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Geographical epidemiology of health and overall deprivation in England, its changes and persistence from 2004 to 2015: a longitudinal spatial population study

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Abstract

Background: Socio-economic deprivation is a key determinant for health. In England, the Index of Multiple Deprivation (IMD) is a widely used composite measure of deprivation. However, little is known about its spatial clustering or persistence across time.

Methods: Data for overall IMD and its health domain were analysed for 2004-2015 at a low geographical area (average of 1500 people). Levels and temporal changes were spatially visualised for the whole of England and its 10 administrative regions. Spatial clustering was quantified using Moran's *I*, correlations over time were quantified using Pearson's ρ.

Results: Between 2004 and 2015 we observed a strong persistence for both overall (ρ=0.94) and health-related deprivation (ρ=0.92). At the regional level, small changes were observed over time, but with areas slowly regressing towards the mean. However, for the North East, North West and Yorkshire, where health-related deprivation was the highest, the decreasing trend in health-related deprivation reversed and we noticed increases in 2015. Results did not support our hypothesis of increasing spatial clustering over time. However, marked regional variability was observed in both aggregate deprivation outcomes. The lowest autocorrelation was seen in the North East and changed very little over time, while the South East had the highest autocorrelation at all time points.

Conclusions: Overall and health-related deprivation patterns persisted in England, with large and unchanging health inequalities between the North and the South. The spatial aspect of deprivation can inform the targeting of health and social care interventions, particularly in areas with high levels of deprivation clustering.

Keywords: England; deprivation; Index of Multiple Deprivation; IMD; clustering; spatial; persistence; north; south.

What is already known on the subject
• Socio-economic deprivation is a key determinant of health. • However, very little is known about the spatial clustering of English deprivation or its persistence across time. • The Index of Multiple Deprivation (IMD) is a comprehensive aggregate measure incorporating seven domains of deprivation. The IMD can provide insight on relative changes in deprivation over time at the regional level.
What this study adds
• Between 2004 and 2015, overall and health-related deprivation in England strongly persisted at a low geographical area level. • For the North of England, where health-related deprivation was the highest, the decreasing trend in health-related deprivation was reversed by 2015. • Spatial clustering for both overall and health-related deprivation appears to have decreased over time, with some exceptions in 2015. • Spatial aspects of deprivation can inform more effective organisation of health services and the targeting of health or social interventions, particularly in areas where there are high levels of deprivation clustering.

Introduction

The impact on health of socio-economic deprivation – for example, lower levels of income, wealth and education – is well established. At the area level, greater deprivation is associated with worse clinical outcomes,[1 2] higher comorbidity levels,[3 4] and lower levels of healthcare access and utilisation.[5 6] Higher individual-level socio-economic deprivation has been linked to poorer health for secondary school students in New Zealand,[7] higher oral-health-related hospitalisation rates in Australia,[8] poorer self-reported health in Germany and the US,[9 10] worse perinatal outcomes in France,[11] and higher all-cause and cause-specific mortality in England and Wales.[12]

Socio-economic deprivation is often found to be a more powerful determinant of health outcomes than medical care.[13] In US studies, only 10-15% of preventable mortality has been estimated to be attributed to medical care.[14] In England, performance of primary care practices on a range of quality of care indicators was not found to be associated with all-cause or cause-specific mortality,[15] whereas local area deprivation was the strongest measured predictor.[16] This highlights the importance of socio-economic deprivation, and the need for accurate and valid measurement to inform policies to address its health impacts.

A major challenge is developing measures that reliably quantify deprivation. Despite international interest, most countries have been slow to create comprehensive deprivation indices; for example, composite indices have only recently been proposed in Canada,[17 18] and the US has yet to develop its own alternative.[19 20] In England, the first widely used composite measure of material deprivation, the Townsend Index, was created in the 1980s, incorporating four indicator variables derived from decennial Census data (unemployment, non-car ownership, non-home ownership and household crowding).[21] A similar measure, the Carstairs Index, was compiled for Scotland, [22] and New Zealand developed its own census-based aggregate measure of deprivation.[23]

In England, a more comprehensive measure, the Index of Multiple Deprivation (IMD), was developed in the 2000s incorporating routine administrative data covering a wider range of indicators (a total of 37 in 2004).[24] Iterations of the index have been reported for 2004,[25], 2007,[26] 2010,[27] and 2015.[28] The current measure quantifies relative deprivation across seven domains, known collectively as the English Indices of Deprivation (income, employment, education and skills, health and disability, crime, barriers to housing and services, and living environment), using an area-based model at a low geography (average of 1500 people) although it was originally developed for a higher level.[29] The overall IMD is calculated as a weighted mean across the seven domains, with income and employment deprivation given the largest weight (22.5% each), followed by health and education deprivation (13.5% each), and

with the other three domains given equal weights (9.3%). English epidemiological studies routinely incorporate the index or individual component domains.

Despite the clinical importance of the English Indices of Deprivation, some aspects remain under-researched. The first is the spatial nature of deprivation, i.e. how clustered it is. The second is the longitudinal trends of clustering and regional deprivation (although the IMD is standardised in each time point and thus does not allow for investigating absolute change,[30-32] it is possible to assess relative changes over time). And the third is the persistence of deprivation over time. All three are important to help guide the organisation of health care services and to target social and health interventions. In this study we longitudinally and spatially describe health-related (i.e. the health and disability domains) and overall deprivation in England (the IMD). We hypothesised that between 2004 and 2015, and especially after the 2008 financial crisis, spatial autocorrelation for deprivation would increase, indicating increasing spatial clustering of both poverty and wealth. We also quantify the longitudinal and spatial properties of deprivation within each of 10 administrative English regions and make comparisons across them. Finally, we quantify the persistence of deprivation over the study period.

Methods

English Indices of Deprivation

Details about the subdomains included in each domain are provided in Table 1. For each domain, the subdomains are normalised on ranking and then standardised, before factor analysis is used to inform on the weighting of each subdomain. Therefore, the subdomain weighting varies over time while the domain weighting does not. The health deprivation domain aggregates information on years of potential life lost, illness and disability, acute morbidity and mood and anxiety disorders. Their respective weights in 2015 were 0.244, 0.287, 0.254 and 0.216. The years these indicators cover also vary due to data availability and other reasons. For 2015 for example, years of potential life lost was based on 2008-2012 calendar year data, illness and disability on 2013 calendar year data, acute morbidity on 2011/12-2012/13 financial year data and mood and anxiety disorders on 2012-2013 calendar year data.

Given the normalisation and standardisation of the subdomains, the aggregate measures, i.e. overall IMD and each of the seven domains, are relative and cannot account for longitudinal improvement or deterioration at the country level. However, longitudinal analyses can still inform on distributional changes in the aggregate measures over time. Deprivation scores are calculated and assigned to very low UK geographical units. Although small changes to the indices have been implemented over time, comparability has been maintained since the

methods used are the same and no major changes have been considered necessary.[28] Separate deprivation measures exist for other UK countries, with varying degrees of similarity to the English IMD.

Lower Super Output Areas

The low geographical units to which the indices of deprivation are assigned are called lower super output areas (LSOAs) and they are designed to contain around 1500 inhabitants, on average. To roughly comply with this size-based definition, they can change following a decennial census. Thus, following the 2011 census, English LSOAs were re-organised into 32,844 units (from 32,482 after the 2001 census) to better reflect population changes, mainly increases.[33] Nevertheless only 2.5% of English LSOAs merged, split or underwent a more complicated change.[34] Census-adjusted population estimates over time and for each English LSOA were obtained from the Office of National Statistics.[35] Using the 2015 population estimates we observed that mean LSOA size was 1654 inhabitants (median: 1595; 1st centile 1102; 99th centile 2926). Since pre-2011 deprivation indices were only reported using 2001 LSOAs we created a weighted means algorithm to assign them to 2011 LSOAs and allow a seamless comparison over time. Spatial coordinates for the 2011 LSOAs were obtained from the ONS open geography portal.[36] We used digital vector boundaries generalised to 20 meters and clipped to the coastline to reduce size and improve visualisation. Finally, LSOAs were organised into 10 regions to allow for comparisons within England, based on the 2006 restructuring of Strategic Health Authorities: North East, North West, Yorkshire & the Humber, East Midlands, West Midlands, East of England, London, South East Coast, South Central and South West.[37]

Analyses

Deprivation outcomes of interest were overall and health-related IMD, in 2004, 2007, 2010 and 2015. We also analysed the fourth health-related IMD domains separately: years of potential life lost, illness and disability, acute morbidity and mood and anxiety disorders. Outcomes and their temporal changes were visualised using spatial maps for all of England and each of the 10 regions.

Spatial autocorrelation, or correlation in a signal among nearby locations in space, was assessed and quantified using Moran's *I*.[38] This measure accounts for the multi-dimensional and multi-directional nature of spatial autocorrelation, and can identify the presence or not of deprivation clusters. A higher value than the one expected under a random spatial pattern would indicate that deprived areas are clustered together and hence a deprived LSOA is more likely to have deprived LSOAs as bordering or close neighbours (and similarly for affluent LSOAs), with a value of 1 indicating perfect spatial correlation. We compared the values for Moran's *I* in the four time points to assess whether existing spatial autocorrelation for

deprivation in 2004 has changed over time. An increasing value for Moran's *I* would indicate an increase in deprivation-related spatial segregation. The measure was calculated for the whole of England and each of the 10 regions, to allow for within-England comparisons.

Pairwise correlations across the four time points were computed (Pearson's rho) to quantify the persistency of area deprivation. Pairwise correlations between overall and health-related IMD but also across health-related IMD subdomains were computed, to assess whether the two main outcomes and the subdomains are different enough to justify reporting on all. To visualise and compare temporal changes in the average deprivation levels between the 10 English regions, we plotted population weighted boxplots for each of the two main outcomes and the health subdomains. Analyses were executed with Stata v14.1 and R v3.3.1. Due of the size of the dataset, effectively the whole of England, statistical significance is irrelevant; any comparison would be statistically significant and thus we focus on effects sizes wherever possible.

Results

Both overall and health-related deprivation was strongly correlated at all time points, indicating small changes over time. Pearson's rho remained above 0.94 for overall deprivation (2004 vs 2007: $\rho = 0.98$; 2004 vs 2010: $\rho = 0.97$; 2004 vs 2015: $\rho = 0.94$) and 0.92 for health-related deprivation (2004 vs 2007: $\rho = 0.97$; 2004 vs 2010: $\rho = 0.93$; 2004 vs 2015: $\rho = 0.92$). Correlation between overall and health-related IMD was strong, as anticipated, but the strength somewhat deteriorated over time from $\rho = 0.88$ in 2004 to $\rho = 0.84$ in 2015. As expected, subdomains of the health-specific deprivation were strongly correlated with overall deprivation, with the lowest values observed for mood and anxiety disorders vs acute morbidity ($\rho = 0.57$ in 2004 and $\rho = 0.63$ in 2015) and the highest for years of potential life lost vs the comparative illness and disability ratio ($\rho = 0.79$ in 2004 and 2015).

Spatial maps were plotted for the whole of England and each region, for all years and each deprivation outcome (overall IMD and health-related IMD and its four subdomains). We present overall deprivation for 2015 and the whole of England in the main paper (Figure 1), and for health-related deprivation in Appendix 2 (Supplemental Figure A1). Longitudinal spatial maps for all other regions and the whole of England are provided in Appendices 1a to 1f, while a longitudinal spatial map for London which allows for visual comparisons over time is presented in Appendix 2 (Supplemental Figure A2).

Temporal changes of deprivation for English regions are presented in Figure 2. Although changes over time are small, areas appear to be very slowly converging towards the English

average for both overall and health-related deprivation. However, for the three northern regions where health-related deprivation was the highest (North-East, North West and Yorkshire & the Humber) the decreasing trend between 2004 and 2010 seems to have been reversed and we observed increases in 2015. The findings are similar across all four health subdomains (Appendix 2, Supplemental Figures A3 and A4).

Spatial autocorrelation results did not support our original hypothesis of increasing spatial clustering over time (Figure 3). Across the whole of England and for overall deprivation, Moran's I was 0.0972 in 2004 (95% CI: 0.0970, 0.0974) but by 2015 it had linearly dropped to 0.0686 (95% CI: 0.0683, 0.0688), indicating a reduction is spatial autocorrelation and clustering. However, the picture was different for health deprivation where spatial autocorrelation was higher at a level of 0.1725 in 2004 (95% CI: 0.1723, 0.1728), dropped to 0.1490 in 2007 (95% CI: 0.1488, 0.1493) and remained relatively stable thereafter (0.1450 in 2010, 95%CI: 0.1448, 0.1453; 0.1505 in 2015, 95%CI: 0.1503, 0.1508). In addition, the levels and trends of spatial autocorrelation were not consistent across the health deprivation subdomains. For years of potential life lost, autocorrelation was relatively stable between 2004 and 2010, but moderately increased in 2015. Spatial autocorrelation was higher for the comparative illness and disability ratio, but it deteriorated over time and in 2015 it was lower than was observed for years of potential life lost. Acute morbidity autocorrelation remained stable over time, although a small increase was seen for 2015. Finally, autocorrelation for mood and anxiety disorders has changed little over time and was the highest observed in 2015. Overall, regarding the health IMD subdomains, spatial clustering appears to be increasing for years of potential life lost and acute morbidity (Figure 3).

Marked regional variability was observed in the two aggregate deprivation outcomes, both for 2004 spatial autocorrelation levels and for their changes over time (Figure 4). The lowest autocorrelation was seen in the North East and it has changed very little over time, while the South East had the highest autocorrelation at all time points although it reduced over time. For the East of England and the South Central coast, autocorrelation for overall deprivation and especially health related deprivation increased in 2015, in contrast to the trends for the rest of the country. Regional variation in autocorrelation was also observed for the health deprivation subdomains (Appendix 2, Supplemental Figures A5 and A6). The smallest regional variation was seen for years of potential life lost, with the South East reporting the highest levels and the North East reporting the lowest. Changes over time were small for this subdomain, but trends also varied by region. For the comparative illness and disability ratio, regional variability was also modest and the general decreasing trend was seen in all regions, while the South East and South West had consistently the highest level and the North East the lowest. For the other two subdomains, acute morbidity and mood and anxiety disorders, regional changes in

autocorrelation over time are more unstable, with the East of England and the South Central demonstrating high levels of autocorrelation.

Discussion

From 2004 to 2015, overall and health-related deprivation strongly persisted at the LSOA level. Regional changes over time were modest for overall deprivation, with regional levels converging towards the English average. However, the picture was different for health-related deprivation (and within each of its four subdomains: years of potential life lost, illness and disability, acute morbidity, and mood and anxiety disorders), with significant national heterogeneity observed and levels consistently higher in the North East and North West, and regional differences persisting over time. Our findings do not provide evidence of increasing clustering for overall deprivation, with autocorrelation for overall deprivation declining over time for the whole of England and each of its 10 regions, with some exceptions in 2015. Despite this overall decreasing trend, regional variation in overall deprivation autocorrelation was observed, with deprivation in the South coast appearing much more clustered than the North, particularly the North East.

For health-related deprivation, levels of autocorrelation were consistently higher than what was observed for overall deprivation, especially for the South coast. However, clustering levels of health-related deprivation for the whole of England remained broadly the same since 2007, with some regional variation of, primarily decreasing, trends. Different autocorrelation trends were observed for the subdomains, with clustering increases for years of potential life lost and acute morbidity.

Strengths and limitations of the study

This large longitudinal study that used data for the whole of England (53 million people in 2011), to investigate spatial and longitudinal patterns of overall and health-related deprivation. To our knowledge, it is the first study of its kind to provide an insight into the temporal persistence of deprivation and it's clustering.

However, some limitations exist. First, there have been some minor changes in the underlying indicators of deprivation over time, which might have influenced our estimates. However, the trends we observe persist between 2007 and 2010 when there were no changes to the measures, while the health deprivation domain has remained unchanged across the whole time period. Second, the IMD and each of each domains are normalised and standardised at each time point, hence the measure cannot account for longitudinal improvement or deterioration at the country level,[39] only for relative regional changes. Third, there are varying levels of lag in

the underlying indicators included in each IMD version (for example data from 2012-13 used for the 2015 IMD), but there is no data overlap across them. Fourth, it is possible that analyses at the LSOA level are masking the relative deprivation trends in smaller and extremely deprived communities.[40] Finally, there was a boundary change following the 2011 census which may have affected our findings,[41] but only 2.5% of LSOAs were affected while we developed an algorithm to make reasonable population weighted based estimates for these localities, depending on whether they merged, split or another change occurred.

Findings

Overcoming material and health deprivation is a global challenge. Neighbourhood connectivity has been shown to be important, both in terms of the housing market and the labour market.[42] However, a lack of connectivity does not fully explain deprivation, which poses a diverse challenge, a fact that needs to be taken into account by policy interventions. The very high persistence of neighbourhood deprivation over the 11-year study period (2004 to 2015), relative to the rest of England, was expected but is nevertheless of concern and highlights the need for more social interventions to tackle inequality and social mobility in England.

The social inequality gap for the North of England, and how it compares to the South, is well known,[43] although our results for overall deprivation indicate it has been slowly closing. In the context of a universal healthcare provider, the National Health Service, persistent deprivation plays an important role in premature mortality in England,[44 45] but it does not fully explain the persistently higher levels of all-cause mortality in the North,[46] which has recently increased at an alarming rate for those aged 25-44.[47] Although health selective migration is likely to be a factor,[48] and it is likely to influence inequalities by age,[49] we found that levels of health-related deprivation were consistently higher in the North, not only in premature mortality but also illness and disability, acute morbidity (hospital admissions), and mood and anxiety disorders.

Despite the longitudinal persistence of overall deprivation, the spatial clustering of neighbourhood deprivation appears to have slowly decreased over time, although large regional variation was observed both in levels of clustering and their changes. For most regions, this reducing trend plateaued after 2010, possibly as a consequence of the 2008 financial crisis, with London and the South East the notable exceptions. This pattern may be related to gentrification projects, which have aimed to regenerate deprived inner city neighbourhoods.[50] Gentrification is a controversial and still debated practice, accused of displacement, segregation and social polarisation,[51] while too often the regeneration agenda is not inclusive.[52]

High levels of spatial clustering for health-related deprivation would have implications for the planning of health services and interventions, since they would imply a non-uniform

distribution of need across a region with hotspots of high levels of morbidity. To address such spatial health inequality, services may need to be redesigned to take this factor into account.[53] For example, general practices may be incentivised to re-locate within such hotspots, and targeted interventions may need to be prioritised in these areas. Similarly, infrastructure and regeneration spending needs to be inclusive and weighted towards the health-deprivation hotspots, rather than uniform. For the South of England we observed modest levels of clustering, which even increased for the South Central region.

The regional clustering of health-related deprivation (and its levels) will be affected by external economic migration, which varies greatly across regions.[54]. On average, external migrants are likely to be more materially deprived than English-born residents but with better health, at least initially.[55] The age structure of the population will also play an important role, and the population in the North of England is older.[47]

Conclusions

Socio-economic deprivation is a key determinant of health. In order to improve population health, policy makers need to not only invest in health care, but also – and perhaps more importantly – to address material and educational inequalities. The time-lag between effective policy intervention and reductions in inequality highlights the need for urgent action. We found that from 2004 to 2015, overall and health-related deprivation patterns persisted in England at a low geographical level. In terms of relative deprivation comparisons, regional levels of overall deprivation appear to be slowly converging to the mean over time. However, regional variation of health-related deprivation changed little, highlighting large and unchanging health inequalities between the North and the South of England. Although this variation can be partially explained by population differences, more needs to be done to address the issue.

Over time, the clustering of overall deprivation, and to a smaller extent of health-related deprivation, decreased, with the regional trends demonstrating high heterogeneity. This decrease and the underlying causes need to be better understood. The spatial aspect of deprivation is often overlooked, but it can provide vital information for the effective organisation of health services and targeting of health or social interventions. This is particularly important for areas such as the South coast of England, where there are high levels of clustering.

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Declaration of competing interests

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Authorship & contributorship

EK designed the study, extracted the data from all sources, performed the analyses and drafted the manuscript. MM, HvM, AMR, DA, IB and TD critically edited the manuscript.

EK is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Data sharing

The data used in this study are freely available and the authors are willing to share in an organised and cleaned final dataset.

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Table 1: Index of multiple deprivation domains, 2015*

Domain (weight)	Subdomains
Income (22.5%)	• Adults and children in Income Support families • Adults and children in income-based Jobseeker's Allowance families • Adults and children in income-based Employment and Support Allowance families • Adults and children in Pension Credit (Guarantee) families • Adults and children in Child Tax Credit and Working Tax Credit families, below 60% median income not already counted • Asylum seekers in England in receipt of subsistence support, accommodation support, or both
Employment (22.5%)	• Claimants of Jobseeker's Allowance, aged 18-59/64 • Claimants of Employment and Support Allowance, aged 18-59/64 • Claimants of Incapacity Benefit, aged 18-59/64 • Claimants of Severe Disablement Allowance, aged 18-59/64 • Claimants of Carer's Allowance, aged 18-59/64
Health and disability (13.5%)	• Years of potential life lost: age/sex standardised measure of premature death • Comparative illness and disability ratio: age/sex standardised morbidity/disability ratio • Acute morbidity: age/sex standardised rate of emergency admission to hospital • Mood and anxiety disorders: composite score based on the rate of adults suffering from mood and anxiety disorders, hospital episodes data, suicide mortality data and health benefits data
Education, Skills & Training (13.5%)	• Key stage 2 attainment: average points score • Key stage 4 attainment: average points score • Secondary school absence • Staying on in education post 16 • Entry to higher education • Adults with no or low qualifications, aged 25-59/64 • English language proficiency, aged 25-59/64
Crime (9.3%)	• Recorded crime rates for: Violence; Burglary; Theft; Criminal damage
Barriers to Housing & Services (9.3%)	• Road distance to: post office; primary school; general store / supermarket; GP surgery • Household overcrowding • Homelessness • Housing affordability
Living Environment (9.3%)	• Housing in poor condition • Houses without central heating • Air quality • Road traffic accidents

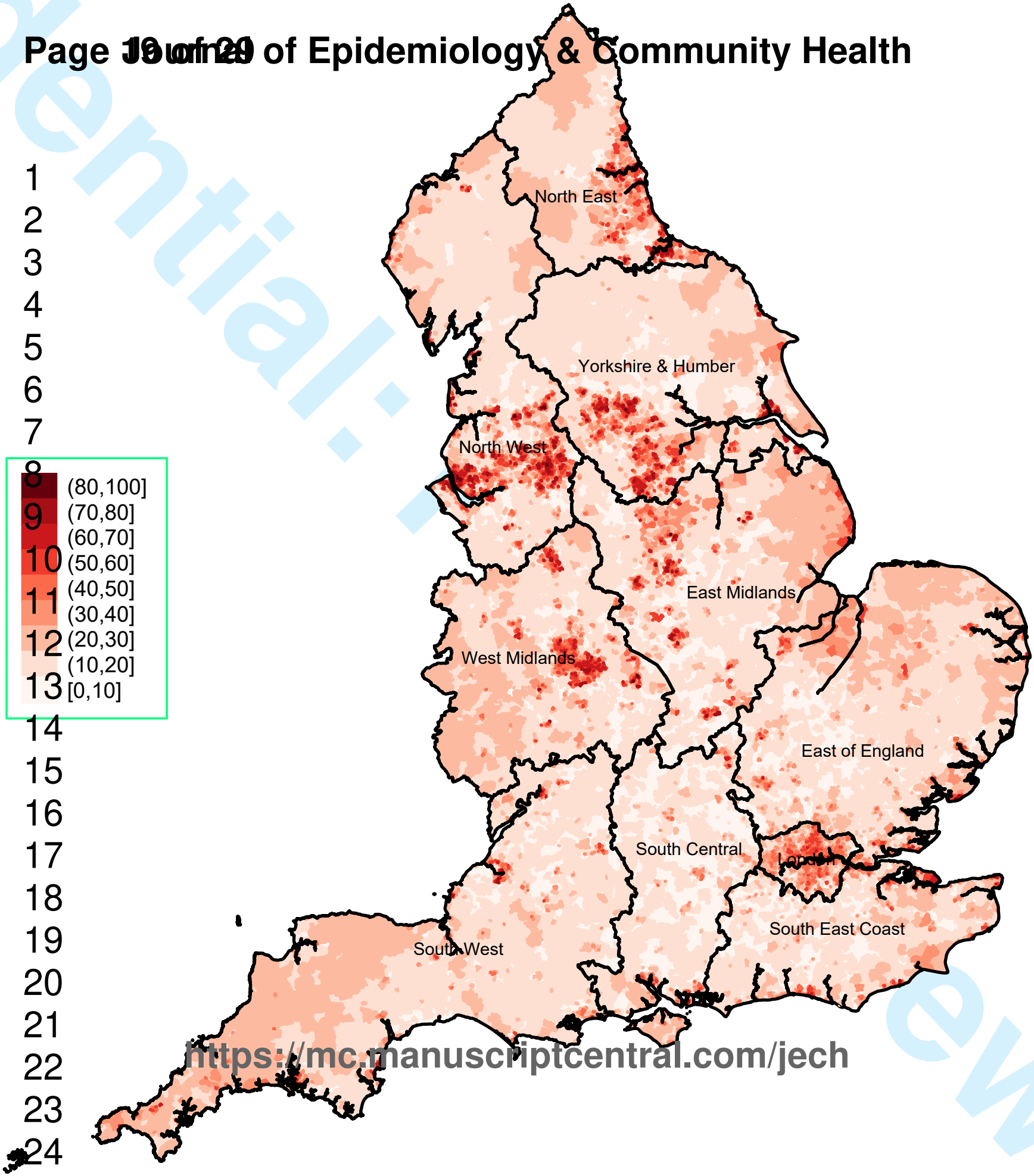
*Details available in the 2015 technical report of the English Indices of Deprivation [28]

Figure 1: Overall deprivation for England, 2015

Figure 2: Overall (top) and health-related (bottom) deprivation for English regions, over time

Figure 3: Spatial autocorrelation with Moran's I for deprivation domains and subdomains, for the whole of England over time

Figure 4: Spatial autocorrelation with Moran's I for overall (top) and health-related (bottom) deprivation by region, over time



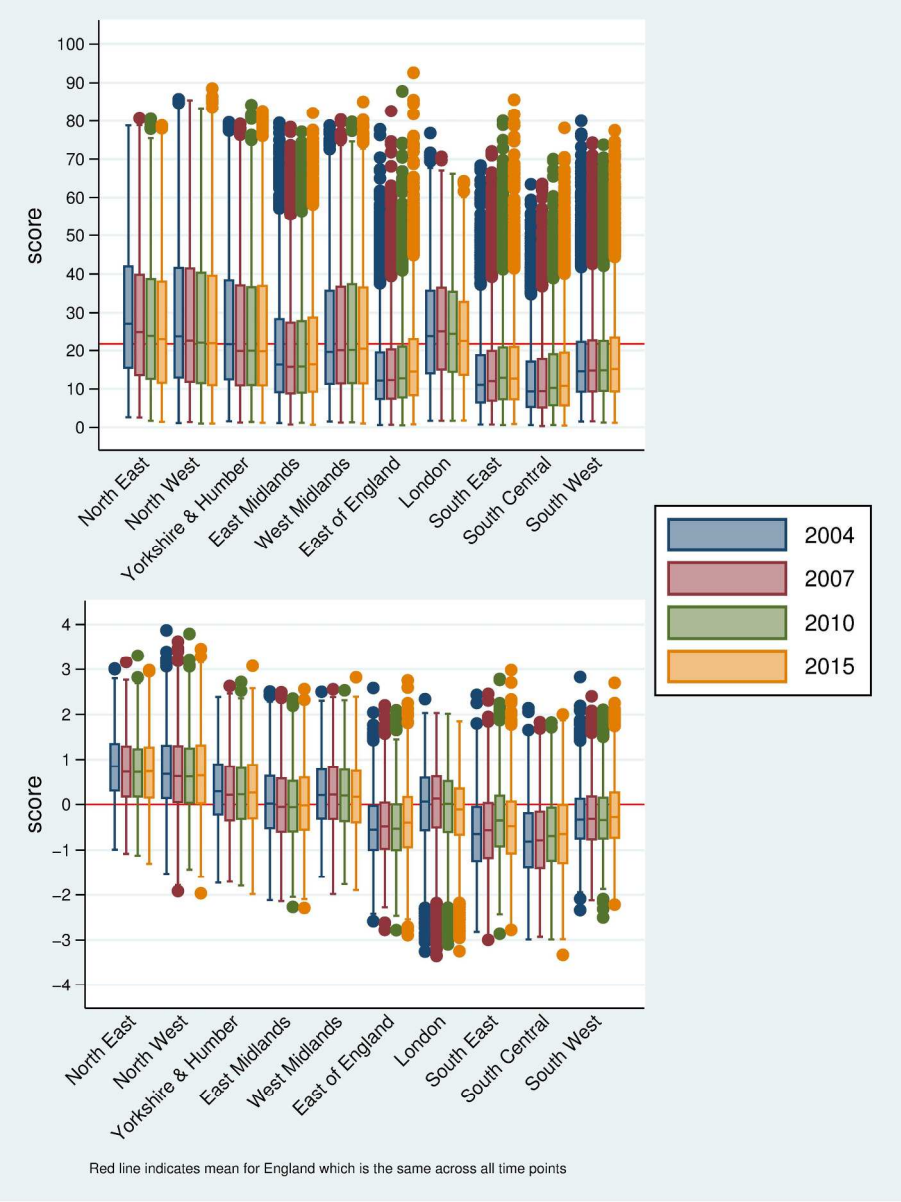


Figure 2: Overall (top) and health-related (bottom) deprivation for English regions, over time

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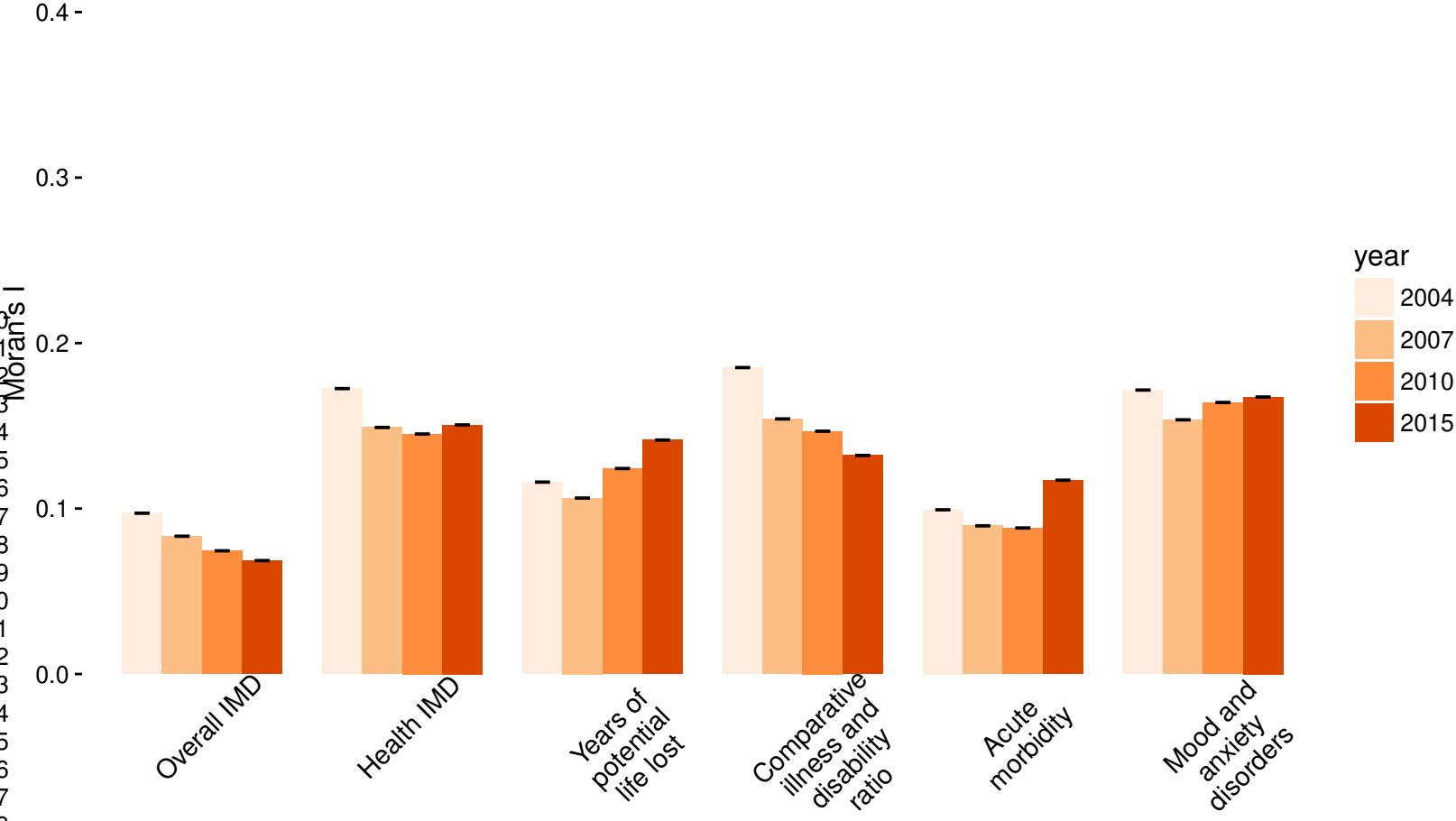
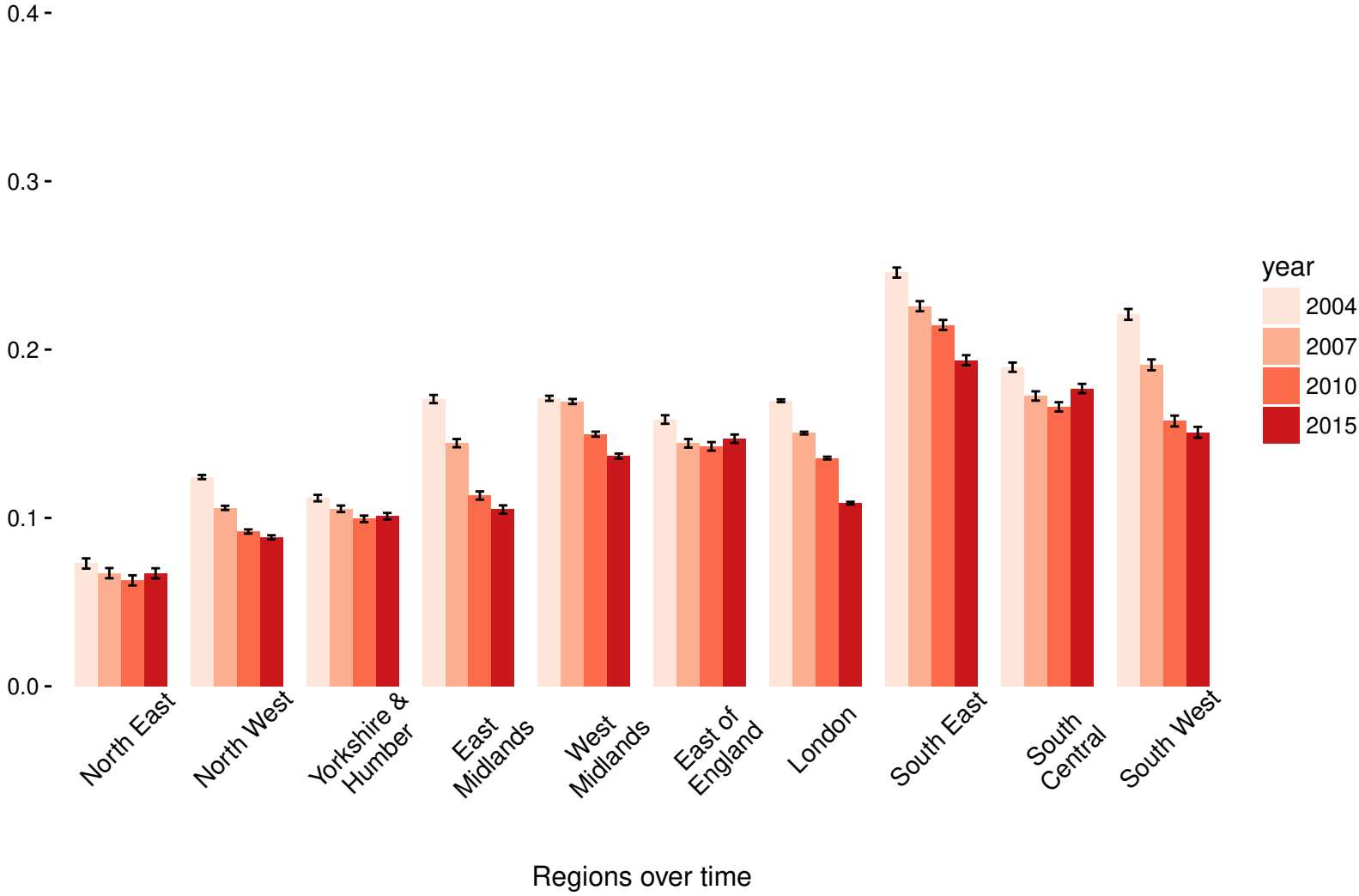


Deprivation domains and subdomains over time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2007
2010
2015
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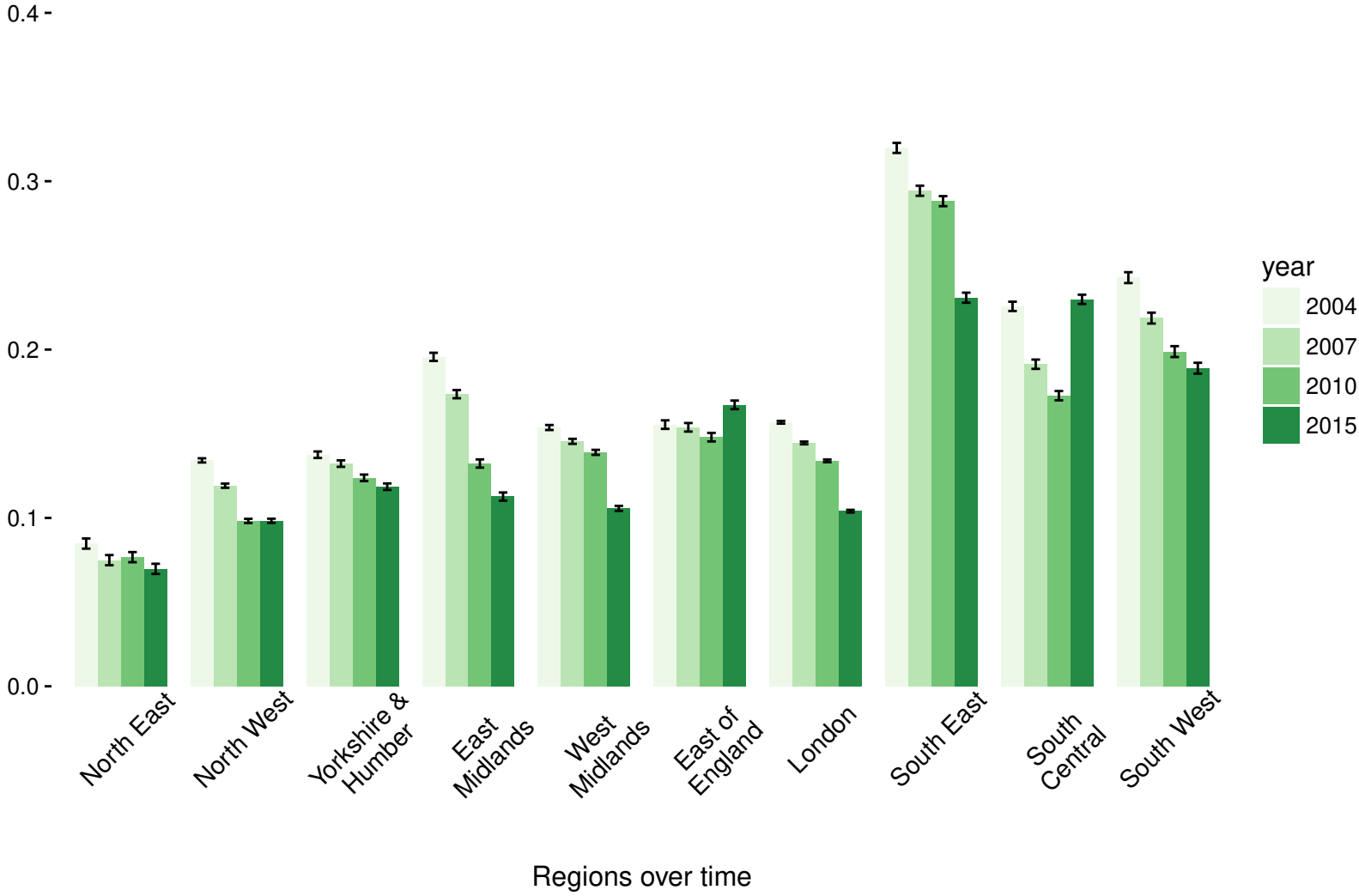
North West
Yorkshire & Humber
East Midlands
West Midlands
East of England
London
South East
South Central
South West
Regions over time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Moran's I
year
2004
2007
2010
2015
North East
North West
Yorkshire & Humber
East Midlands
West Midlands
East of England
London
South East
South Central
South West
Regions over time

Online Appendix 2 for "Geographical epidemiology of health and overall deprivation in England, its changes and persistence from 2004 to 2015: a longitudinal spatial study"

Figure A1: Health-related deprivation for England, 2015

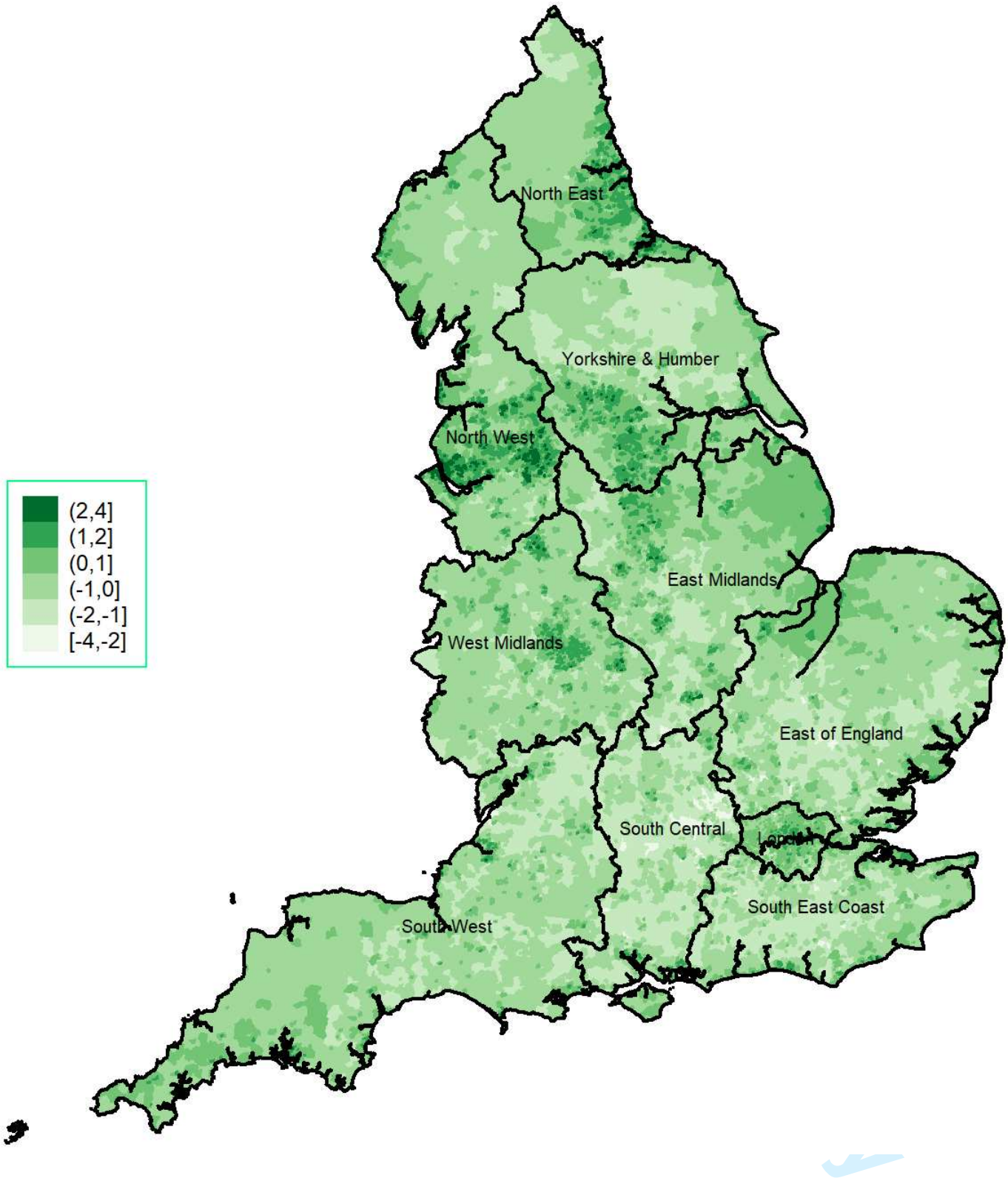

Figure A2: Overall (top) and health-related (bottom) deprivation for Greater London, over time

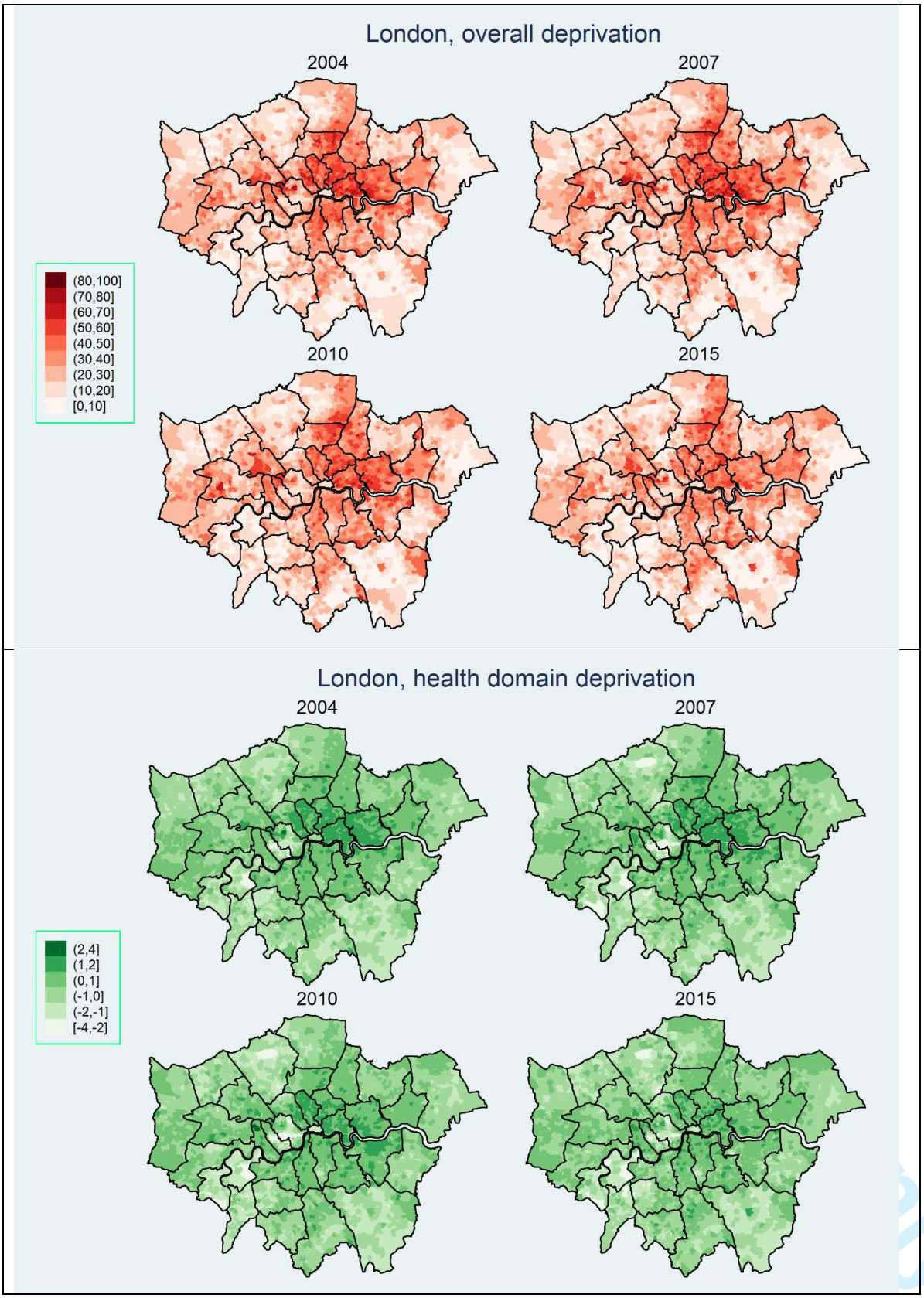

Figure A3: Health-related deprivation subdomains for English regions, over time (1 of 2)

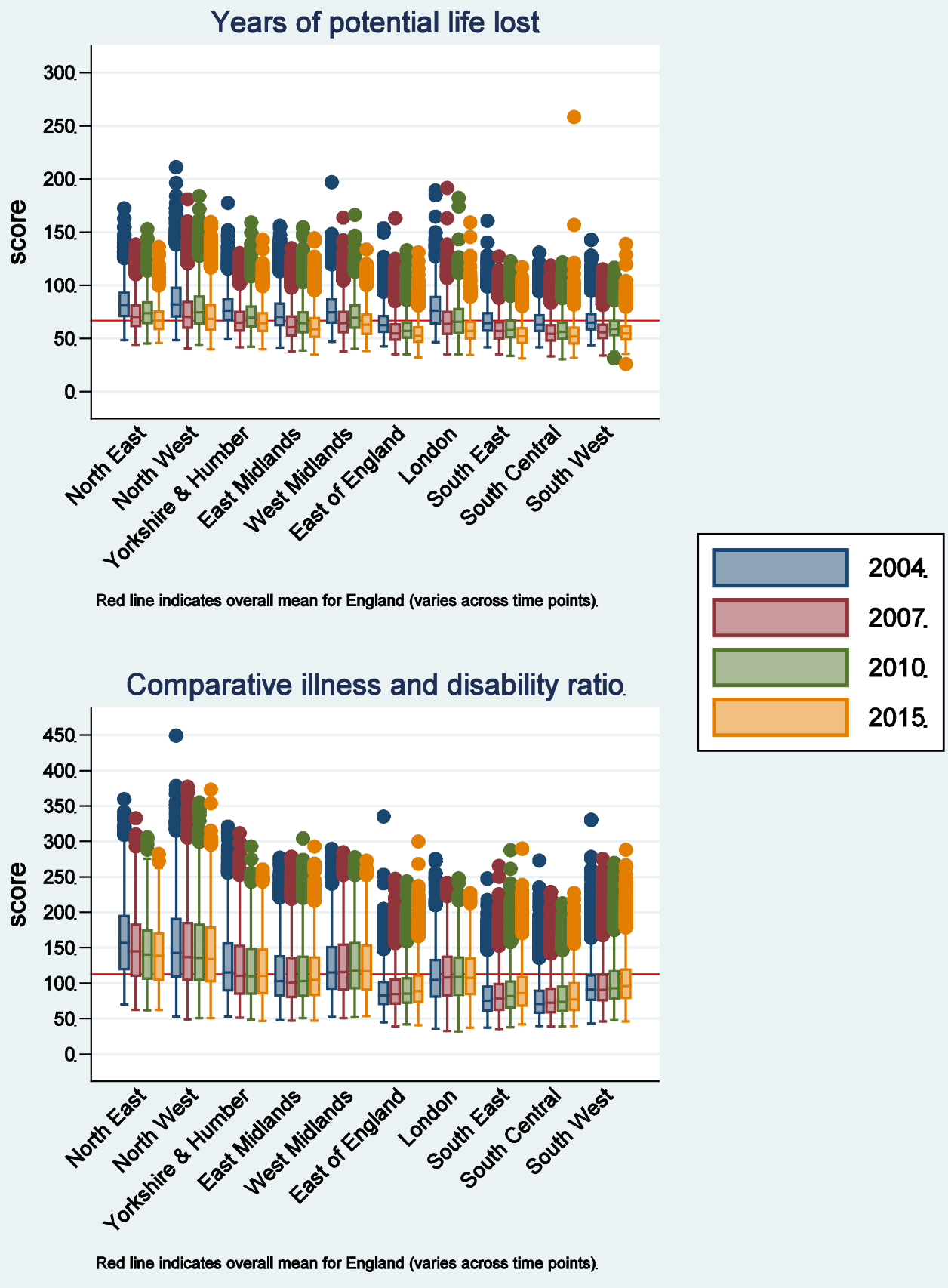

Figure A4: Health-related deprivation subdomains for English regions, over time (2 of 2)

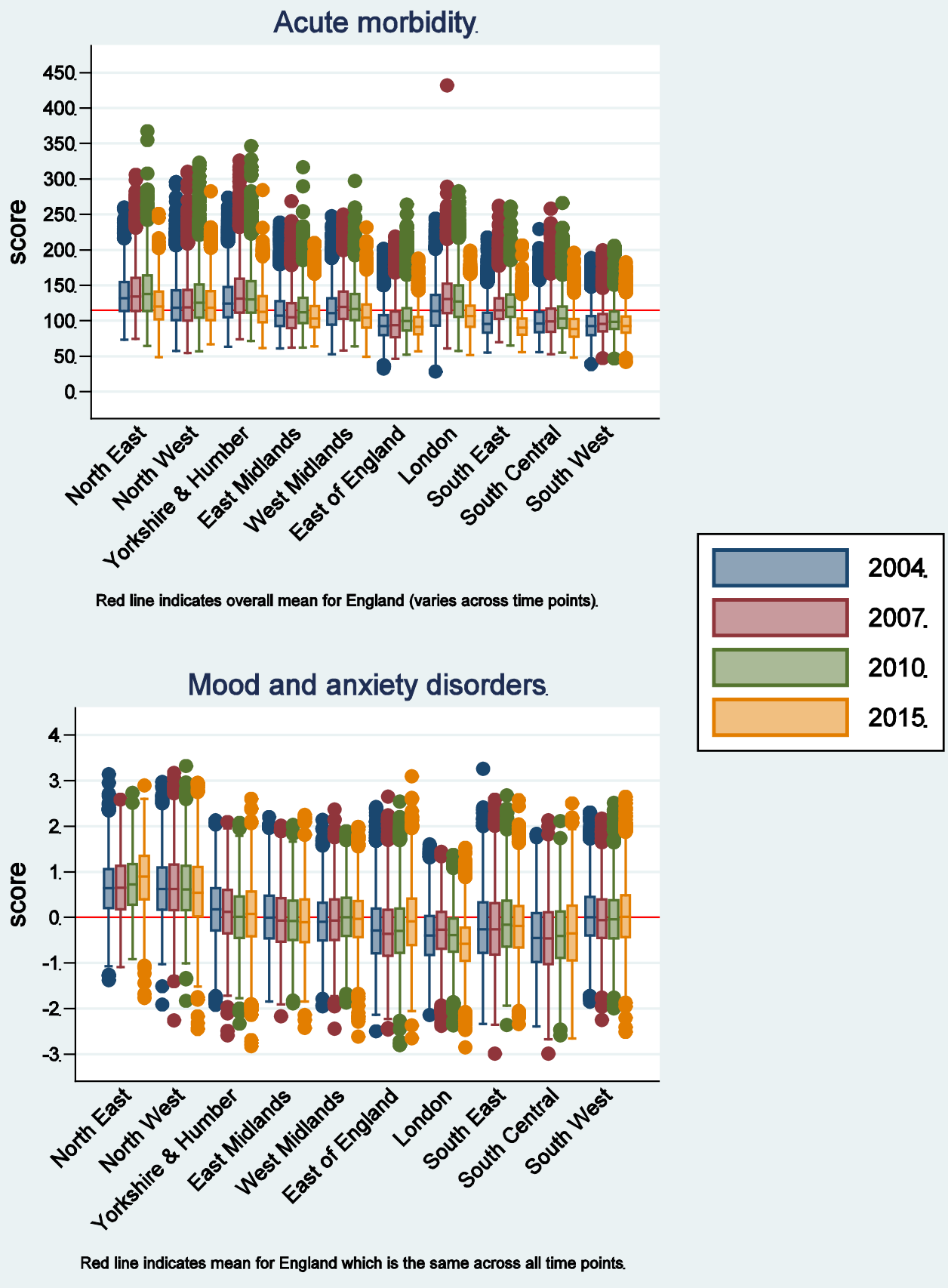

Figure A5: Spatial autocorrelation with Moran's I for years of potential life lost (top) and the comparative illness and disability ratio (bottom), by region and over time

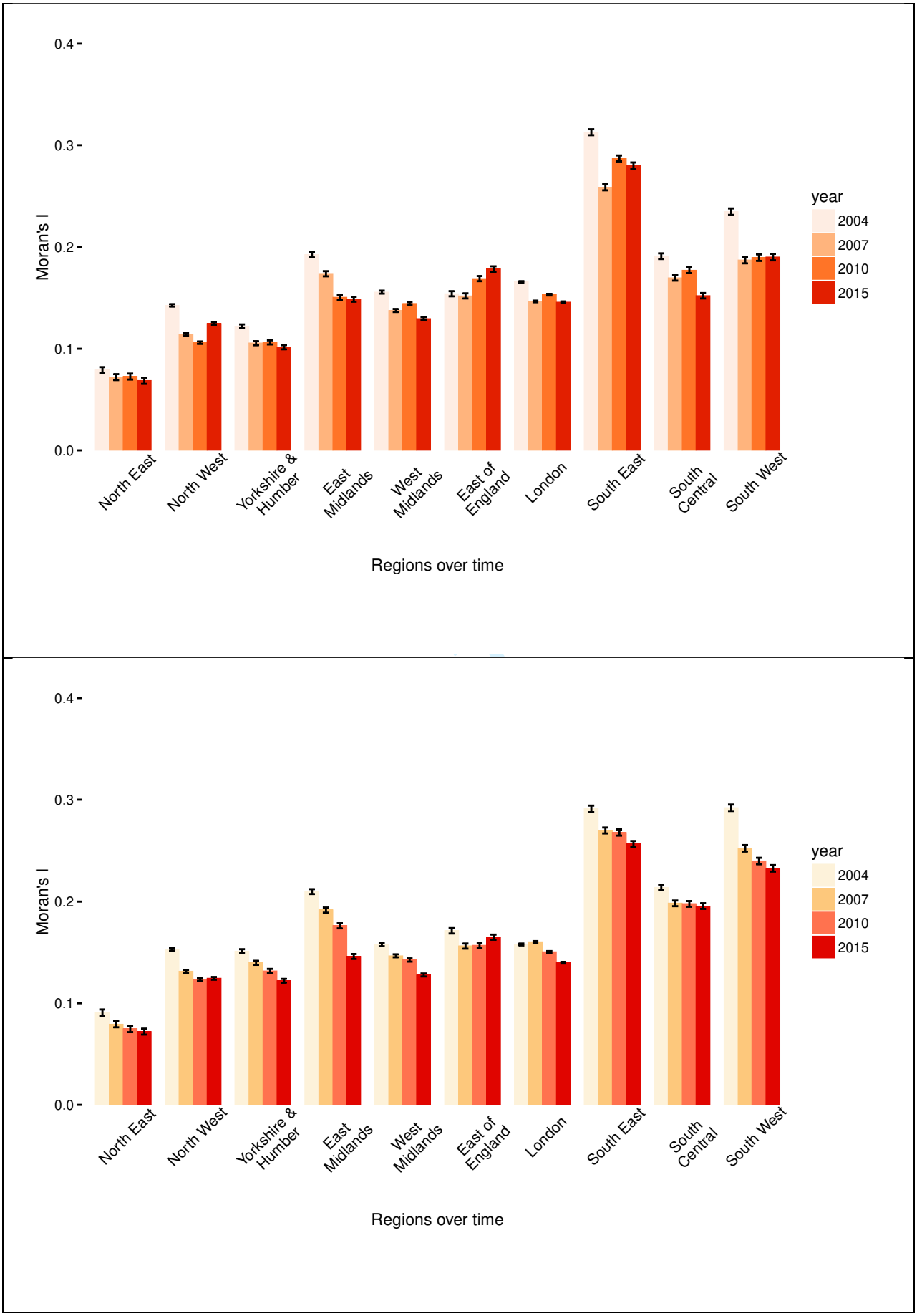

Figure A6: Spatial autocorrelation with Moran's I for acute morbidity (top) and mood and anxiety disorders (bottom), by region and over time