 95% confidence intervals (CI) for the three model parameters.

Parameter	Model 1 Estimate	Model 1 CI 95%	Model2 Estimate	Model2 CI 95%
α_1	75.466	(75.596, 76.135)	75.131	(74.990, 75.272)
α_2	81.120	(80.883, 81.357)	81.375	(80.927, 81.823)
β_1	-0.154	(-0.180, -0.128)	-	-
β_2	-0.129	(-0.167, -0.091)	-	-
$\log \omega_1^2$	1.810	(1.494, 2.126)	3.036	(2.955, 3.117)
$\log \omega_2^2$	2.581	(2.272, 2.890)	3.160	(3.033, 3.287)
$\log \omega_{12}$	1.671	(1.257, 2.086)	2.871	(2.768, 2.974)
γ	39.221	(28.242, 50.200)	39.190	(28.073, 50.306)
$\log \tau^2$	6.226	(3.611, 8.841)	6.232	(5.678, 6.586)
$\log \delta$	7.336	(6.845, 7.827)	7.349	(6.318, 7.846)
$\log \nu^2$	2.586	(2.244, 2.927)	2.589	(2.064, 2.932)
Log-likelihood	-1429.491		-1465.432	

Table 1 shows the point and interval estimates for the model with (Model 1) and without (Model 2) IMD.

The likelihood-ratio test for the null hypothesis $\beta_1 = \beta_2 = 0$ yields a p-value smaller than 0.001, hence indicating that Model 1 is a better fit to data.

We find that the fraction of total variance explained is about 38.92% for females and 63.52% for males, respectively.

We estimate that the range of the spatial correlation, defined as the distance beyond which the correlation is below 0.05, is approximately 4.6 km.

The correlation in LEB between males and females, is 0.59 with associated 95% confidence interval (0.31, 0.90).

Figure 3 (upper and lower panel) shows spatially continuous predictions of LEB for females and males.

As expected, female LEB is consistently higher than for males. We notice that spatially continuous predictions provide useful insights into the variation in LEB within MSOAs that is otherwise hidden by the aggregated estimates at MSOA-level.

To demonstrate this, we selected the MSOA with the lowest and largest estimated value in LEB for both males and females.

More specifically, for males, the lowest estimated value in LEB at MSOA-level is about 70.2 years and the largest is 85.2 years, whilst for females, these are respectively 73.5 years and 89.6 years.

In the maps of Figure 3, we then draw the contour lines for these same values in LEB.

These reveal the actual extent of the areas where LEB reaches its highest and lowest values, that cannot be possibly discerned from MSOA-level estimate: the white contour lines encompass a relatively small at the intersection of Childwall, Woolton and Church; the green contour lines, instead, delineate a wide area consisting of three disjoint sub-regions in the north-west and north-east of Liverpool.

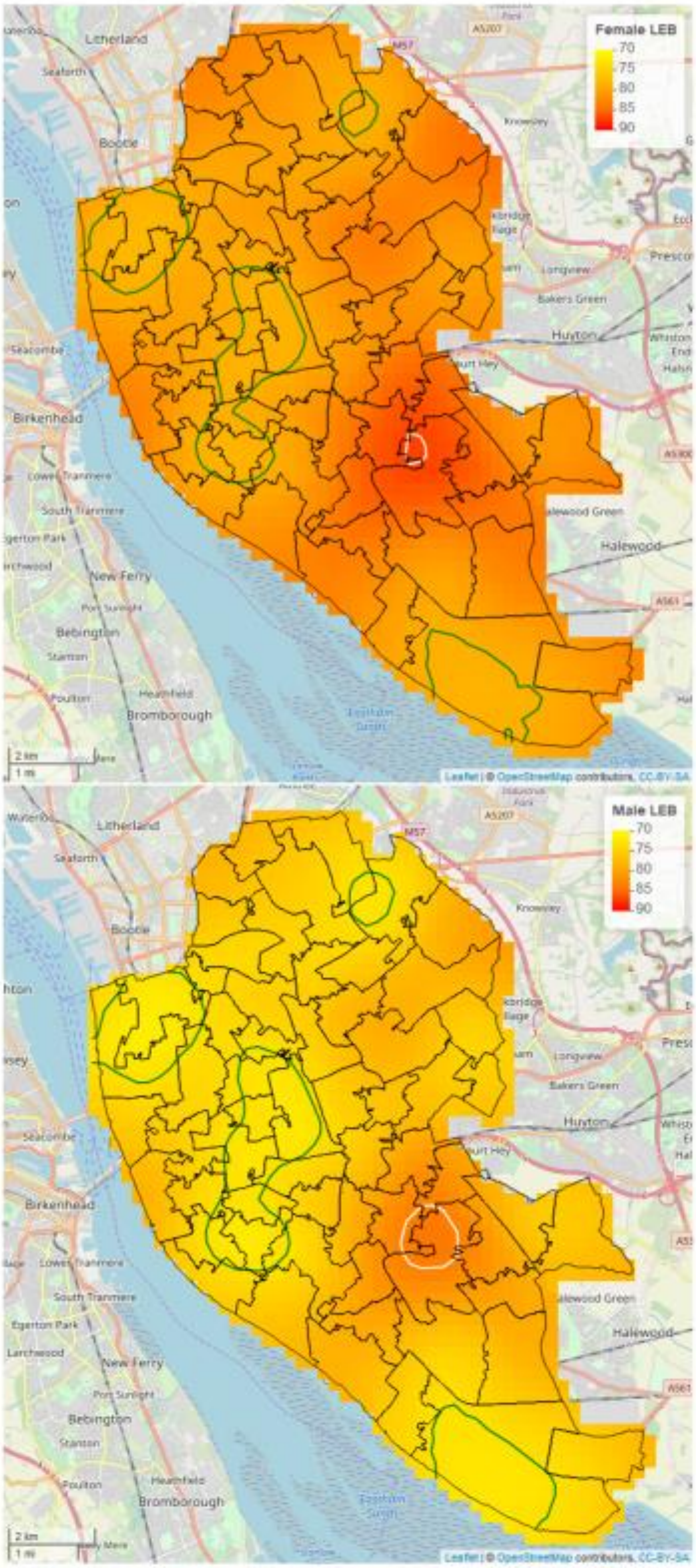

Figure 3: Spatially continuous prediction maps of female (upper panel) and male (lower panel) life expectancy at birth (LEB) in Liverpool, UK. In the upper panel, the white contour lines are for a LEB of 89.6 years and the green contour lines for a LEB of 73.5 yers; in the lower panel, the white contour lines correspond to 70.2 years and the green contour lines to 85.2 years.

Conclusion/discussion:

We have developed a model-based geostatistical approach that allows us to model the relationship between life expectancy and the index of multiple deprivation when these are provided over misaligned partitions of the study area.

Unlike existing methods of analysis, one of the main advantages of our approach is that it allows us to combine information from multiple data sources without coarsening their resolution to a common spatial scale.

The underpinning principle of our modelling framework is that spatially aggregated data should be treated as the realization of an aggregated spatially continuous stochastic process.

Furthermore, it is also more widely applicable to more complex data scenarios where information is provided at a range of spatial scales, from pixel-level to areal-level.

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