Birmingham City Health and Economic Impact Assessment study

**For:** UK:100

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*Draft for comment*



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**Table of Contents**

[1.0 Executive Summary and Key results 3](#_Toc12271931)

[2.0 Introduction 6](#_Toc12271932)

[3.0 Method 6](#_Toc12271933)

[3.1 Air Quality data 6](#_Toc12271934)

[3.2 Health assessment 6](#_Toc12271935)

[3.3 Economic assessment 7](#_Toc12271936)

[4.0 Air Quality modelling 9](#_Toc12271937)

[5.0 Health Estimates of the mortality impact of air pollution and its economic valuation 12](#_Toc12271938)

[5.1 Mortality impact 12](#_Toc12271939)

[5.2 Life-expectancy from birth in 2011 17](#_Toc12271940)

[6.0 Health Estimates of the mortality burden of air pollution 19](#_Toc12271941)

[6.1 Burden background 19](#_Toc12271942)

[6.2 Combined estimate for PM2.5 and NO2 using multi pollutant model results 19](#_Toc12271943)

[6.3 Single pollutant model estimates 21](#_Toc12271944)

[6.4 Summary of burden results 22](#_Toc12271945)

[7.0 Discussion 23](#_Toc12271946)

[8.0 Appendix 26](#_Toc12271947)

[8.1 Additional tables- method 26](#_Toc12271948)

[8.2 Additional tables - impact 28](#_Toc12271949)

[8.3 Additional tables – burden 37](#_Toc12271950)

[8.4 Additional Health and economic assessment methods 41](#_Toc12271951)

[9.0 References 45](#_Toc12271952)

# Executive Summary and Key results

UK100 commissioned Kings College London (King’s) to produce a health and economic impact assessment associated with current[[1]](#footnote-2) and future pollution levels in Birmingham City. In this study, King’s combined the relationships between Defra’s Air Quality modelling concentrations and health outcomes for each parliamentary constituency in Birmingham. King’s has previously carried out similar mortality burden calculations for London and Greater Manchester but to our knowledge this is the first time that the new burden recommendations (COMEAP, 2018a)[[2]](#footnote-3) that include a combined PM2.5 and NO2 approach have been applied in practice in a large city area[[3]](#footnote-4). The calculations relate to deaths or loss of life expectancy from all causes rather than separately for specific causes or for cases of specific illnesses.

Mortality impact (long –term exposure)

The population in Birmingham would gain around 440,000 life years over a lifetime to 2134[[4]](#footnote-5) if air pollution concentrations improved as projected from 2011 to 2030[[5]](#footnote-6), compared with remaining at 2011 concentrations. The average life expectancy of a child born in Birmingham in 2011 would improve by around 2.5 to 4 months for the same comparison.

Taking into account the UK Government’s projected future changes in air pollution concentrations from 2011 to 2030, the population would still be losing between 0.3 to 0.8 million life years after these air pollution changes in Birmingham (a life year is one person living for one year). Put another way, children born in 2011 are still estimated to die 2-7 months early[[6]](#footnote-7) on average, if exposed over their lifetimes to the projected future air pollution concentrations in Birmingham. Males are more affected than females. This is due to the fact that men have higher death rates and die earlier than women.

The report provides figures for both PM2.5 and NO2 separately but then uses one or the other as the best indicator pollutant rather than adding results together to avoid large overestimation (details in the report below). The ‘best indicator’ approach may result in a small underestimate.

Economic costs

Economists assign monetary values to the health benefits in order to compare the benefits with the real costs of implementing a package of policies. The largest proportion of the monetary value comes from a survey asking 170 members of the public how much they would be willing to pay to reduce their risk of experiencing a loss of one month of life (in good health) due to air pollution. Added up across time, people and the total health effects, this is then used to represent the amount society thinks should be spent to reduce these risks. NHS costs and loss of productivity are not included.

The monetized benefits over a lifetime[[7]](#footnote-8) of improvements to future anthropogenic PM2.5 and NO2 concentrations, compared with 2011 concentrations remaining unchanged, has been estimated to be up to £240 million on average/year (at 2014 prices).

Despite the projected future improvements in air pollution concentrations from 2011 to 2030, the economic health impact costs in Birmingham over a lifetime are still between £190 - £470 million on average per year.

These are what is called ‘annualised’ figures - a term for an average per year when the result is not the same every year. They are not actual costs but a measure of the amount of money society believes it would be reasonable to spend on policies to reduce air pollution (for avoiding adverse health effects of the remaining pollution) or was reasonable to have spent on policies that have already reduced air pollution.

Mortality burden (long –term exposure)

Mortality burden calculations are a simplified calculation at one point in time. They are not suitable for analyzing several years in succession because they do not have a mechanism for allowing the number of deaths the year before to influence the age and population size the following year (lifetables do this, see impact calculations above). Nonetheless, they provide a useful feel for the size of the air pollution problem.

In 2011 in Birmingham the equivalent of[[8]](#footnote-9) between 570 to 709 deaths are estimated to be attributable to air pollution (anthropogenic PM2.5 and NO2). These deaths occur mostly at older ages, as is typical for deaths in the general population.

The results varied by constituency with highest in Erdington and lowest in Hall Green. The ranking by constituency did not fully follow the ranking in pollutant concentrations. This is because the results are also influenced by variations in death rates by constituency, which in turn are driven in part by the proportion of elderly in the population and the level of deprivation.

The results for both life years lost after pollution improvements and attributable deaths from 2011 are smaller than the results for Greater Manchester from a 2018 report, primarily due to the smaller population in the smaller area of Birmingham city (around 1 million compared with 2.7 million for Greater Manchester). But they are not as much smaller as the population would predict due to higher pollution concentrations in Birmingham City. This also shows in the fact that the loss of life expectancy (which is independent of population) is greater in Birmingham than in Manchester. Gains in life years are smaller in Birmingham City than in Greater Manchester, again mainly due to population and the similar proportional reduction in pollution concentrations over time.

Limitations

The main report presents a wider range of uncertainty around the results for the mortality burden, mortality impacts and economic costs than the figures shown here.

The study was focused on air pollution changes within the Birmingham city area. Reductions in emissions will also have benefits for air pollution concentrations in the wider region (the West Midlands and beyond). For example, reductions in NOx emissions will reduce nitrate concentrations and thus PM2.5 concentrations in the wider region. The health benefits of this are not reflected here, although they are likely to be smaller than those in the city itself.

There will be further impacts from ozone concentrations. The long-term ozone exposure (representative of summer smog ozone concentrations metric) is projected to decrease over time compared with 2011 but less than other pollutants such as NO2 and PM2.5.

This study addressed the effect of air pollution on deaths and loss of life-expectancy. This included all causes of death grouped together so covers, for example, respiratory, lung cancer and cardiovascular deaths for which there is good evidence for an effect of air pollution. It does not, however, cover the effect of air pollution on health where this does not result in death. So well established effects (such as respiratory and cardiovascular hospital admissions, effects on asthma, low birth weight etc) and other outcomes more recently potentially linked with air pollution (such as dementia) are not included. Their inclusion would increase the benefit of policies to further reduce air pollution.

# Introduction

UK100 has asked King’s College London (King’s) to help produce an Health Impact assessment (HIA) and economic assessment of Birmingham City (Birmingham) formed of ten parliamentary constituencies (constituencies) (Edgbaston, Erdington, Hall Green, Hodge Hill, Ladywood, Northfield, Perry Barr, Selly Oak, Yardley and Sutton Coldfield). To do this, King’s first downloaded the air quality data in Birmingham, which then, combined with relationships between concentrations and health outcomes, were used to calculate the impacts on health from the air pollution emitted in each constituency.

# Method

## Air Quality data

From 1kmx1km grid data to ward concentration

To create maps of annual average air quality (PM2.5 and NO2) for Birmingham, King’s downloaded air quality data from the DEFRA Local Air Quality Management webpages (<https://uk-air.defra.gov.uk/data/laqm-background-maps>). Specifically, we downloaded PM2.5 and NO2 data for the regions of 'Midlands' for the year 2011, and for the years 2015 to 2030. The 2011 data were downloaded from the 2011 model predictions, and the 2015 to 2030 data were downloaded from the 2015 model predictions. Using these data of regular 1km by 1km pollutant points we then created a raster layer (for every year and pollutant) in the R statistical analysis package. Mean spatially-weighted concentrations for each Ward were then calculated, using the Ward boundaries from the Governments Open Data portal (<http://geoportal.statistics.gov.uk/datasets/wards-december-2016-generalised-clipped-boundaries-in-the-uk>).

From ward to population-weighted constituency concentration

Population-weighting average concentration (PWAC): Population-weighting was done at Ward level. The ward concentrations were multiplied by the population aged 30 plus for each gender and the resulting population-concentration product summed across all wards in each constituency and then divided by the constituency population. The constituency population-weighted means were then used directly in the health impact calculations across all constituencies. (This process allows one health calculation per constituency rather than calculations in each separate ward). A map of Birmingham parliamentary constituencies can be found in Figure 1.

## Health assessment

It is now well established that adverse health effects, including mortality, are statistically associated with outdoor ambient concentrations of air pollutants. Moreover, toxicological studies of potential mechanisms of damage have added to the evidence such that many organisations (e.g. US Environmental Protection Agency; World Health Organisation, COMEAP) consider the evidence strong enough to infer a causal relationship between the adverse health effects and the air pollution concentrations.

The concentration-response functions used and the spatial scales of the input data is given in Table 10, Table 11 and Table 12 in the Appendix. The concentration-response functions are based on the latest advice from the Committee on the Medical Effects of Air Pollutants in 2018 (COMEAP, 2018a). Previously, burden calculations were based only on concentrations of PM2.5 (COMEAP, 2010). The new COMEAP report considers whether there is an additional burden or impact from nitrogen dioxide or other pollutants with which it is closely correlated.

Results are given with and without a cut-off[[9]](#footnote-10) of 5 µg m-3 for NO2 and 7 µg m-3 for PM2.5.

This study uses this epidemiological evidence to estimate the health impacts of the changes in air pollutant concentrations discussed in the air quality modelling section below.

## Economic assessment

Economists assign monetary values to the health benefits in order to compare the benefits with the real costs of implementing a package of policies. The largest proportion of the monetary value comes from a survey asking 170 members of the public how much they would be willing to pay to reduce their risk of experiencing a loss of one month of life (in good health) due to air pollution (Chilton et al, 2004). Added up across time, people and the total health effects, this is then used to represent the amount society thinks should be spent to reduce these risks. NHS costs and loss of productivity are not included.

In undertaking a valuation in monetary terms of the mortality impacts described in the previous section, we have used the methods set out in an earlier report from King’s College London on the health impacts of air pollution in London (Walton et al., 2015) and in King’s latest NIHR report (Williams et al., 2018b). This built on previous work by the study team for Defra and the Inter-departmental Group on Costs and Benefits (IGCB) within the UK government. The methods are therefore consistent with those used in government in the UK.

Life years lost were valued using values recommended in Defra guidance[[10]](#footnote-11), updated to 2014 prices. Consistent with this guidance, values for future life years lost were increased at 2% per annum, then discounted using the declining discount rate scheme in the HMT Green Book.[[11]](#footnote-12) The economic impact was then annualised back to 2014, i.e. divided by the total number of years but front-loaded to take into account that benefits accrued sooner are valued more than those accrued later.

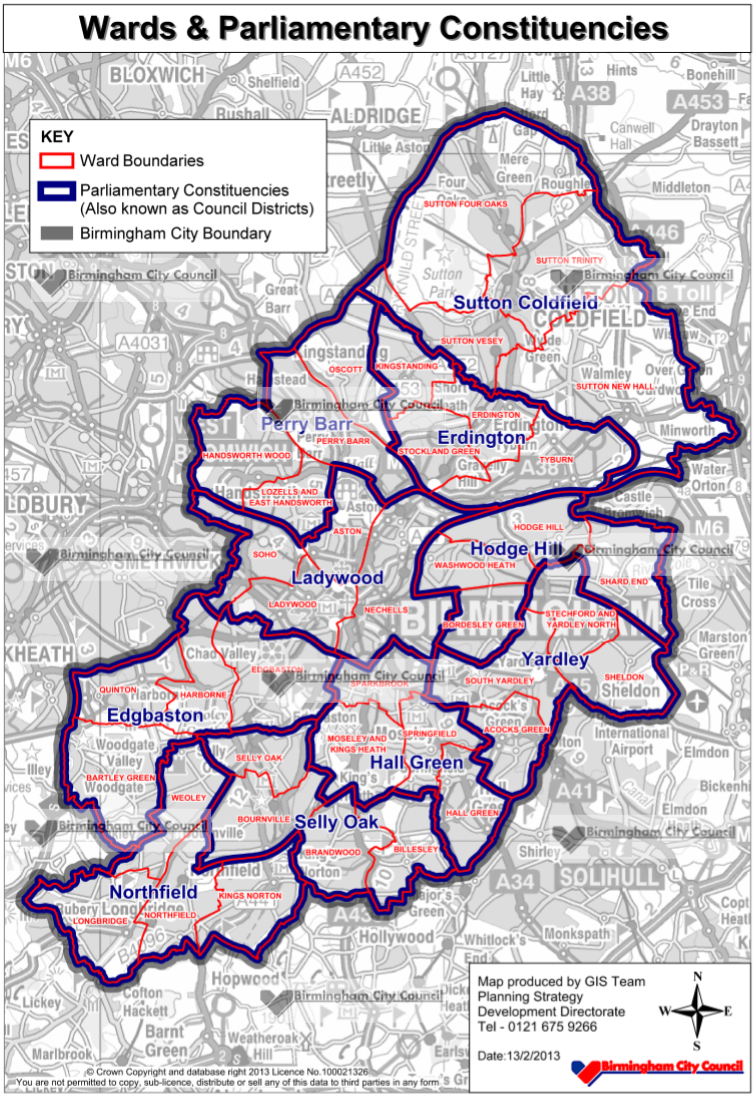


Figure 1 Map of Birmingham’s parliamentary constituencies[[12]](#footnote-13)

# Air Quality modelling

2011 and 2015 concentrations representing current reference years and any future years up to 2030 have been estimated from the 2015 baseline[[13]](#footnote-14). Birmingham air quality annual status report (2018) shows that Birmingham has been in breach of both the national air quality objective for NO2 and the World Health Organization guideline for PM2.5 (<https://www.birmingham.gov.uk/downloads/file/11938/air_quality_annual_status_report_2018_containing_data_for_2017>). The reader should refer to the Background Maps User guide (<https://laqm.defra.gov.uk/review-and-assessment/tools/background-maps.html#about>) for information on an estimated breakdown of the relative source of pollution and on how pollutant concentrations change over time.

A summary of the population-weighted average concentration (PWAC) between 2011 and 2030 in each constituency is shown in Table 1 and Table 2 for anthropogenic PM2.5 and NO2, respectively.

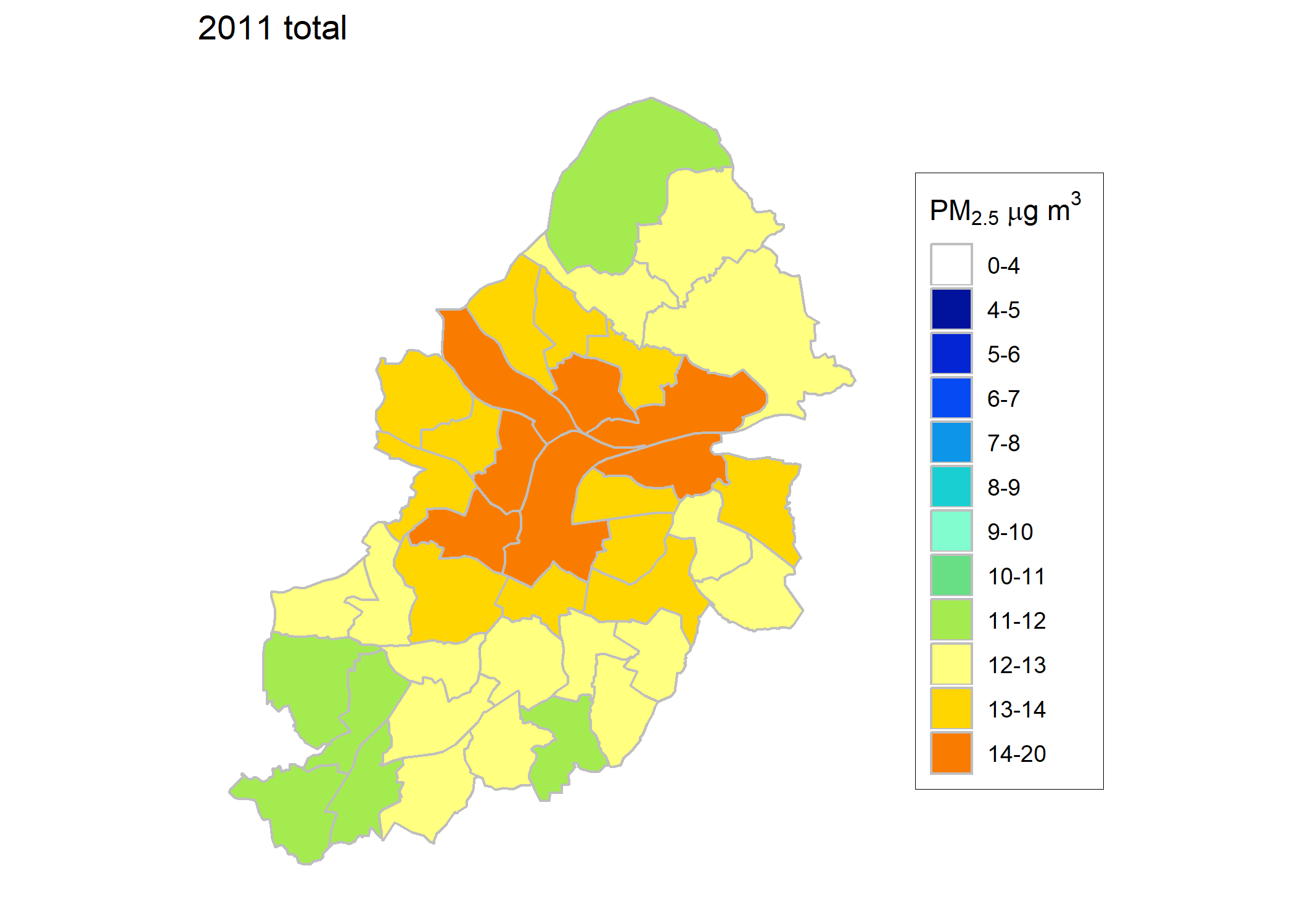
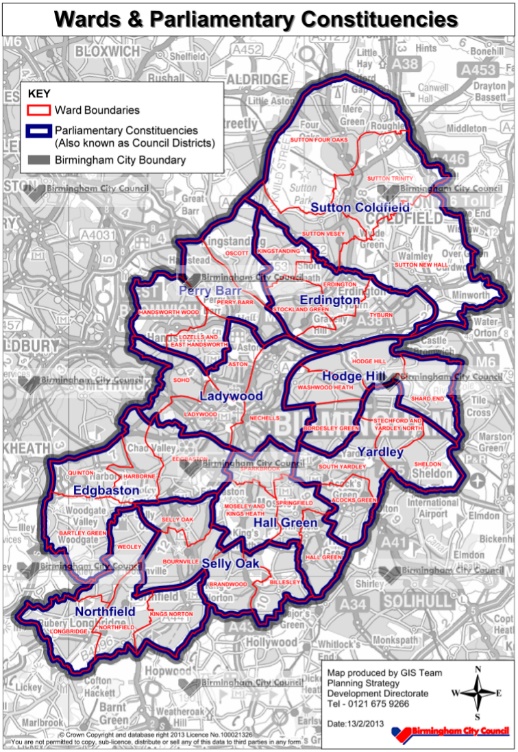
Table 1 Anthropogenic PM2.5 PWAC (in μg m-3) (annual) by constituency

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Local authority | 2011 | 2015 | 2020 | 2025 | 2030 |
| Edgbaston | 12.21 | 9.35 | 8.79 | 8.61 | 8.56 |
| Erdington | 13.58 | 10.38 | 9.75 | 9.55 | 9.52 |
| Hall Green | 12.57 | 9.61 | 9.02 | 8.83 | 8.79 |
| Hodge Hill | 13.41 | 10.11 | 9.49 | 9.31 | 9.27 |
| Ladywood | 14.24 | 11.02 | 10.29 | 10.10 | 10.08 |
| Northfield | 11.60 | 8.96 | 8.43 | 8.25 | 8.21 |
| Perry Barr | 13.58 | 10.52 | 9.88 | 9.69 | 9.67 |
| Selly Oak | 12.00 | 9.15 | 8.60 | 8.42 | 8.38 |
| Yardley | 12.91 | 9.73 | 9.13 | 8.95 | 8.91 |
| Sutton Coldfield | 12.08 | 9.24 | 8.70 | 8.52 | 8.48 |

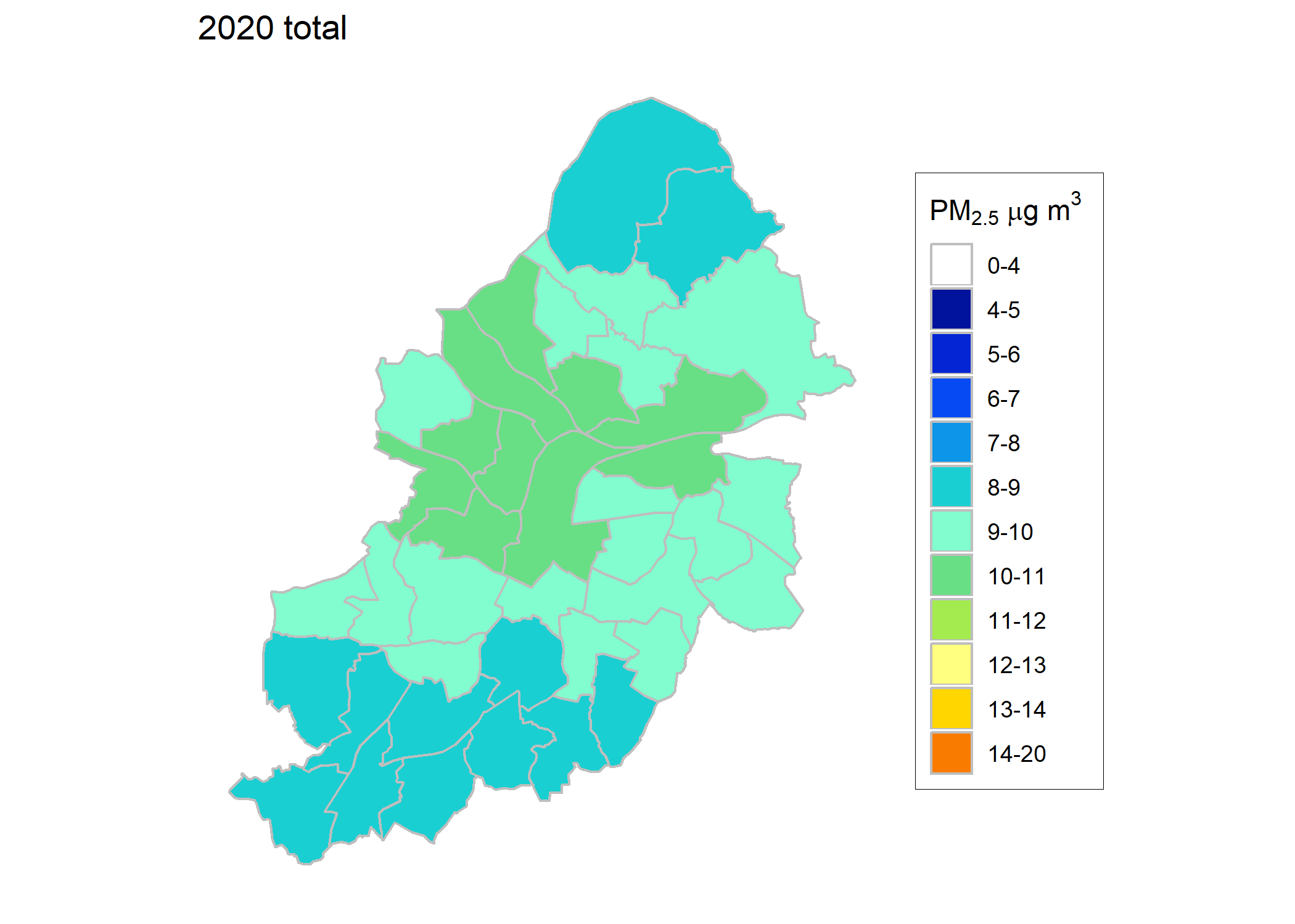
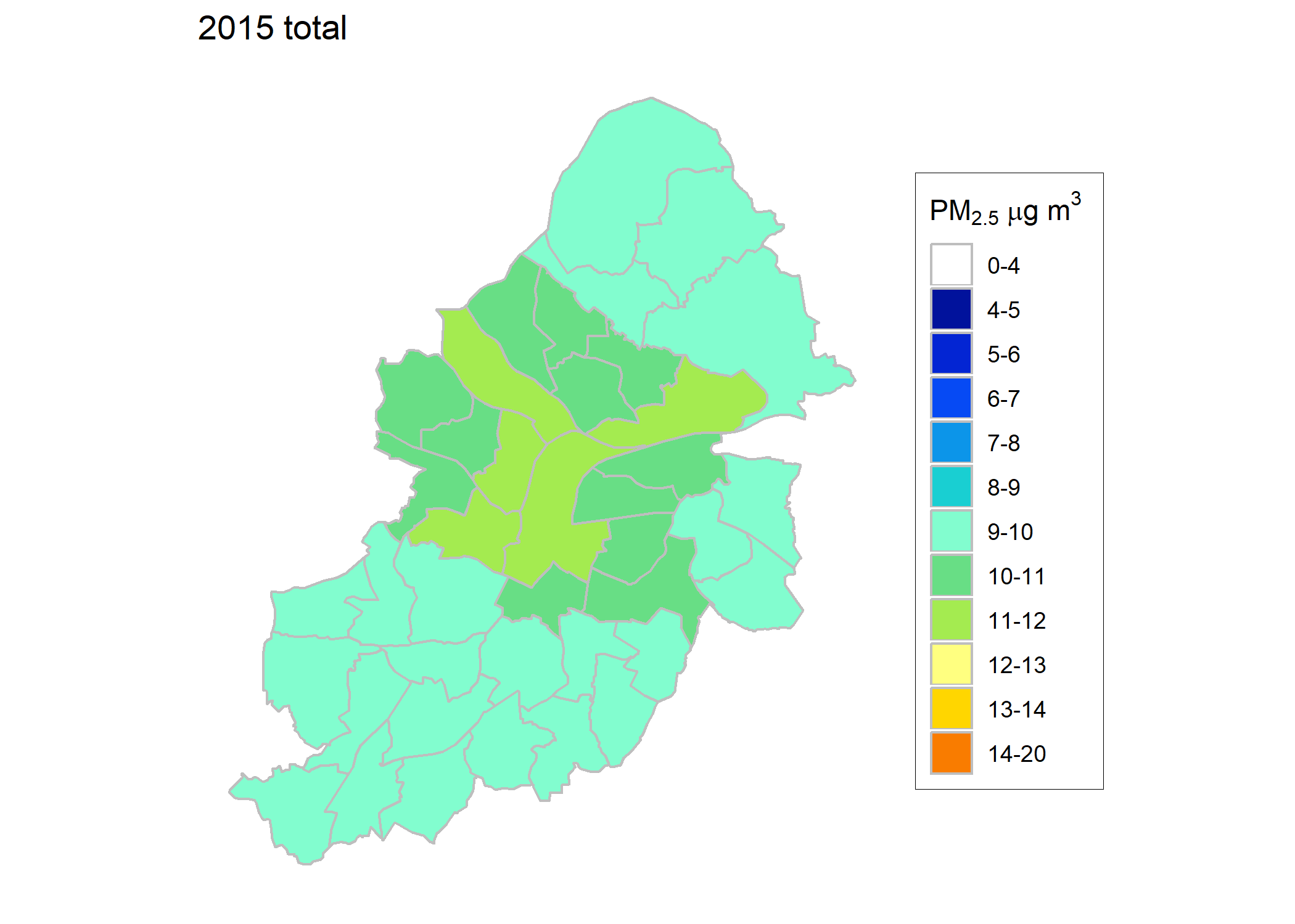
Table 2 NO2 PWAC (in μg m-3) (annual) by constituency

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Local authority | 2011 | 2015 | 2020 | 2025 | 2030 |
| Edgbaston | 23.34 | 18.69 | 15.46 | 12.66 | 11.14 |
| Erdington | 29.66 | 23.89 | 19.67 | 16.22 | 14.35 |
| Hall Green | 24.87 | 20.88 | 17.33 | 14.49 | 12.92 |
| Hodge Hill | 28.63 | 23.99 | 20.04 | 16.98 | 15.26 |
| Ladywood | 32.54 | 28.03 | 23.29 | 19.60 | 17.54 |
| Northfield | 20.89 | 16.38 | 13.59 | 11.24 | 9.95 |
| Perry Barr | 29.55 | 23.45 | 19.11 | 15.75 | 13.95 |
| Selly Oak | 22.62 | 18.19 | 15.16 | 12.69 | 11.35 |
| Yardley | 26.42 | 22.00 | 18.46 | 15.76 | 14.21 |
| Sutton Coldfield | 22.63 | 17.82 | 14.72 | 12.14 | 10.71 |

Maps of PM2.5 and NO2 annual mean concentration by wards are shown in Figure 2 and Figure 3, respectively.



City Centre



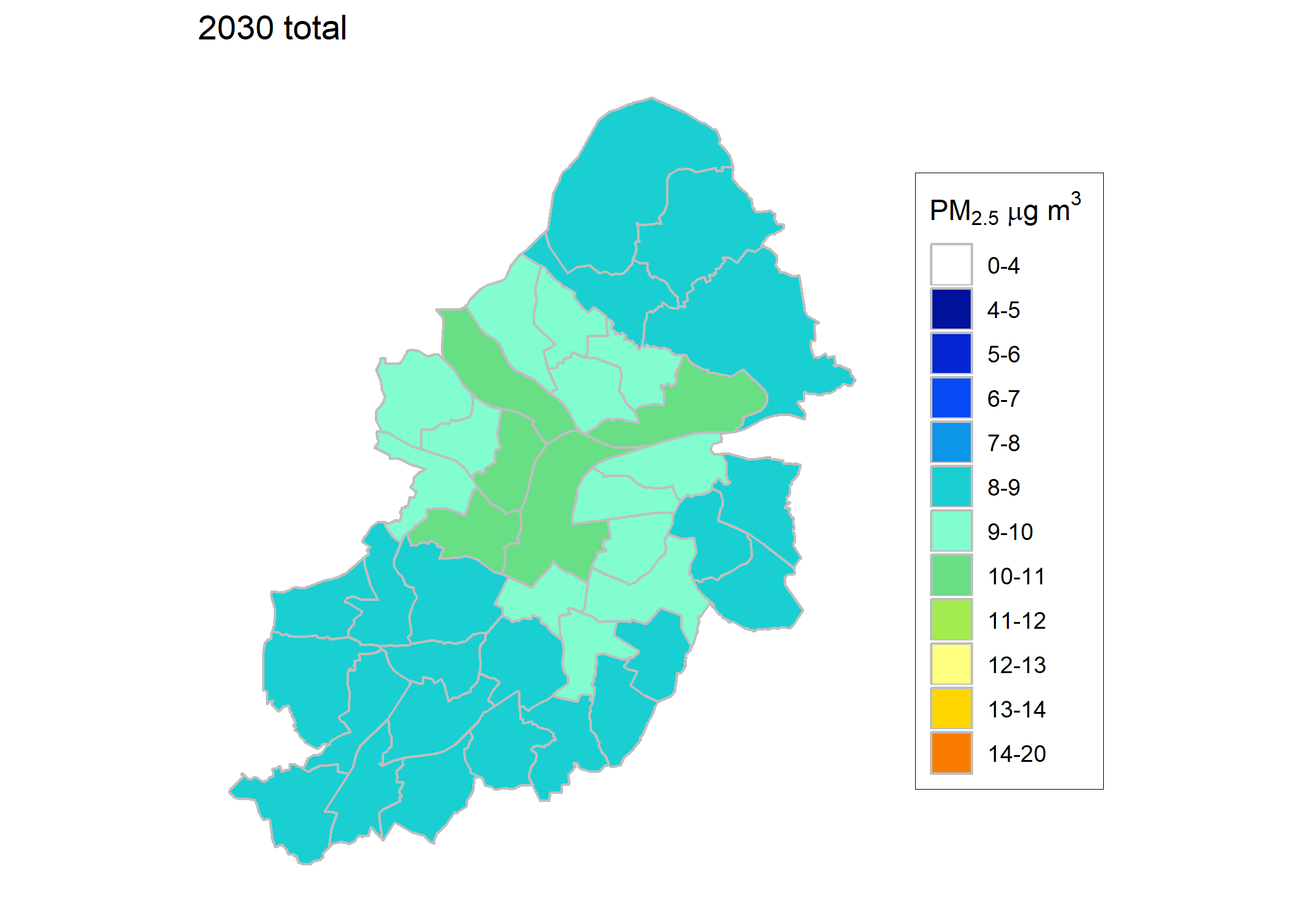
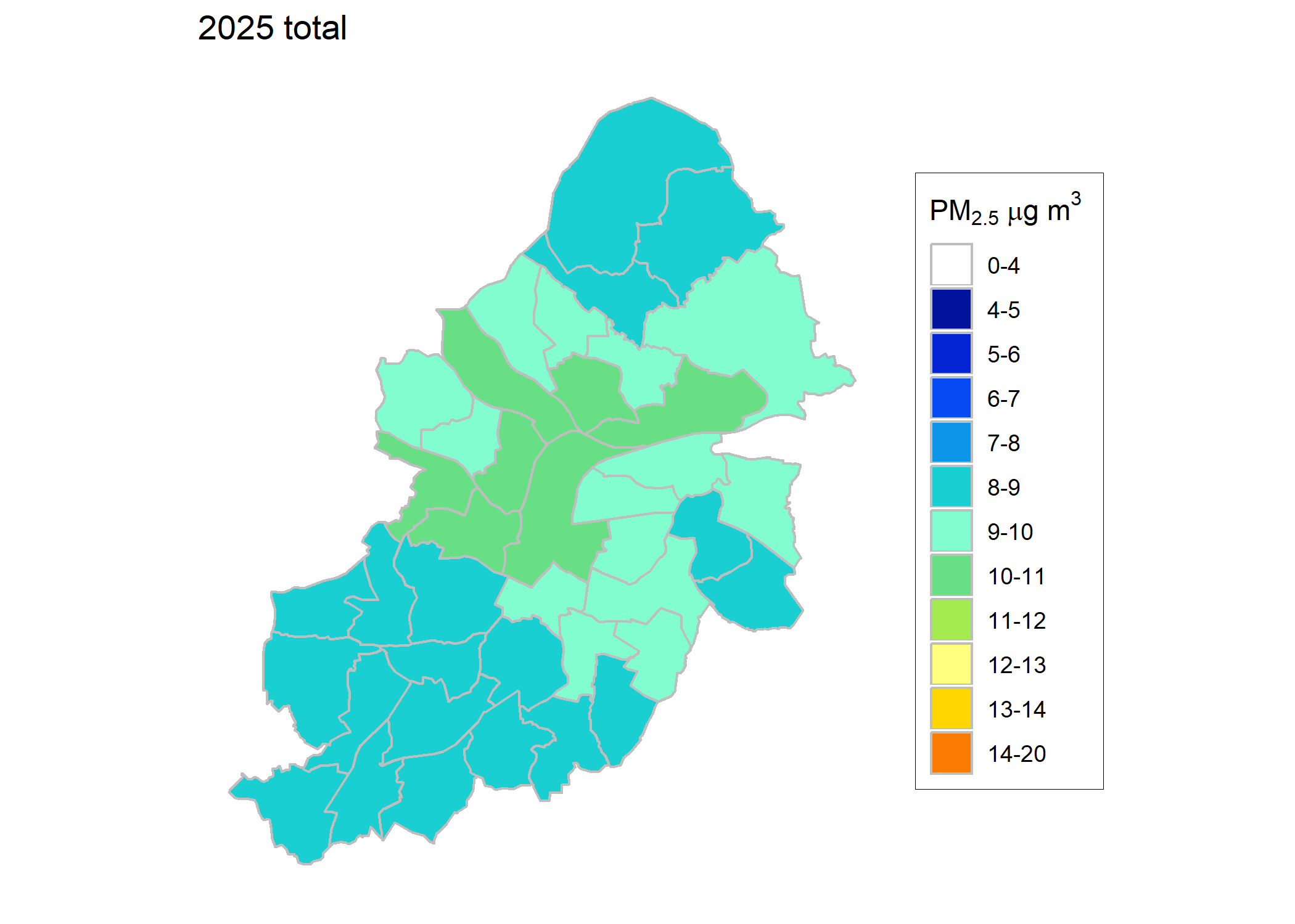
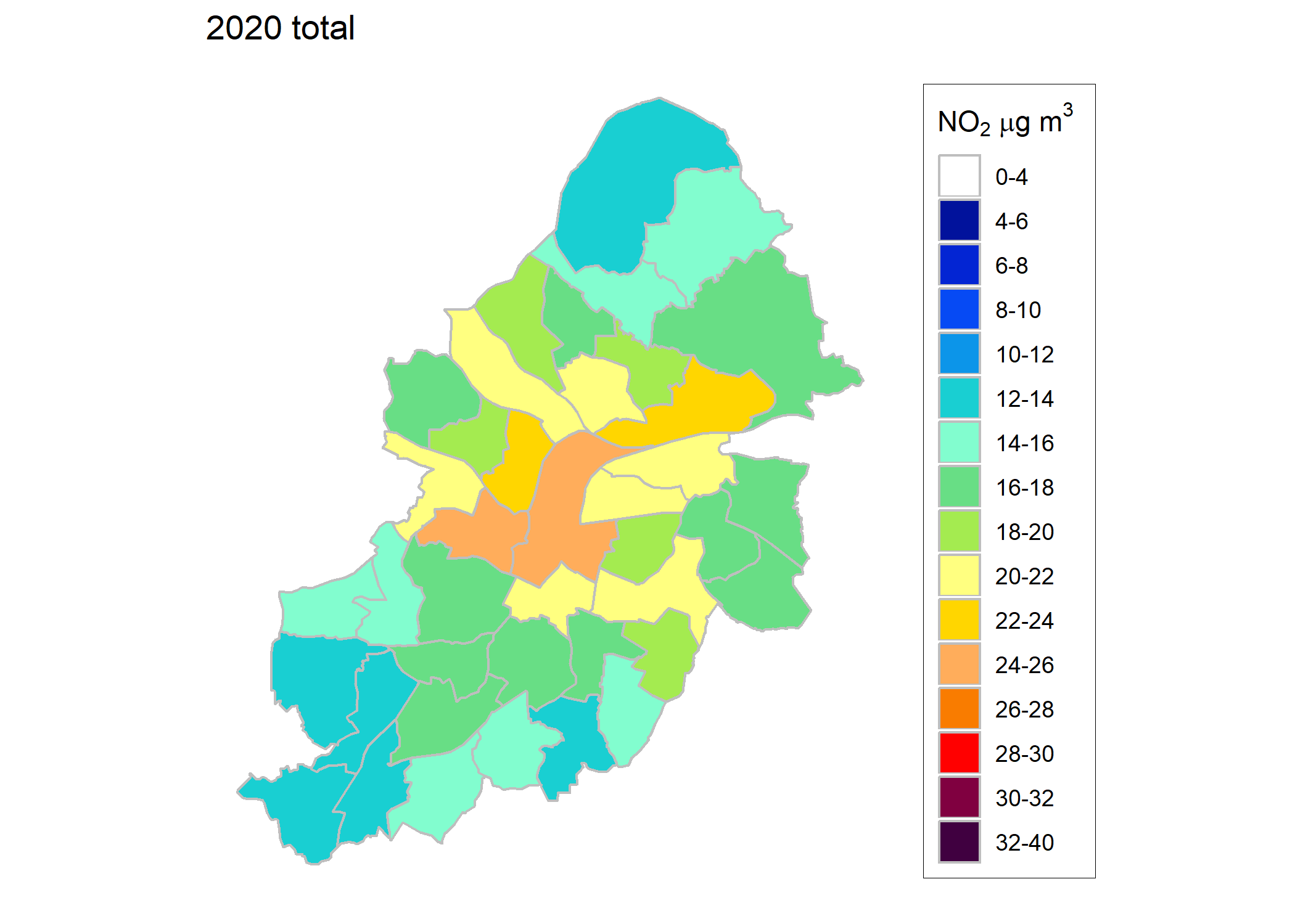
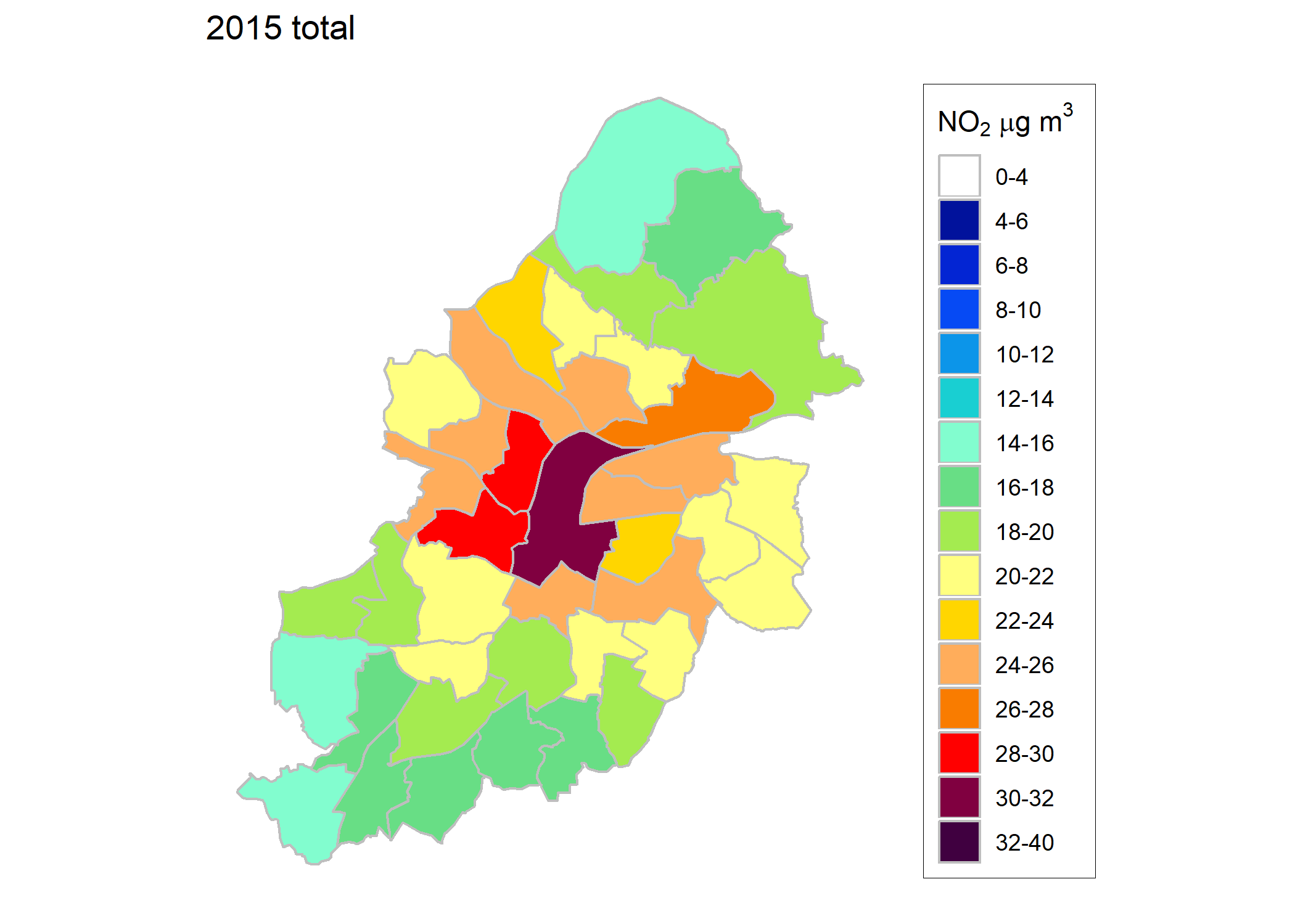
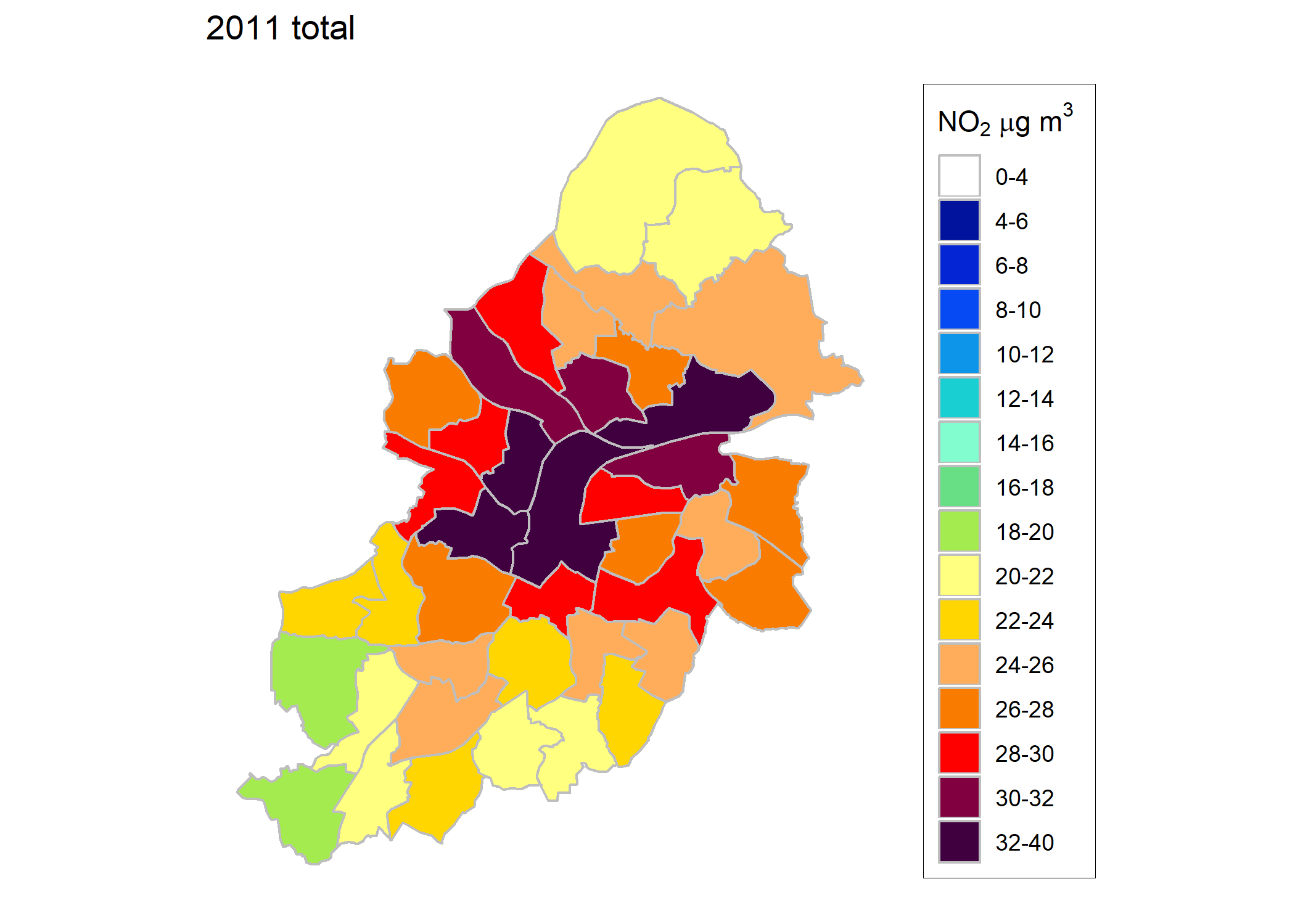
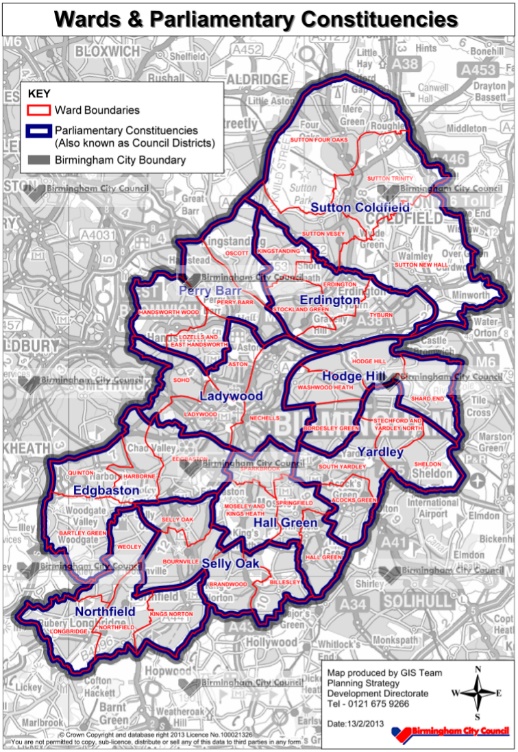


Figure 2 Annual mean PM2.5 concentrations (in μg m-3) by wards between 2011 and 2030



City Centre

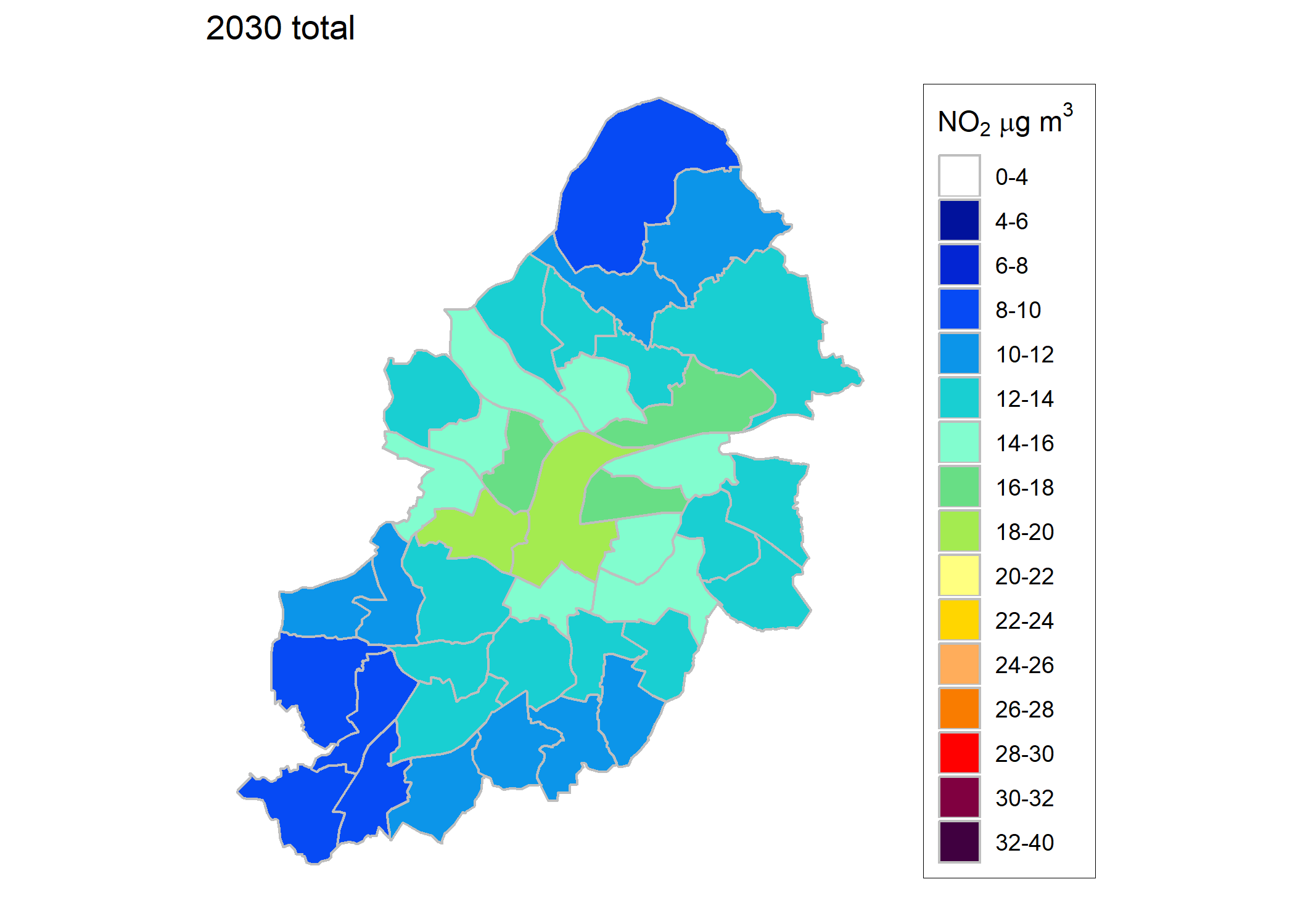
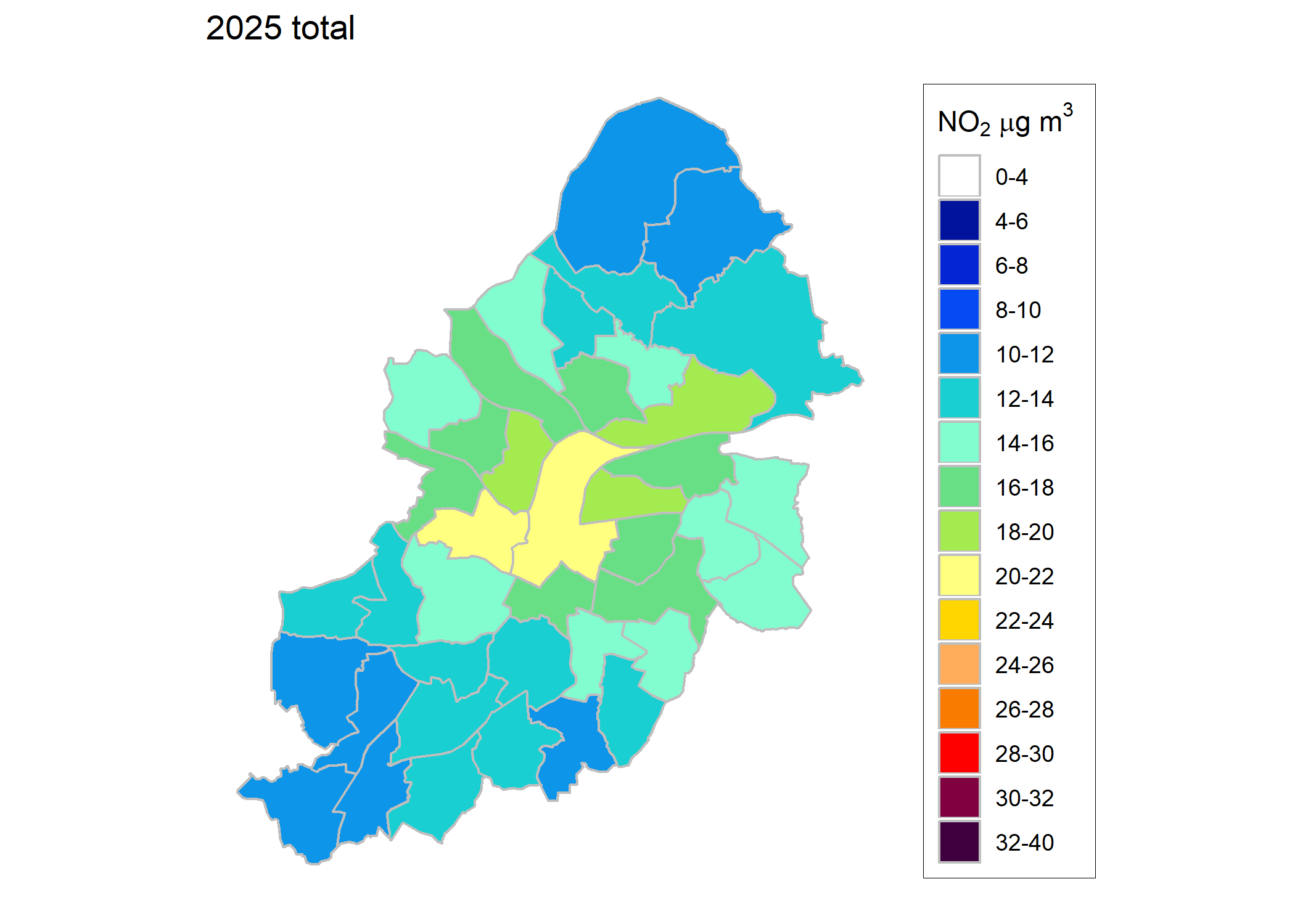


Figure 3 Annual mean NO2 concentrations (in μg m-3) by wards between 2011 and 2030

# Health Estimates of the mortality impact of air pollution and its economic valuation

## Mortality impact

Impacts in the next section are all expressed in terms of life years – the most appropriate metric for the health impact of air pollution concentration changes over time. This used a full life-table approach rather than the short-cut method used for burden and the data for these calculations had already been incorporated for previous work (Williams et al., 2018a).

Calculations are first given for PM2.5 and NO2 separately. Because air pollutants are correlated with each other, the air pollutant concentrations in the health studies represent both the pollutants themselves but also other air pollutants closely correlated with them. Health impacts from changes in NO2 and PM2.5 represent the health impacts of changes in the air pollution mixture in slightly different ways that overlap i.e. they should not be added. This is discussed further at the end of this section.

The results from the life table calculations assuming that the concentration does not reduce from 2011 levels and assuming the predicted concentration between 2011 and 2030 (concentrations were modelled at 2011, 2015, 2020, 2025 and 2030 but also interpolated for the intervening years) are shown in Table 3, for anthropogenic PM2.5 and NO2. Results for each constituency can be found in the Appendix in Table 13 and Table 17 (life table calculations for anthropogenic PM2.5 with and without a cut-off), in Table 14 and Table 18 (life table calculations for NO2 with and without a cut-off) and Table 15 and Table 16 (central and lower/upper CI estimates of annualised economic impact for anthropogenic PM2.5 and NO2 without a cut-off) and Table 19 (central CI estimates of annualised economic impact for anthropogenic PM2.5 and NO2 with a cut-off ).

The life years lost gives a large number because the life years (one person living for one year) is summed over the whole population in Birmingham over 124 years. For context, the total life years lived with baseline mortality rates is around 198 million, so these losses of life years involve about 0.5% of total life years lived.

If 2011 concentrations of anthropogenic PM2.5 remained unchanged for 124 years, around 0.6 – 1.2 million life years would be lost across Birmingham’s population over that period. This improves to around 0.2 – 0.8 million life years lost with the predicted concentration between 2011 and 2030 changes examined here.

Another way of representing the health impacts if air pollution concentrations remained unchanged (in 2011) compared with the projected future changes (2011 to 2030) is provided by the results for NO2. If 2011 concentrations of NO2 remained unchanged for 124 years, around 0.8 – 0.9 million life years would be lost across Birmingham’s population over that period. This improves to around 0.3 – 0.5 million life years lost with the predicted concentration between 2011 and 2030 changes examined here.

Summarising these results is not easy. The results should not be added as there is considerable overlap. On the other hand, either result is an underestimate to some extent as it is missing the impacts that are better picked up in the calculations using the other pollutant. COMEAP (2017, 2018a) suggested taking the larger of the two alternatives in the calculation of benefits. We have interpreted this as the larger of the two alternatives in the case of each calculation. Note that this means that the indicator pollutant changes in different circumstances. In the case above, for no cut-off, this is the result for PM2.5 (0.8 vs 0.5 million life years lost for NO2). However, for the cut-off, this is the result for NO2 (0.3 vs 0.2 million life years lost for PM2.5). This is one of the first times these recommendations have been applied in practice, so other interpretations e.g. keeping the same indicator pollutant with and without a cut-off, are possible. All the relevant data are in the tables to enable creation of summaries in a different form.

So, the overall summary for the projected future changes in air pollution concentrations from 2011 to 2030 would be around 0.3 to 0.8 million life years lost for the population of Birmingham over 124 years.

Table 3 Total life years lost across the Birmingham population for anthropogenic PM2.5 and NO2 and the associated annualised economic impact (central estimate)

|  |  |  |  |
| --- | --- | --- | --- |
| Pollutant | Scenario | Life years lost  Central estimate (without cut-off  with cut-off) | Annualised economic impact (in 2014 prices)  (without cut-off  with cut-off) |
| Anthropogenic PM2.5 (representing the regional air pollution mixture and some of the local mixture) | Concentration does not reduce from 2011 levels | 1,169,520  562,960 | £653,424,492  £313,958,210 |
| Predicted concentration between 2011 and 2030 | **831,708**  213,344 | **£467,766,599**  £121,993,163 |
| NO2 (representing the local mixture and the rural air pollution mixture) | Concentration does not reduce from 2011 levels | 942,827  767,457 | £525,828,421  £427,680,084 |
| Predicted concentration between 2011 and 2030 | 505,434  **328,491** | £289,339,663  **£190,370,755** |

For anthropogenic PM2.5 assuming no net migration, with projected new births, 2011-2134, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) with a relative risk (RR) of 1.06 per 10 μg m-3 of anthropogenic PM2.5 without cut-off and with 7 μg m-3 cut-off[[14]](#footnote-15), with lags from the USEPA.

For NO2 assuming no net migration, with projected new births, 2011-2134, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) with a relative risk (RR) of 1.023 per 10 μg m-3 of NO2 without cut-off and with 5 μg m-3 cut-off, with lags from the USEPA.

(Results with cut-offs do not extrapolate beyond the original data, results with no cut-off represent the possibility that there are effects below the cut-off value (it is unknown whether or not this is the case).)

Figures in bold are the larger of the alternative estimates using PM2.5 or NO2, as summarized in the headline results.

Table 3 also gives the economic impacts (economic costs). Note that these are derived from applying monetary valuation to the health impacts. The monetary values are derived from surveys of what people are willing to pay to avoid the risk of the relevant health impact. They do not represent the costs of the policies or the costs to the NHS.

If 2011 concentrations of anthropogenic PM2.5 remained unchanged for 124 years, the annualised economic cost would be around £310 – 650 million. This improves to around £120 – 470 million with the projected baseline concentration changes examined here.

If 2011 concentrations of NO2 remained unchanged for 124 years, the annualised economic cost would be around £430 – 530 million. This improves to around £190 – 290 million with the predicted concentration between 2011 and 2030 changes examined here.

The overall summary for the projected baseline would be annualised economic costs of around £190 to 470 million.

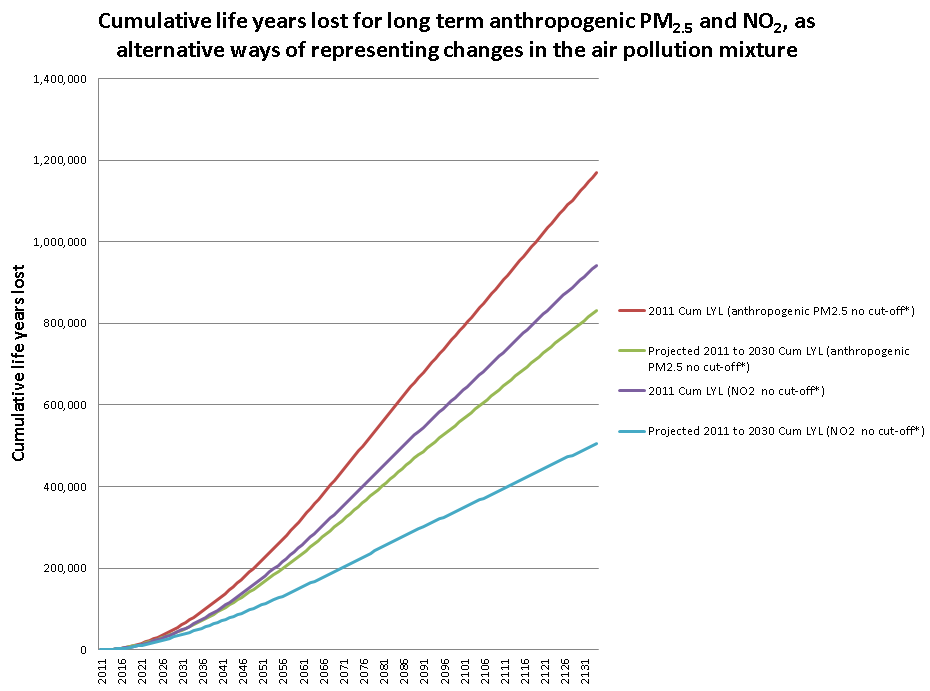


Figure 4 Cumulative life years lost for anthropogenic PM2.5 and NO2 if 2011 concentrations remained unchanged and the baseline (current policies 2011-2030) across the Birmingham population (no migration), with projected new births, compared with life years lived with baseline mortality rates (incorporating mortality improvements over time) 2011-2134. RR 1.06 per 10 μg m-3 for anthropogenic PM2.5 and RR 1.023 per 10 μg m-3 for NO2, EPA lag

\* Cut-off results not shown

Figure 4 shows that the cumulative life years lost for the predicted concentration between 2011 and 2030 accumulates more slowly than the constant 2011 concentration results for both anthropogenic PM2.5 and NO2 as a result of the reduced concentrations from 2011 to 2030. It is worth remembering that there is a delay before the full benefits of concentration reductions are achieved. This is not just due to a lag between exposure and effect, but also because the greatest gains occur when mortality rates are highest i.e. in the elderly.

Table 4 shows the differences between the predicted concentrations between 2011 and 2030 and both particulate levels and NO2 concentration constant at 2011 levels. Using PM2.5 as an indicator of the regional pollution and some of the local pollution mixture gives an estimate of 340,000 to 350,000 life years gained as a result of the predicted concentration between 2011 and 2030. Using NO2 as an indicator of mostly the local pollution mixture and the rural pollution gives a larger estimate of 440,000 life years gained. This makes sense because the concentration projected (2011 to 2030) suggests more continuous declines in NO2 concentrations (likely to be mostly due to the improvement in NOX emissions of large parts of the road transport sector) than for PM2.5, reflecting the fact that PM reduction from traffic is not larger due to the increasing contribution from non-exhaust emissions and also that the declines in regional PM2.5 are relatively small.

Thus, using NO2 rather than PM2.5, as the indicator of changes in the traffic pollution mixture seems more appropriate for future changes as presented here. This is a different indicator compared with the overall impact in terms of life years lost[[15]](#footnote-16). Regional pollution is a greater contributor to absolute total concentrations than to future changes so there is also some sense in PM2.5 being the indicator in this case.

The overall summary would be that taking into account predicted air pollution concentration changes between 2011 and 2030, the population in Birmingham would gain around 440,000 life years over a lifetime.

Table 4 Life years saved (and associated monetised benefits) across Birmingham population of the predicted concentration between 2011 and 2030 compared with 2011 anthropogenic PM2.5 concentrations and NO2 remaining unchanged

|  |  |  |  |
| --- | --- | --- | --- |
| Pollutant | Scenario | Total life years **saved** compared with 2011 concentrations maintained  (without cut-off  with cut-off) | Monetised benefits compared with 2011 concentrations maintained  (without cut-off  with cut-off) |
| Anthropogenic PM2.5 (representing the regional air pollution mixture and some of the local mixture) | Predicted concentration between 2011 and 2030 | 337,812  349,616 | £185,657,893  £191,965,047 |
|
| NO2 (representing the local mixture and the rural air pollution mixture) | Predicted concentration between 2011 and 2030 | **437,393**  **438,966** | **£236,488,758**  **£237,309,329** |
|

Figures in bold are the larger of the alternative estimates using PM2.5 or NO2, as summarized in the headline results.

Table 4 also provides an estimate of the economic impact as a result of the improvements in pollution from 2011 to 2030 versus 2011 pollution remaining unchanged. The annualised monetary benefit of anthropogenic PM2.5 and NO2 improvements has been estimated to be up to £240 million (at 2014 prices).

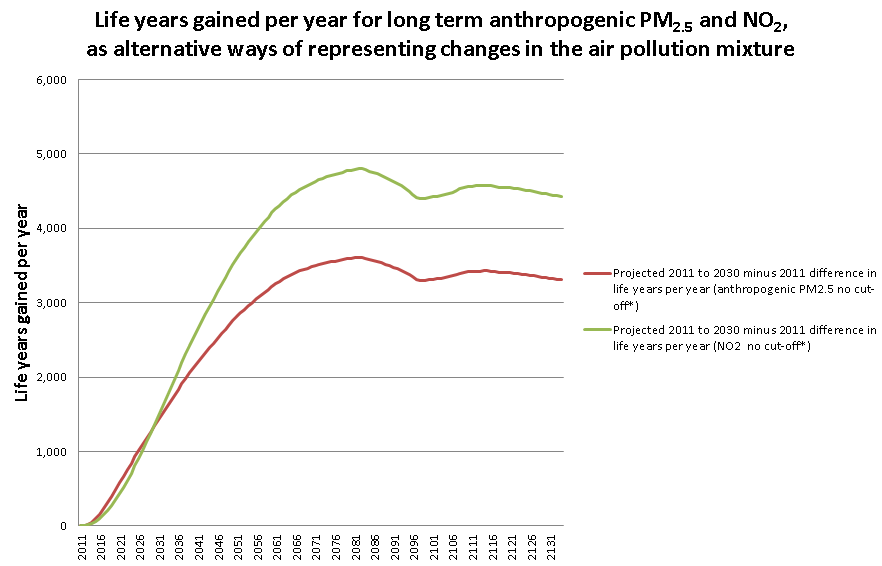


Figure 5 Life years gained per year from long-term exposure to the improvements in pollution from 2011 to 2030 of anthropogenic PM2.5 and NO2 relative to 2011 concentrations remaining unchanged

\* Cut-off results not shown

Figure 5 shows the effect of the decrease in PM2.5 and NO2 concentration from 2011 to 2030 (as seen in Table 1 and Table 2).

## Life-expectancy from birth in 2011

Total life years across the population is the most appropriate metric for cost-benefit analysis of policies as it captures effects in the entire population. However, it is a difficult type of metric to communicate as it is difficult to judge what is a ‘small’ answer or a ‘large’ answer. Life-expectancy from birth is a more familiar concept for the general public, although it only captures effects on those born on a particular date. Results for life expectancy from birth are shown in Table 5. Results for each constituency can be found in the Appendix in Table 20 and Table 21 (Loss of life expectancy for anthropogenic PM2.5 and NO2 with and without a cut-off).

This shows that the average loss of life expectancy from birth in Birmingham would be about 20 – 41 weeks for male and 17 – 35 weeks for female if 2011 PM2.5 concentrations were unchanged but improves to 7 – 29 weeks for male and 6 – 25 weeks for female for the predicted concentration between 2011 and 2030 (an improvement by about 10-13 weeks).

Using NO2, the average loss of life expectancy from birth in Birmingham would be about 27 – 33 weeks for male and 23 – 28 weeks for female if NO2 concentrations were unchanged from 2011 but improves by about 13-16 weeks to 11 – 17 weeks for male and 9 – 15 weeks for female with projected future changes between 2011 and 2030 included.

The overall summary would be that the projected future changes provide an improvement in average life expectancy from birth in 2011 of around 2.5 – 4 months (11 – 17 weeks) but an average loss of life expectancy from birth in 2011 of around 2 to 7 months (9 – 29 weeks) remains even with the reduced concentrations. Males are more affected than females – this is mainly due to the higher mortality rates in men compared with women rather than differences in air pollution exposure.

Table 5 Loss of life expectancy by gender across Birmingham from birth in 2011 (followed for 105 years) for anthropogenic PM2.5 and NO2

|  |  |  |  |
| --- | --- | --- | --- |
| Pollutant | Scenario | Loss of life expectancy from birth compared with baseline mortality rates, 2011 birth cohort (in weeks)  (without cut-off  with cut-off) | |
| Male | Female |
| Anthropogenic PM2.5 | Concentration does not reduce from 2011 levels | 40.9  19.8 | 34.9  17.0 |
| Predicted concentration between 2011 and 2030 | **28.8**  7.2 | **24.6**  6.2 |
| NO2 | Concentration does not reduce from 2011 levels | 33.2  27.1 | 28.4  23.2 |
| Predicted concentration between 2011 and 2030 | 17.0  **10.9** | 14.5  **9.3** |

Figures in bold are the larger of the alternative estimates using PM2.5 or NO2, as summarized in the headline results.

Additional data such as the loss of life expectancy lower and upper estimate and the full range of confidence intervals with and without the counterfactual for both PM2.5 and NO2 are available upon request to the authors.

# Health Estimates of the mortality burden of air pollution

## Burden background

Burden calculations are a snapshot of the burden in one year, assuming that concentrations had been the same for many years beforehand. They are intended as a simpler calculation than the more detailed assessments that are given above (in the mortality impact section). They are not suitable for calculation is several successive years as they do not have a mechanism for allowing the number of deaths the year before to influence the age and population size the following year as the lifetables used in impact calculations do. They are included here as a comparison with similar calculations presented elsewhere (COMEAP, 2010; Walton et al., 2015; Dajnak et al., 2018). The concentration-response functions used for these calculations are evolving over time. Previous recommendations favoured methods similar to the single pollutant model approach presented below. The latest COMEAP (2018a) report shows that a majority of the committee supported a new approach using information from multi pollutant model results but COMEAP (2018a) also recommended using a range to reflect the uncertainty. Single pollutant models relate health effects to just one pollutant at a time, although because pollutants tend to vary together, they may in fact represent the effects of more than one pollutant. Single pollutant models for different pollutants cannot therefore be added together as there may be substantial overlap. Multi-pollutant models aim to disentangle the effects of separate pollutants but this is difficult to do. Despite the best attempts, it may still be the case that some of the effect of one pollutant ‘attaches’ to the effects ascribed to another pollutant, leading to an underestimation of the effects of one pollutant and an overestimation of the effects of another. In this situation, the combined effect across the two pollutants should give a more reliable answer[[16]](#footnote-17) than the answers for the individual pollutants that may be over- or under-estimated. This was the basis for the approach described below, including adding results derived from information within each of 4 separate studies first, before combining them as a range. The intention is not to present the individual pollutant results separately as final results, although the calculations are done as intermediate stages towards the overall results.

[Burden calculations would normally include accompanying estimates of the burden life years lost[[17]](#footnote-18). This would require inputting average loss of life expectancy by age and gender for calculations in each ward. For this small project, it was not possible to do this.]

The calculations are based on deaths from all causes including respiratory, lung cancer and cardiovascular deaths, the outcomes for which there is strongest evidence for an effect of air pollution.

## Combined estimate for PM2.5 and NO2 using multi pollutant model results

Using the exploratory new combined method (COMEAP, 2018a) gives an estimate for the 2011 mortality burden in Birmingham of 2011 levels of air pollution (represented by NO2 and anthropogenic PM2.5) to be equivalent to 570 to 709 attributable deaths at typical ages, or a result equivalent to 400 to 430 deaths when cut-offs for each pollutant were implemented. Estimates for individual constituencies are provided in Table 6. The results varied by constituency with highest in Erdington and lowest in Hall Green. The ranking by constituency did not fully follow the ranking in pollutant concentrations (see Table 1 and Table 2). This is because the results are also influenced by variations in death rates by constituency (highest in Erdington, lowest in Ladywood), which in turn are driven in part by the proportion of elderly in the population (highest in Sutton Coldfield, lowest in Ladywood) and the level of deprivation (similar across most constituencies, but better in Sutton Coldfield). Details are given in Table 23 in the Appendix.

These results use recommendations from COMEAP, 2018a. For each of the four individual cohort studies that included multi-pollutant model results[[18]](#footnote-19), the burden results were estimated separately using mutually adjusted summary coefficients for PM2.5 and NO2 and then the adjusted PM2.5 and NO2 results were summed to give an estimated burden of the air pollution mixture. Example of the calculations for each study for individual constituencies and Birmingham of 2011 levels of NO2 and PM2.5 can be found the appendix in Table 24 and Table 25. The uncertainty of each separate study was not quantified (COMEAP, 2018a) but it is worth noting that each of the individual results also has uncertainty associated with it.

Table 6 Estimated burden (from the estimates derived by using information from multi-pollutant model results from 4 different cohort studies) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 and NO2 (with and without cut-off)

|  |  |  |
| --- | --- | --- |
| Zone | Anthropogenic PM2.5 and NO2  (without cut-off) | Anthropogenic PM2.5 and NO2  (with cut-off) |
| Attributable deaths (using coefficients derived from information in 4 studies below\*) | Attributable deaths (using coefficients derived from information in 4 studies below\*) |
| Edgbaston | 47 - 59 | 32 - 34 |
| Erdington | 75 - 91 | 55 - 59 |
| Hall Green | 46 - 57 | 32 - 35 |
| Hodge Hill | 69 - 85 | 50 - 53 |
| Ladywood | 50 - 60 | 38 - 40 |
| Northfield | 49 - 64 | 32 - 34 |
| Perry Barr | 56 - 69 | 42 - 44 |
| Selly Oak | 56 - 72 | 37 - 41 |
| Yardley | 65 - 81 | 46 - 49 |
| Sutton Coldfield | 56 - 72 | 37 - 41 |
| Birmingham | 570 -709 | 400 - 430 |

\*Using COMEAP’s recommended concentration-response coefficient of 1.029, 1.033, 1.053 and 1.019 per 10 μg m-3 of anthropogenic PM2.5 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

\*Using COMEAP’s recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 μg m-3 of NO2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for PM2.5 from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

## Single pollutant model estimates

The previous mortality burden method using single pollutant model estimates would have estimated that Birmingham’s 2011 levels of anthropogenic PM2.5 would lead to effects equivalent to 554 (range[[19]](#footnote-20) 378 to 724) attributable deaths at typical ages, or results equivalent to 266 (range 180 to 350) deaths when the cut-off was implemented. Estimates for individual constituencies are provided in Table 7. This represents the regional pollution mixture and partial represents the contribution from traffic pollution.

These results use recommendations from COMEAP, 2010. Walton et al. (2015) used both COMEAP (2010) recommendations and WHO (2013) recommendations that included recommendations for nitrogen dioxide to provide estimates for London. The results were presented as a range from PM2.5 alone to the sum of the PM2.5 and NO2 results, but the uncertainty of the latter was emphasized. Since then it has become clearer that the overlap is likely to be substantial (COMEAP, 2015). COMEAP (2018a) concluded that the combined adjusted coefficients were similar to, or slightly larger than, the single-pollutant association reported with either pollutant alone.

The lower and upper estimates in Table 7 are based on the 95% confidence intervals (1.04 – 1.08) around the pooled summary estimate (1.06) for the increase in risk from Hoek et al (2013). COMEAP recently agreed to use this range (COMEAP, 2018b) rather than the wider ones of 1.01 – 1.12 in the original COMEAP (2010) report. Nonetheless, the wider ones remain reflective of the fact that the uncertainties are wider than just the statistical uncertainty represented by the confidence intervals. We have included results for this wider range of uncertainty in Table 22 of the Appendix but as a rough guide the range goes from around a sixth to around double the central estimate in Table 7.

Table 7 Estimated burden (from single-pollutant model summary estimate) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 (with and without cut-off)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5  (without cut-off) | | | Anthropogenic PM2.5  (with cut-off) | | |
| Attributable deaths | | | Attributable deaths | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Edgbaston | 48 | 32 | 62 | 22 | 15 | 28 |
| Erdington | 70 | 47 | 91 | 36 | 24 | 47 |
| Hall Green | 45 | 31 | 59 | 21 | 14 | 28 |
| Hodge Hill | 65 | 45 | 85 | 33 | 22 | 43 |
| Ladywood | 45 | 31 | 58 | 24 | 16 | 31 |
| Northfield | 51 | 35 | 67 | 22 | 15 | 29 |
| Perry Barr | 53 | 36 | 69 | 27 | 18 | 35 |
| Selly Oak | 57 | 39 | 75 | 26 | 17 | 34 |
| Yardley | 63 | 43 | 83 | 31 | 21 | 40 |
| Sutton Coldfield | 57 | 39 | 74 | 26 | 17 | 34 |
| Birmingham | 554 | 378 | 724 | 266 | 180 | 350 |

Using COMEAP’s recommended concentration-response coefficient of 1.06 per 10 μg m-3 of anthropogenic PM2.5 for the central estimate (lower estimate RR of 1.04 and upper estimate RR 1.08)

In addition to the combined multi-pollutant model derived estimates in the section above, the COMEAP (2018a) report suggests also calculating the burden using the single pollutant model result for NO2 (this may represent the burden of traffic pollution more clearly than that of PM2.5). The results give estimates that Birmingham’s 2011 levels of NO2 lead to effects equivalent to 442 (range[[20]](#footnote-21) 158 to 694) attributable deaths at typical ages, or results equivalent to 359 (range 128 to 565) deaths when the cut-off was implemented. Estimates for individual constituencies are provided in Table 8.

Table 8 Estimated burden (from single pollutant model summary estimate) of effects on annual mortality in 2011 of 2011 levels of NO2 (with and without cut-off)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Zone | NO2 (without cut-off) | | | NO2 (with cut-off) | | |
| Attributable deaths | | | Attributable deaths | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Edgbaston | 36 | 13 | 56 | 28 | 10 | 44 |
| Erdington | 59 | 21 | 93 | 50 | 18 | 78 |
| Hall Green | 35 | 13 | 55 | 28 | 10 | 45 |
| Hodge Hill | 54 | 19 | 85 | 45 | 16 | 71 |
| Ladywood | 40 | 14 | 63 | 34 | 12 | 54 |
| Northfield | 37 | 13 | 58 | 28 | 10 | 44 |
| Perry Barr | 45 | 16 | 70 | 37 | 13 | 59 |
| Selly Oak | 43 | 15 | 67 | 33 | 12 | 53 |
| Yardley | 51 | 18 | 80 | 41 | 15 | 65 |
| Sutton Coldfield | 42 | 15 | 66 | 33 | 12 | 52 |
| Birmingham | 442 | 158 | 694 | 359 | 128 | 565 |

Using COMEAP’s recommended concentration-response coefficient of 1.023 per 10 μg m-3 of NO2 for the central estimate (lower estimate RR of 1.008 and upper estimate RR 1.037)

## Summary of burden results

Results without the cut-off give a range of 570-709 attributable deaths using the approach derived from multi-pollutant model results. This compares with around 554 attributable deaths[[21]](#footnote-22) using the single-pollutant model estimate for PM2.5 (the previous method) and around 442 attributable deaths using the single-pollutant model estimate for NO2 (a good indicator of traffic pollution). As expected, the estimate combining effects of NO2 and PM2.5 is slightly larger than for either pollutant alone but not by much, reflecting the substantial overlap between the single pollutant model estimates for PM2.5 and NO2. Nonetheless, there are substantial ranges of uncertainty around these estimates so it is not clear cut that there is an additional effect over and above estimates using the previous method.

The message from the results with a cut-off is similar with a range of 400-430 attributable deaths using the approach derived from multi-pollutant model results compared with 266 (PM2.5 single-pollutant model) and 359 (NO2 single-pollutant model). In this case, the result for NO2 is larger than that for PM2.5 - probably a reflection of the different cut-offs for NO2 and PM2.5.

In developing policy in the face of uncertainty, it is useful to have guidance on the result using the most conservative assumptions and that using approaches using recent trends in evidence and methods that may also be more uncertain. In this case, the ‘conservative assumptions’ result would be 266 attributable deaths (long-established method for PM2.5, avoids the complexities of interpreting multi-pollutant model results) and the ‘exploratory, more up to date, extrapolate beyond the data’ results would be 570-709 attributable deaths (combined NO2 and PM2.5; no cut-off). For messages incorporating most of the uncertainties, the message would be ‘somewhere between about 150 and 700 attributable deaths’.

# Discussion

This study addressed the effect of air pollution on deaths and loss of life-expectancy. This included all causes of death grouped together so covers, for example, respiratory, lung cancer and cardiovascular deaths for which there is good evidence for an effect of air pollution. It does not, however, cover the effect of air pollution on health where this does not result in death. So well established effects (such as respiratory and cardiovascular hospital admissions, effects on asthma, low birth weight etc) and other outcomes more recently potentially linked with air pollution (such as dementia) are not included. Their inclusion would increase the benefit of policies to further reduce air pollution.

Ozone

Study from Williams et al. (2018a and 2018b) shows that ozone concentrations in 2035 and 2050 are projected to increase in winter because the NOx removal process is reduced through reductions in NOx emissions. So-called summer smog ozone concentrations are projected to decrease because of the reductions in emissions of ozone precursors. Williams (2018a and 2018b) study found that the long-term ozone exposure metric recommended by WHO (2013) is projected to decrease over time compared with 2011. This outcome is a relatively small change compared with that for the other pollutants, due to the WHO threshold of 35 parts per billion and the effect being on respiratory mortality, not all cause mortality. Williams et al. (2018a and 2018b) also warned that the increased proportion of ozone in the mixture of oxidant gases, including NO2, is potentially of some concern because ozone has a higher redox potential than does NO2, and so could possibly increase the hazard from oxidative stress, although it is too early to be confident about this theory.

Comparison with results for Greater Manchester

The current authors performed a similar analysis for Greater Manchester in 2018 (Dajnak et al., 2018). This analysis was similar for the impact calculations although the Greater Manchester report predated the multi-pollutant model aspects of the new burden methodology published in COMEAP (2018). Even with the same methodology comparisons for the impact calculations are complex because the results are driven by multiple factors changing over time (not only the pollutant concentrations but also the mortality rates and new births and the changes in population age distribution and size as a result of the pollutant changes). Nonetheless, some approximate comparisons can be made.

*Life years lost still remaining after pollution improvements:* The largest result in both Birmingham and Greater Manchester was for PM2.5 with no cut-off. The result was larger for Greater Manchester (1.6 million life years lost) with the result for Birmingham city being about half of that at 0.8 million life years lost. The primary driver of this difference is probably the difference in population – the area of Greater Manchester is larger area and has a larger population (2,682,727 people) with the population for Birmingham city being about a third of that (1,073,188). However, there is a higher concentration of PM2.5 in Birmingham than in Manchester (Table 9) which will increase the life years lost in Birmingham relative to Manchester. This probably contributes to the fact that the Birmingham results is only half of that in Manchester rather than a third of it as would (loosely) be predicted by the differences in population. The equivalent results for NO2 with no cut-off is 1 million life years lost in Greater Manchester and 0.5 million life years lost in Birmingham city. This is again around half the life years lost in Birmingham compared with Manchester, with the explanations being similar.

The comparison of the results with a cut-off give different messages for NO2 and PM2.5. The comparison for NO2 with a cut-off is similar to the no cut-off results (the result for Birmingham, 0.3 million life years lost, about half that for Manchester, 0.6 million life years lost). For PM2.5, however, the result for Birmingham (0.21 million life years lost) is more similar and, in fact, more than that for Greater Manchester (0.18 million life years lost). This is because the PM2.5 concentrations in Greater Manchester are much closer to the 7 μg m-3 cut-off (and are probably below it in some areas). It is therefore assumed that the particulate pollution has no effect on life-years lost in those areas, reducing the total overall.

Table 9 Anthropogenic PM2.5 PWAC (in μg m-3) (annual) and NO2 PWAC (in μg m-3) (annual) for Birmingham City and Greater Manchester

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Pollutant | Location | 2011 | 2015 | 2020 | 2025 | 2030 |
| Anthropogenic PM2.5 PWAC\* | Birmingham City | 12.82 | 9.81 | 9.21 | 9.02 | 8.99 |
| Greater Manchester | 11.39 | 8.09 | 7.62 | 7.47 | 7.44 |
| NO2 PWAC\* | Birmingham City | 26.12 | 21.33 | 17.68 | 14.75 | 13.14 |
| Greater Manchester | 22.39 | 18.78 | 14.94 | 12.08 | 10.65 |

\*For Birmingham City: average of the PWAC by constituency from Table 1 and Table 2, above. For Greater Manchester, average of the PWAC by local authority from Table 1 and Table 2 (Dajnak et al., 2018).

*Loss of life expectancy still remaining after pollution improvements:* The influence of the difference in pollution concentrations between Greater Manchester and Birmingham City can be seen more clearly in the results for loss of life expectancy from birth. This is because it comes from the total life years lost in those exposed for a lifetime divided by the size of that population. So, the difference in population has already been taken into account. The loss of life expectancy using PM2.5 as an indicator without a cut-off was 21/24 weeks (Female/Male) in Greater Manchester and 25/29 weeks (F/M) in Birmingham City, close but somewhat higher in Birmingham as with the concentrations. The comparison was similarly close but higher in Birmingham for life expectancy using NO2 without a cut-off as an indicator (12 – 14 weeks compared with 15-17 weeks in Birmingham). As with the previous discussions of total life years lost, the difference between Greater Manchester and Birmingham City is more marked for PM2.5 with a cut-off than for NO2 with a cut-off because the cut-off of 7 µg m-3 is closer to the general concentrations in Manchester.

*Gains in life years from pollution improvements:* Similar factors influence the comparative results for life years gained between the two cities. As with the life years lost after the pollution improvements, the results for NO2 in Birmingham are about half those in Manchester, driven mainly by the lower population but also partially cancelled out by the higher pollution levels. There are NO2 reductions in both cities (Table 9), which also influence the answer but proportionately the reductions are quite similar. For PM2.5, there is proportionally a slightly greater reduction in Manchester and this shows in the fact that the gains from PM2.5 in Birmingham are a bit less than half those in Manchester.

*Mortality burden:* The mortality burden in Birmingham city is again smaller in Birmingham city than in Greater Manchester but not by as much as predicted by the smaller population, given the higher pollution levels.

In all the cases discussed above, other factors may also be having an influence such as the mortality rates (see discussion of differences across constituencies in section 6.2)

Comparisons are more difficult with an earlier report in London (Walton *et al* 2015) as the methodology has changed to a greater extent and the time periods of the pollution changes are also different. The mortality burden result for the single pollutant model for PM2.5. This was 52,630 life-years lost, equivalent to 3,537 deaths at typical ages for 2010 compared with 554 attributable deaths for Birmingham for 2011. (Due to the short duration of the Birmingham project life years lost was not calculated for mortality burden). Again, this difference is primarily driven by the larger population in London (8 million vs 1 million).

In summary, this report shows the gains in life years from the projected pollution improvements but also that adverse health impacts will still remain i.e. there is still justification for further pollution improvements beyond those already made.

# Appendix

## Additional tables- method

Additional data such as the annualised economic impact and the loss of life expectancy lower and upper estimate and the full range of confidence interval with and without counterfactual for both PM2.5 and NO2 are available upon request to the authors.

Table 10 Concentration-response functions (CRFs) for long-term exposures and mortality (for impact calculations of general changes in pollutant concentrations (rather than policies targeting one pollutant alone) and for the single-pollutant model aspect of burden calculations).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Pollutant | Averaging time | Hazard ratio per 10 μg m-3 | Confidence interval | Counterfactual | Comment/Source |
| PM2.5 | Annual average | 1.06 | 1.04-1.08  1.01-1.12\* | Zero  Or 7 μg m-3 | Age 30+, Anthropogenic PM2.5 (Hazard ratio COMEAP (2010) and COMEAP (2017))  Age 30+, total PM2.5 (cut-off reference COMEAP (2010)) |
| NO2 | Annual average | 1.023 | 1.008 – 1.037 | Zero  or 5 μg m-3 | Age 30+ (Hazard ratio COMEAP (2017), cutoff COMEAP (2016) |

\*This wider uncertainty is only used as an addition for the single-pollutant model aspect of burden calculations

Table 11 Concentration-response functions (CRFs) for long-term exposures and mortality burden from the four multi-pollutant model cohort studies including multi-pollutant model estimates

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Pollutant | Averaging time | Hazard ratio  per 10 μg m-3 | Counterfactual | Comment/Source |
| PM2.5 | Annual average | 1.029 (Jerrett)  1.033 (Fischer)  1.053 (Beelen)  1.019 (Crouse) | Zero  Or 7 μg m-3 | Age 30+, Anthropogenic PM2.5 (Hazard ratio COMEAP (2010) and COMEAP (2017))  Age 30+, total PM2.5 (cut-off reference COMEAP (2010)) |
| NO2 | Annual average | 1.019 (Jerrett)  1.016 (Fischer)  1.011 (Beelen)  1.020 (Crouse) | Zero  or 5 μg m-3 | Age 30+ (Hazard ratio COMEAP (2017), cutoff COMEAP (2016) |

\*Derived from applying the % reduction on adjustment for the other pollutants in each individual study to the pooled single pollutant summary estimate as in COMEAP (2018a)

Table 12 Geographic scales of health impact calculations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Concentrations | Concentration output for health impacts | Population by gender and age group | Population-weighting | Mortality data | Impact calculations |
| 1km | Ward | Ward | Ward to parliamentary constituency | Constituency | Sum of constituency results |

## Additional tables - impact

Table 13 Life years lost by gender across the parliamentary constituencies and Birmingham population for anthropogenic PM2.5 (without cut-off)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Gender | Concentration does not reduce from 2011 levels | | | Predicted concentration between 2011 and 2030 | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Edgbaston | Female | 41,817 | 28,270 | 54,993 | 29,872 | 20,169 | 39,336 |
| Edgbaston | Male | 47,845 | 32,303 | 63,000 | 34,045 | 22,965 | 44,871 |
| Erdington | Female | 56,758 | 38,352 | 74,675 | 40,409 | 27,272 | 53,229 |
| Erdington | Male | 60,739 | 41,008 | 79,977 | 43,186 | 29,130 | 56,919 |
| Hall Green | Female | 53,596 | 36,236 | 70,475 | 38,004 | 25,660 | 50,042 |
| Hall Green | Male | 68,977 | 46,621 | 90,729 | 48,931 | 33,031 | 64,444 |
| Hodge Hill | Female | 73,997 | 50,018 | 97,324 | 51,807 | 34,972 | 68,230 |
| Hodge Hill | Male | 87,589 | 59,168 | 115,272 | 61,301 | 41,363 | 80,769 |
| Ladywood | Female | 77,966 | 52,704 | 102,537 | 55,768 | 37,650 | 73,437 |
| Ladywood | Male | 99,111 | 67,042 | 130,260 | 70,987 | 47,947 | 93,437 |
| Northfield | Female | 44,448 | 30,043 | 58,463 | 32,002 | 21,604 | 42,145 |
| Northfield | Male | 51,005 | 34,464 | 67,110 | 36,709 | 24,776 | 48,355 |
| Perry Barr | Female | 55,567 | 37,574 | 73,059 | 40,121 | 27,093 | 52,822 |
| Perry Barr | Male | 65,961 | 44,570 | 86,786 | 47,612 | 32,135 | 62,714 |
| Selly Oak | Female | 45,213 | 30,515 | 59,555 | 32,035 | 21,603 | 42,233 |
| Selly Oak | Male | 50,440 | 34,060 | 66,408 | 35,745 | 24,114 | 47,107 |
| Yardley | Female | 55,329 | 37,384 | 72,802 | 38,813 | 26,193 | 51,132 |
| Yardley | Male | 63,099 | 42,626 | 83,040 | 44,231 | 29,846 | 58,276 |
| Sutton Coldfield | Female | 34,402 | 23,232 | 45,289 | 24,650 | 16,630 | 32,483 |
| Sutton Coldfield | Male | 35,663 | 24,054 | 47,006 | 25,480 | 17,175 | 33,605 |
| Birmingham | Female | 539,092 | 364,328 | 709,172 | 383,480 | 258,845 | 505,089 |
| Birmingham | Male | 630,428 | 425,916 | 829,588 | 448,228 | 302,482 | 590,498 |
| Birmingham | Total | 1,169,520 | 790,244 | 1,538,761 | 831,708 | 561,327 | 1,095,587 |

Table 14 Life years lost by gender across the parliamentary constituencies and Birmingham population for NO2 (without cut-off)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Gender | Concentration does not reduce from 2011 levels | | | Predicted concentration between 2011 and 2030 | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Edgbaston | Female | 31,231 | 11,014 | 49,603 | 15,991 | 5,622 | 25,473 |
| Edgbaston | Male | 35,874 | 12,627 | 57,076 | 18,297 | 6,427 | 29,170 |
| Erdington | Female | 48,435 | 17,082 | 76,913 | 25,056 | 8,808 | 39,913 |
| Erdington | Male | 51,839 | 18,258 | 82,424 | 26,717 | 9,387 | 42,581 |
| Hall Green | Female | 41,505 | 14,642 | 65,896 | 22,617 | 7,954 | 36,015 |
| Hall Green | Male | 53,461 | 18,851 | 84,915 | 29,214 | 10,272 | 46,529 |
| Hodge Hill | Female | 61,732 | 21,781 | 97,992 | 34,266 | 12,052 | 54,558 |
| Hodge Hill | Male | 73,135 | 25,778 | 116,204 | 40,583 | 14,266 | 64,649 |
| Ladywood | Female | 69,588 | 24,568 | 110,396 | 38,838 | 13,666 | 61,812 |
| Ladywood | Male | 88,585 | 31,311 | 140,379 | 49,940 | 17,584 | 79,434 |
| Northfield | Female | 31,356 | 11,051 | 49,830 | 16,067 | 5,646 | 25,602 |
| Northfield | Male | 35,959 | 12,667 | 57,169 | 18,396 | 6,463 | 29,320 |
| Perry Barr | Female | 47,294 | 16,699 | 75,021 | 23,685 | 8,331 | 37,711 |
| Perry Barr | Male | 56,133 | 19,796 | 89,142 | 28,156 | 9,898 | 44,850 |
| Selly Oak | Female | 33,317 | 11,720 | 53,038 | 17,715 | 6,220 | 28,249 |
| Selly Oak | Male | 37,200 | 13,095 | 59,179 | 19,803 | 6,957 | 31,567 |
| Yardley | Female | 44,291 | 15,613 | 70,371 | 25,075 | 8,816 | 39,942 |
| Yardley | Male | 50,530 | 17,807 | 80,303 | 28,576 | 10,045 | 45,522 |
| Sutton Coldfield | Female | 25,229 | 8,882 | 40,132 | 13,052 | 4,584 | 20,807 |
| Sutton Coldfield | Male | 26,131 | 9,183 | 41,636 | 13,389 | 4,699 | 21,359 |
| Birmingham | Female | 433,979 | 153,051 | 689,191 | 232,362 | 81,699 | 370,082 |
| Birmingham | Male | 508,848 | 179,374 | 808,429 | 273,072 | 95,998 | 434,982 |
| Birmingham | Total | 942,827 | 332,425 | 1,497,620 | 505,434 | 177,697 | 805,064 |

Table 15 Central Annualised economic impact estimate (in 2014 prices) across the parliamentary constituencies and Birmingham population for anthropogenic PM2.5 and NO2 (without cut-off)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 | | NO2 | |
| Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 |
| Central estimate | Central estimate | Central estimate | Central estimate |
| Edgbaston | £51,375,485 | £36,887,202 | £38,446,958 | £20,290,037 |
| Erdington | £66,406,816 | £47,595,352 | £56,668,413 | £30,229,656 |
| Hall Green | £67,609,835 | £48,241,268 | £52,377,027 | £29,303,571 |
| Hodge Hill | £86,585,316 | £60,962,701 | £72,263,115 | £40,997,725 |
| Ladywood | £95,542,313 | £68,701,219 | £85,342,521 | £48,816,024 |
| Northfield | £54,880,838 | £39,801,589 | £38,695,791 | £20,486,583 |
| Perry Barr | £67,720,755 | £49,183,873 | £57,629,795 | £29,752,759 |
| Selly Oak | £54,654,167 | £39,009,105 | £40,289,947 | £22,062,293 |
| Yardley | £66,258,293 | £46,798,522 | £53,044,830 | £30,799,172 |
| Sutton Coldfield | £42,390,673 | £30,585,767 | £31,070,025 | £16,601,844 |
| Birmingham | £653,424,492 | £467,766,599 | £525,828,421 | £289,339,663 |

Table 16 Lower and upper Annualised economic impact estimate (in 2014 prices) across the parliamentary constituencies and Birmingham population for anthropogenic PM2.5 and NO2 (without cut-off)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 | | NO2 | |
| Predicted concentration between 2011 and 2030 | | Predicted concentration between 2011 and 2030 | |
| Lower estimate | Upper estimate | Lower estimate | Upper estimate |
| Edgbaston | £24,891,249 | £48,599,024 | £7,130,009 | £32,333,244 |
| Erdington | £32,110,056 | £62,719,962 | £10,624,270 | £48,165,659 |
| Hall Green | £32,565,183 | £63,534,358 | £10,304,365 | £46,667,294 |
| Hodge Hill | £41,139,787 | £80,313,255 | £14,415,399 | £65,294,631 |
| Ladywood | £46,394,151 | £90,445,925 | £17,185,511 | £77,657,261 |
| Northfield | £26,862,529 | £52,429,746 | £7,198,587 | £32,648,513 |
| Perry Barr | £33,201,158 | £64,776,119 | £10,462,671 | £47,381,022 |
| Selly Oak | £26,310,392 | £51,419,078 | £7,749,165 | £35,172,582 |
| Yardley | £31,576,843 | £61,661,858 | £10,826,995 | £49,062,531 |
| Sutton Coldfield | £20,623,913 | £40,325,956 | £5,829,480 | £26,474,681 |
| Birmingham | £315,675,261 | £616,225,282 | £101,726,453 | £460,857,417 |

Table 17 Life years lost by gender across the parliamentary constituencies and Birmingham for PM2.5 (with 7 μg m-3 cut-off)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Gender | Concentration does not reduce from 2011 levels | | | Predicted concentration between 2011 and 2030 | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Edgbaston | Female | 18,760 | 12,651 | 24,731 | 6,366 | 4,288 | 8,403 |
| Edgbaston | Male | 21,510 | 14,498 | 28,373 | 7,259 | 4,888 | 9,583 |
| Erdington | Female | 28,732 | 19,376 | 37,878 | 11,822 | 7,964 | 15,603 |
| Erdington | Male | 30,720 | 20,709 | 40,514 | 12,612 | 8,495 | 16,648 |
| Hall Green | Female | 24,977 | 16,846 | 32,924 | 8,795 | 5,924 | 11,608 |
| Hall Green | Male | 32,148 | 21,680 | 42,382 | 11,367 | 7,656 | 15,004 |
| Hodge Hill | Female | 36,997 | 24,954 | 48,767 | 14,032 | 9,452 | 18,519 |
| Hodge Hill | Male | 43,774 | 29,516 | 57,717 | 16,622 | 11,196 | 21,940 |
| Ladywood | Female | 41,253 | 27,829 | 54,367 | 18,310 | 12,337 | 24,161 |
| Ladywood | Male | 52,465 | 35,404 | 69,121 | 23,345 | 15,731 | 30,800 |
| Northfield | Female | 18,711 | 12,616 | 24,672 | 5,766 | 3,883 | 7,612 |
| Northfield | Male | 21,455 | 14,464 | 28,293 | 6,602 | 4,446 | 8,715 |
| Perry Barr | Female | 28,141 | 18,985 | 37,086 | 12,123 | 8,168 | 15,997 |
| Perry Barr | Male | 33,363 | 22,499 | 43,982 | 14,377 | 9,685 | 18,974 |
| Selly Oak | Female | 19,840 | 13,370 | 26,175 | 6,239 | 4,201 | 8,237 |
| Selly Oak | Male | 22,171 | 14,944 | 29,244 | 6,979 | 4,700 | 9,214 |
| Yardley | Female | 26,543 | 17,898 | 34,997 | 9,462 | 6,373 | 12,489 |
| Yardley | Male | 30,287 | 20,421 | 39,936 | 10,785 | 7,264 | 14,237 |
| Sutton Coldfield | Female | 15,291 | 10,307 | 20,168 | 5,176 | 3,486 | 6,834 |
| Sutton Coldfield | Male | 15,820 | 10,658 | 20,877 | 5,303 | 3,571 | 7,002 |
| Birmingham | Female | 259,247 | 174,832 | 341,766 | 98,091 | 66,074 | 129,463 |
| Birmingham | Male | 303,713 | 204,791 | 400,441 | 115,252 | 77,632 | 152,118 |
| Birmingham | Total | 562,960 | 379,623 | 742,207 | 213,344 | 143,706 | 281,581 |

Table 18 Life years lost by gender across the parliamentary constituencies and Birmingham population for NO2 (with 5 μg m-3 cut-off)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Gender | Concentration does not reduce from 2011 levels | | | Predicted concentration between 2011 and 2030 | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Edgbaston | Female | 24,564 | 8,650 | 39,065 | 9,258 | 3,250 | 14,765 |
| Edgbaston | Male | 28,263 | 9,938 | 45,009 | 10,633 | 3,732 | 16,966 |
| Erdington | Female | 40,334 | 14,209 | 64,120 | 16,873 | 5,926 | 26,904 |
| Erdington | Male | 43,161 | 15,188 | 68,686 | 17,971 | 6,309 | 28,663 |
| Hall Green | Female | 33,226 | 11,705 | 52,820 | 14,256 | 5,007 | 22,729 |
| Hall Green | Male | 42,807 | 15,075 | 68,076 | 18,464 | 6,484 | 29,440 |
| Hodge Hill | Female | 51,036 | 17,985 | 81,110 | 23,464 | 8,243 | 37,401 |
| Hodge Hill | Male | 60,469 | 21,291 | 96,177 | 27,811 | 9,767 | 44,344 |
| Ladywood | Female | 58,996 | 20,804 | 93,701 | 28,135 | 9,889 | 44,825 |
| Ladywood | Male | 75,133 | 26,520 | 119,219 | 36,324 | 12,773 | 57,846 |
| Northfield | Female | 23,902 | 8,412 | 38,035 | 8,546 | 3,000 | 13,635 |
| Northfield | Male | 27,402 | 9,641 | 43,619 | 9,768 | 3,428 | 15,585 |
| Perry Barr | Female | 39,370 | 13,883 | 62,531 | 15,664 | 5,503 | 24,968 |
| Perry Barr | Male | 46,713 | 16,456 | 74,263 | 18,640 | 6,546 | 29,720 |
| Selly Oak | Female | 25,982 | 9,132 | 41,396 | 10,337 | 3,627 | 16,497 |
| Selly Oak | Male | 29,026 | 10,207 | 46,222 | 11,574 | 4,062 | 18,466 |
| Yardley | Female | 35,966 | 12,663 | 57,206 | 16,680 | 5,858 | 26,597 |
| Yardley | Male | 41,040 | 14,447 | 65,290 | 19,011 | 6,676 | 30,315 |
| Sutton Coldfield | Female | 19,687 | 6,924 | 31,348 | 7,469 | 2,621 | 11,918 |
| Sutton Coldfield | Male | 20,380 | 7,157 | 32,492 | 7,612 | 2,670 | 12,150 |
| Birmingham | Female | 353,062 | 124,367 | 561,331 | 150,682 | 52,923 | 240,237 |
| Birmingham | Male | 414,394 | 145,920 | 659,054 | 177,808 | 62,447 | 283,495 |
| Birmingham | Total | 767,457 | 270,287 | 1,220,386 | 328,491 | 115,370 | 523,732 |

Table 19 Annualised economic impact (in 2014 prices) across the parliamentary constituencies and Birmingham population for PM2.5 and NO2 (with 7 μg m-3 and 5 μg m-3 cut-off for PM2.5 and NO2, respectively)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 | | NO2 | |
| Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 |
| Central estimate | Central estimate | Central estimate | Central estimate |
| Edgbaston | £23,069,783 | £8,088,749 | £30,264,686 | £12,043,928 |
| Erdington | £33,592,790 | £14,183,538 | £47,182,867 | £20,666,070 |
| Hall Green | £31,502,362 | £11,432,109 | £41,931,729 | £18,766,104 |
| Hodge Hill | £43,272,635 | £16,804,911 | £59,741,837 | £28,369,599 |
| Ladywood | £50,564,437 | £22,806,055 | £72,368,899 | £35,697,933 |
| Northfield | £23,084,994 | £7,432,709 | £29,488,817 | £11,206,998 |
| Perry Barr | £34,265,161 | £15,084,249 | £47,962,747 | £19,984,928 |
| Selly Oak | £24,001,756 | £7,853,300 | £31,427,705 | £13,147,583 |
| Yardley | £31,786,720 | £11,689,665 | £43,074,754 | £20,755,045 |
| Sutton Coldfield | £18,817,573 | £6,617,878 | £24,236,043 | £9,732,568 |
| Birmingham | £313,958,210 | £121,993,163 | £427,680,084 | £190,370,755 |

Table 20 Loss of life expectancy by gender across the parliamentary constituencies and Birmingham from birth in 2011 for anthropogenic PM2.5 (without cut-off) and NO2 (without cut-off)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Zone | Gender | Loss of life expectancy from birth compared with baseline mortality rates, 2011 birth cohort followed for 105 years (weeks) | | | |
|  |  | Anthropogenic PM2.5 (without cut-off) | | NO2 (without cut-off) | |
|  |  | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 |
| Edgbaston | Female | 31.1 | 22.0 | 23.3 | 11.2 |
| Edgbaston | Male | 36.7 | 25.8 | 27.5 | 13.2 |
| Erdington | Female | 39.7 | 27.9 | 33.9 | 16.5 |
| Erdington | Male | 44.5 | 31.3 | 38.0 | 18.5 |
| Hall Green | Female | 31.0 | 21.8 | 24.0 | 12.6 |
| Hall Green | Male | 38.3 | 26.9 | 29.7 | 15.5 |
| Hodge Hill | Female | 37.5 | 26.0 | 31.3 | 16.8 |
| Hodge Hill | Male | 44.8 | 31.1 | 37.4 | 20.0 |
| Ladywood | Female | 40.7 | 28.9 | 36.3 | 19.7 |
| Ladywood | Male | 48.1 | 34.2 | 43.0 | 23.4 |
| Northfield | Female | 30.3 | 21.5 | 21.4 | 10.3 |
| Northfield | Male | 35.9 | 25.5 | 25.3 | 12.1 |
| Perry Barr | Female | 34.9 | 25.0 | 29.7 | 14.1 |
| Perry Barr | Male | 42.1 | 30.1 | 35.8 | 17.0 |
| Selly Oak | Female | 32.4 | 22.7 | 23.9 | 12.1 |
| Selly Oak | Male | 37.0 | 26.0 | 27.3 | 13.8 |
| Yardley | Female | 35.5 | 24.6 | 28.4 | 15.4 |
| Yardley | Male | 39.8 | 27.6 | 31.9 | 17.3 |
| Sutton Coldfield | Female | 28.4 | 20.0 | 20.8 | 9.9 |
| Sutton Coldfield | Male | 31.8 | 22.4 | 23.4 | 11.1 |
| Birmingham | Female | 34.9 | 24.6 | 28.4 | 14.5 |
| Birmingham | Male | 40.9 | 28.8 | 33.2 | 17.0 |

Table 21 Loss of life expectancy by gender across the parliamentary constituencies and Birmingham from birth in 2011 for anthropogenic PM2.5 (with 7 μg m-3 cut-off) and NO2 (with 5 μg m-3 cut-off)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Zone | Gender | Loss of life expectancy from birth compared with baseline mortality rates, 2011 birth cohort followed for 105 years (weeks) | | | |
|  |  | Anthropogenic PM2.5 (with 7 μg m-3 cut-off) | | NO2 (with 5 μg m-3 cut-off) | |
|  |  | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 | Concentration does not reduce from 2011 levels | Predicted concentration between 2011 and 2030 |
| Edgbaston | Female | 14.0 | 4.4 | 18.3 | 6.1 |
| Edgbaston | Male | 16.5 | 5.2 | 21.7 | 7.3 |
| Erdington | Female | 20.1 | 7.9 | 28.2 | 10.8 |
| Erdington | Male | 22.5 | 8.9 | 31.6 | 12.0 |
| Hall Green | Female | 14.5 | 4.9 | 19.2 | 7.7 |
| Hall Green | Male | 17.9 | 6.0 | 23.8 | 9.6 |
| Hodge Hill | Female | 18.8 | 6.9 | 25.9 | 11.3 |
| Hodge Hill | Male | 22.4 | 8.2 | 30.9 | 13.5 |
| Ladywood | Female | 21.5 | 9.4 | 30.8 | 14.1 |
| Ladywood | Male | 25.5 | 11.1 | 36.5 | 16.8 |
| Northfield | Female | 12.8 | 3.6 | 16.3 | 5.1 |
| Northfield | Male | 15.1 | 4.3 | 19.3 | 6.1 |
| Perry Barr | Female | 17.7 | 7.4 | 24.8 | 9.1 |
| Perry Barr | Male | 21.3 | 8.9 | 29.8 | 10.9 |
| Selly Oak | Female | 14.3 | 4.2 | 18.7 | 6.8 |
| Selly Oak | Male | 16.3 | 4.8 | 21.4 | 7.7 |
| Yardley | Female | 17.0 | 5.8 | 23.1 | 10.0 |
| Yardley | Male | 19.1 | 6.5 | 25.9 | 11.2 |
| Sutton Coldfield | Female | 12.7 | 3.9 | 16.3 | 5.3 |
| Sutton Coldfield | Male | 14.2 | 4.4 | 18.2 | 5.9 |
| Birmingham | Female | 17.0 | 6.2 | 23.2 | 9.3 |
| Birmingham | Male | 19.8 | 7.2 | 27.1 | 10.9 |

## Additional tables – burden

Table 22 Estimated burden (from single-pollutant model summary estimate with wider estimates of uncertainty) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 (with and without cut-off)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 (without cut-off) | | | Anthropogenic PM2.5 (with cut-off) | | |
| Attributable deaths | | | Attributable deaths | | |
| Central estimate | Lower estimate | Upper estimate | Central estimate | Lower estimate | Upper estimate |
| Edgbaston | 48 | 8 | 90 | 22 | 4 | 41 |
| Erdington | 70 | 12 | 130 | 36 | 6 | 68 |
| Hall Green | 45 | 8 | 86 | 21 | 4 | 41 |
| Hodge Hill | 65 | 12 | 123 | 33 | 6 | 63 |
| Ladywood | 45 | 8 | 84 | 24 | 4 | 46 |
| Northfield | 51 | 9 | 97 | 22 | 4 | 42 |
| Perry Barr | 53 | 9 | 99 | 27 | 5 | 51 |
| Selly Oak | 57 | 10 | 108 | 26 | 4 | 49 |
| Yardley | 63 | 11 | 119 | 31 | 5 | 59 |
| Sutton Coldfield | 57 | 10 | 107 | 26 | 4 | 49 |
| Birmingham | 554 | 98 | 1,041 | 266 | 46 | 510 |

Using COMEAP’s recommended concentration-response coefficient of 1.06 per 10 μg m-3 of anthropogenic PM2.5 for the central estimate (lower estimate RR of 1.01 and upper estimate RR 1.12)

Table 23 Estimated burden (from the estimates derived by using information from multi-pollutant model results from 4 different cohort studies) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 and NO2 (with cut-off), total population in each constituency in 2011, mortality rate (total death age 30 plus divided by total population age 30 plus) in each constituency, ratio of the population age 65 and above over the total population in each constituency and deprivation index Carstairs quintiles[[22]](#footnote-23)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5 and NO2  (without cut-off) | Total population | Mortality rate  (age group 30 plus) | Ratio Population above 65 when compared with total population | Carstairs quintile |
| Attributable deaths (using coefficients derived from information in 4 studies below\*) |
| Edgbaston | 47 - 59 | 96,579 | 1.29% | 14% | 4.5 |
| Erdington | 75 - 91 | 97,791 | 1.62% | 14% | 5 |
| Hall Green | 46 - 57 | 115,921 | 1.07% | 11% | 4.5 |
| Hodge Hill | 69 - 85 | 121,700 | 1.49% | 10% | 5 |
| Ladywood | 50 - 60 | 126,713 | 1.03% | 7% | 5 |
| Northfield | 49 - 64 | 101,434 | 1.29% | 15% | 5 |
| Perry Barr | 56 - 69 | 107,105 | 1.20% | 12% | 4.75 |
| Selly Oak | 56 - 72 | 104,078 | 1.51% | 14% | 4.5 |
| Yardley | 65 - 81 | 95,115 | 1.45% | 14% | 5 |
| Sutton Coldfield | 56 - 72 | 106,753 | 1.31% | 20% | 2.25 |

\*Using COMEAP’s recommended concentration-response coefficient of 1.029, 1.033, 1.053 and 1.019 per 10 μg m-3 of anthropogenic PM2.5 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

\*Using COMEAP’s recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 μg m-3 of NO2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for PM2.5 from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

Table 24 Estimated burden (from multi pollutant study) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 and NO2 (without cut-off)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5  (without cut-off)  (not to be used separately) | | | | NO2  (without cut-off)  (not to be used separately) | | | | Anthropogenic PM2.5 and NO2  (without cut-off)  (combined estimate has less uncertainty) | | | |
| Attributable deaths | | | | Attributable deaths | | | | Attributable deaths | | | |
| Jerrett | Fischer | Beelen | Crouse | Jerrett | Fischer | Beelen | Crouse | Jerrett | Fischer | Beelen | Crouse |
| Edgbaston | 24 | 27 | 42 | 16 | 30 | 25 | 17 | 31 | 54 | 52 | 59 | 47 |
| Erdington | 35 | 39 | 62 | 23 | 49 | 42 | 29 | 52 | 84 | 81 | 91 | 75 |
| Hall Green | 23 | 26 | 40 | 15 | 29 | 25 | 17 | 31 | 52 | 51 | 57 | 46 |
| Hodge Hill | 33 | 37 | 58 | 22 | 45 | 38 | 27 | 47 | 78 | 75 | 85 | 69 |
| Ladywood | 22 | 25 | 40 | 15 | 33 | 28 | 20 | 35 | 55 | 53 | 60 | 50 |
| Northfield | 26 | 29 | 46 | 17 | 31 | 26 | 18 | 32 | 57 | 55 | 64 | 49 |
| Perry Barr | 26 | 30 | 47 | 17 | 37 | 32 | 22 | 39 | 63 | 62 | 69 | 56 |
| Selly Oak | 29 | 32 | 51 | 19 | 35 | 30 | 21 | 37 | 64 | 62 | 72 | 56 |
| Yardley | 32 | 36 | 56 | 21 | 42 | 36 | 25 | 44 | 74 | 72 | 81 | 65 |
| Sutton Coldfield | 28 | 32 | 51 | 19 | 35 | 30 | 21 | 37 | 63 | 62 | 72 | 56 |
| Birmingham | 277 | 314 | 493 | 184 | 368 | 311 | 216 | 386 | 645 | 625 | 709 | 570 |

Using COMEAP’s recommended concentration-response coefficient of 1.029, 1.033, 1.053 and 1.019 per 10 μg m-3 of anthropogenic PM2.5 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

Using COMEAP’s recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 μg m-3 of NO2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for PM2.5 from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

Table 25 Estimated burden (from multi pollutant study) of effects on annual mortality in 2011 of 2011 levels of anthropogenic PM2.5 and NO2 (with cut-off)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Zone | Anthropogenic PM2.5  (with cut-off)  (not to be used separately) | | | | NO2  (with cut-off)  (not to be used separately) | | | | Anthropogenic PM2.5 and NO2  (with cut-off) | | | |
| Attributable deaths | | | | Attributable deaths | | | | Attributable deaths | | | |
| Jerrett | Fischer | Beelen | Crouse | Jerrett | Fischer | Beelen | Crouse | Jerrett | Fischer | Beelen | Crouse |
| Edgbaston | 11 | 12 | 19 | 7 | 23 | 20 | 14 | 25 | 34 | 32 | 33 | 32 |
| Erdington | 18 | 20 | 32 | 12 | 41 | 35 | 24 | 43 | 59 | 55 | 56 | 55 |
| Hall Green | 11 | 12 | 19 | 7 | 24 | 20 | 14 | 25 | 35 | 32 | 33 | 32 |
| Hodge Hill | 16 | 18 | 29 | 11 | 37 | 32 | 22 | 39 | 53 | 50 | 51 | 50 |
| Ladywood | 12 | 14 | 21 | 8 | 28 | 24 | 17 | 30 | 40 | 38 | 38 | 38 |
| Northfield | 11 | 12 | 20 | 7 | 23 | 20 | 14 | 25 | 34 | 32 | 34 | 32 |
| Perry Barr | 13 | 15 | 24 | 9 | 31 | 26 | 18 | 33 | 44 | 41 | 42 | 42 |
| Selly Oak | 13 | 14 | 23 | 8 | 28 | 23 | 16 | 29 | 41 | 37 | 39 | 37 |
| Yardley | 15 | 17 | 27 | 10 | 34 | 29 | 20 | 36 | 49 | 46 | 47 | 46 |
| Sutton Coldfield | 13 | 14 | 23 | 8 | 28 | 23 | 16 | 29 | 41 | 37 | 39 | 37 |
| Birmingham | 132 | 150 | 237 | 87 | 298 | 252 | 175 | 313 | 430 | 402 | 412 | 400 |

Using COMEAP’s recommended concentration-response coefficient of 1.029, 1.033, 1.053 and 1.019 per 10 μg m-3 of anthropogenic PM2.5 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for nitrogen dioxide from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

Using COMEAP’s recommended concentration-response coefficient of 1.019, 1.016, 1.011 and 1.020 per 10 μg m-3 of NO2 derived by applying to a single pollutant model summary estimate the % reduction in the coefficient on adjustment for PM2.5 from the Jerrett *et al* (2013), Fischer *et al* (2015), Beelen *et al* (2014) and Crouse *et al* (2015) studies , respectively

## Additional Health and economic assessment methods

*Anthropogenic PM2.5*: Non-anthropogenic PM2.5 was derived by subtracting the modelled contribution from natural sources – here sea-salt - from the total PM2.5 modelled as above to give anthropogenic PM2.5.

*Population data in Birmingham:* 2011 census data by ward by 5 year age group and gender (ONS, 2012) was split into 1 year age groups using the age ratios from single year of age and gender population data, by LSOA, for mid-2012 (ONS, 2016a).

*Deaths data in Birmingham*: Deaths data by gender and 5 year age group by ward for 2011 was obtained on request from ONS (ONS, 2016b). It was scaled to 1 year age groups using age group ratios from data by LSOA by single year of age and gender for mid-2014 (ONS, 2016c). Ward data was then aggregated up to constituency level.

Mortality Burden

The calculations followed COMEAP (2018a) and earlier methodology from COMEAP (2010) and Gowers et al (2014).

Using the COMEAP (2010)/Gowers *et* al (2014) methodology as the first example, the relative risk (RR) per 10 μg m-3 was scaled to a new relative risk for the relevant anthropogenic PM2.5 concentration. The equation used was:

RR(x) = 1.06x/10 where x is the average concentration of interest.

The new RR(x) was then converted to the attributable fraction (AF) using the following formula:

AF = (RR-1)/RR multiplied by 100 to give a percentage.

The attributable fraction was then multiplied by the number of deaths in the relevant gender and 5-year age group aged 30+ to give the number of attributable deaths.

The attributable deaths were then summed across the 5-year age groups above aged 30, for both males and females, to give a total for each ward.

The calculations above were done at ward level and the results for deaths summed to give a total for each constituency. This allows different death rates in different wards and constituency to influence the results.

The process was repeated for the lower and upper confidence intervals around the relative risks, and for a cut-off of 7 μg m-3 PM2.5.

The COMEAP (2018a) methodology uses the above method for PM2.5 but also calculates a result using a single-pollutant model relative risk for NO2 and a result combining multi-pollutant model estimates for NO2 and PM2.5.

The method for the single-pollutant model calculation for NO2 is exactly analogous to that above for PM2.5 except that the relative risk used is 1.023 (1.008 – 1.037) and the cut-off where used is 5 μg m-3 NO2.

The method using multi-pollutant model results is also based on the same method for scaling the relevant relative risks (see Table 10) according to the relevant pollution concentration. In this case though, there are more calculations (16) because calculations are done separately for each pollutant for relative risks derived from each of 4 studies, both with and without the relevant cut-off for each pollutant. There is also an additional step in that the NO2 and PM2.5 results within each study are summed and then the final result expressed as the range for the sums across the 4 studies. This can be illustrated by examining Table 24 and Table 25 (with and without the cut-offs). It can be seen for Edgbaston, for example, that the sum of column 2 (24 attributable deaths) and column 6 (30 attributable deaths) leads to the result in column 10 (54 attributable deaths). In this example, the results in columns 2 and 6 should be regarded only as intermediate steps in the calculation as it may be that one is over-estimated and the other under-estimated. This is thought to cancel out for the summed result, which is therefore more robust.

Mortality Impact

*Projections for the baseline life tables before applying concentration changes*

Natural change – current population size, age distributions and mortality rates will generate future changes in population and age structure in any case. We did not add this separately as it is already taken into account in our life table modelling.

Changes in births over time – actual data on numbers of births in each local authority was used from 2011-2015(ONS, 2016d), birth projections by local authority were used from 2016 to 2033 (ONS, 2016e) and the ratio of birth projections to 2039 births for England obtained from national populations projections (ONS, 2015a) was used to scale 2039 births in local authorities to local authority births for 2040 to 2114. No projections were available after 2114 so births were left constant for 2115 to 2134.

Changes in births over time by constituency – births in each local authority as above was weighted by the 2011 birth data in each constituency aggregated from the population data in Birmingham by ward using 2011 census data (as above).

Mortality rate improvements were applied to the 2011 all cause hazard rates according to the projected % improvements per year provided by ONS. Percentage improvements for different example ages are provided in Office for National Statistics (ONS, 2015b); we requested the full set of percentage improvements from ONS.

Migration – predicting migration at the current time post the European referendum is particularly uncertain with both increases and decreases forecast. We did not therefore include this in our first analyses as presented in this report. Over the country as a whole this contribution to overall health impacts is likely to be small. This can be explored further in future work.

*Lags*: The approach allowed for a delay between exposure and effect using the recommended distribution of lags from COMEAP (COMEAP, 2010) i.e. 30% of the effect in the first year, 12.5% in each of years 2-5 and 20% spread over years 5-20. An analogous approach was used for the effects of long-term exposure to NO2. HRAPIE (WHO, 2013) recommended that, in the absence of information on likely lags between long-term exposure to NO2 and mortality, calculations should follow whatever lags are chosen for PM2.5.

*Calculations*

The relative risk (RR) per 10 μg m-3 was scaled to a new relative risk for the appropriate population-weighted mean for each gender in each parliamentary constituency for each scenario and year. The equation used (for the example coefficient of 1.06) was: RR(x) = 1.06x/10 where x is the concentration of interest (with a negative sign for a reduction). Concentrations were assumed to reduce linearly between the years in which modelled concentrations were available (2011, 2015, 2020, 2025, 2030). The scaled RR was then used to adjust the all cause hazard rates in the life table calculations.

For the 5 μg m-3 cut-off for NO2, ward concentrations were interpolated between 2011, 2015, 2020, 2025 and 2030 and 5 μg m-3 was then subtracted from the ward concentrations in each year. Any resulting negative concentrations were then set to zero before all the ward concentrations were population-weighted to local authority level as normal.

Life table calculations were programmed in SQL based on the methods used in the standard IOMLIFET spreadsheets 132 with the following amendments:

* Extension to 2134 (105 years after 2030)
* Adjustment of the baseline hazard rates over time according to projected mortality rate improvements
* Inclusion of changes in numbers of births over time
* IOMLIFET excludes neonatal deaths. We included neonatal deaths and followed the South East Public Health Observatory life-expectancy calculator[[23]](#footnote-24) and Gowers et al. (2014) in taking into account the uneven distribution of deaths over the course of the first year when calculating the survival probability. (The survival probability (the ratio of the number alive at the end of the year to the number alive at the beginning) is derived by the equivalent of adding half the deaths back onto the mid-year population to give the starting population and subtracting half the deaths from the mid-year population to give the end population, assuming deaths are distributed evenly across the year. This is not the case in the first year where a weighting factor based on 90% of the deaths occurring in the first half of the year and 10% in the second half is used instead. After rearrangement the actual formula is (1- 0.1 x hazard rate)/(1+ 0.9 x hazard rate) rather than the (1- 0.5 x hazard rate)/(1+ 0.5 x hazard rate) used in other years.)

Results for total and annual life years lost by parliamentary constituency were then summed to Birmingham level. We also used the life tables to calculate changes in life expectancy.

Economic valuation[[24]](#footnote-25)

The approach taken here is based on the discipline of environmental economics (ExternE, 2005). Environmental economics was developed partly in response to recognition of the externalities, or external costs, posed by various human activities. ‘Externalities’ are unforeseen effects that arise from action that benefits one party generally to the detriment of others, when those effects are external, or not considered, in the decision-making process. Notable examples include the loss of utility from effects of air pollution arising from power generation or transport. The question faced by the economist in this situation is not how to allocate a defined amount of resource (the health service budget), but how much should be spent to mitigate externalities. This requires that health impacts are monetised in order that the benefits of action can be compared directly with the costs in a benefit-cost analysis.

Several approaches have been taken to value mortality impacts (the impacts that dominate the assessment made in this report), though all seek to quantify public preference, demonstrating consistency in objective with the health economics work in deriving QALYs for various conditions. The methods used for valuing a death fall into three categories:

Wage-risk studies, which consider the additional wage demanded of people working in risky occupations, providing an estimate of willingness to accept (WTA) risk.

Consumer market studies, that consider the willingness of individuals to pay (WTP) for equipment that will reduce their risk of death. Several studies were carried out on car safety equipment (air bags, etc.) before they were made mandatory.

Contingent valuation (CV) surveys, where individuals are asked for their WTP for treatments that will reduce the risk of a health impact of some kind, or of dying within X years.

Early work in this field was affected by various biases. Considerable effort has been taken over the last three decades to identify these biases and refine CV approaches to reduce them, with some success.

In the context of health valuation, the underlying calculations are similar whichever of the three methods just mentioned is used. In the case of the wage risk studies, for example, it may be observed that construction workers operating at height will accept an additional risk of death annually of 1 in 1,000 (0.001), for an additional wage of £1000. The value of statistical life (VSL) calculated from these figures would be £1000/0.001 - £1,000,000. A review by OECD gives an averaged VSL for EU Member States of €3million. UK Government, via the Department for Transport, adopts a value that is lower by about 40% of £1.56 million (DfT, 2017).

Opinion is divided as to whether valuation of mortality should concern ‘deaths’ or ‘life years lost’. The OECD is firmly committed to use of the VSL (OECD, 2012). UK government, through the Interdepartmental Group on Costs and Benefits, however, values mortality in terms of the loss of life expectancy expressed as the ‘Value of a Life Year’ (VOLY), taking a value of £36,379 in 2014 prices. The basic approach to quantification, however, is the same, with values elicited against a change in the risk of a health outcome, in this case, the loss of a life year. The large difference between the unit values for VSL and VOLY is partly mitigated in subsequent analysis by the number of life years lost being about 10 times higher than the number of deaths. However, the UK government position generates estimates of air pollution damage that are significantly lower than estimates made using the OECD position. Given that the UK government position is followed here, results should be considered to be at the conservative end of plausible ranges.

Similar calculations can be made to assess the WTP to avoid ill health more generally, such as development of respiratory or cardiovascular disease. The total impact for morbidity has a number of elements:

WTP to avoid lost utility (being well, and enjoying the opportunities that good health offers)

The costs of health care

Costs to the marketed economy through lost productivity

Costs have been defined for a variety of endpoints of relevance to air pollution in analysis for UK government and also for other bodies, such as the European Commission (Holland, 2014a and 2014b).

Adopted values, discounting and uplift

The values of most relevance concern acute and chronic mortality, as these have been shown by numerous studies to dominate the CBA. The value of a lost year of life to chronic exposure as applied in the current analysis is £36,379, assuming that it reflects the loss of a year of life in ‘normal health’ taken from the guidance issued by Defra (2019).

It is important to factor the time at which impacts occur into the analysis for two reasons. The first is that values should be uplifted for future years to capture the likely effect of (anticipated) growth in incomes on WTP for health protection. The second, opposing effect, concerns the need to discount future values on the basis that money or goods are more valuable now than at some point in the future. There are several reasons for this. One is that resource available now can be used to increase the availability of resource in the future. An obvious example concerns investment in infrastructure projects that facilitate economic development. Along similar lines, investment in health research may lead to the development of cures or treatments for illnesses in the future. Further information can be found in Guidance from Her Majesty’s Treasury in the ‘Green Book’ (HMT, 2018).

The Green Book recommends the use of declining discount rates for effects quantified over prolonged periods. However, the impact of using declining discount rates in line with the HMT recommendation, rather than constant discount rates, will be minimal as they apply only after 30 years have passed, by which time values are reduced by two thirds. The impact of the declining rates will clearly increase over time, though the rate of decline (see Table 26) is so slight this will still make little difference.

Table 26 Schedule of declining long-term discount rates from HMT, 2018

|  |  |
| --- | --- |
| Period of years | Discount rate |
| 0 – 30 | 3.5% |
| 31 – 75 | 3.0% |
| 76 – 125 | 2.5% |
| 126 – 200 | 2.0% |
| 201 – 300 | 1.5% |
| 301+ | 1.0% |

The government guidance (HMT, 2019) recommends that future values should be uplifted at 2% per annum given that “It is expected that as people’s incomes rise, so too does their willingness to pay to reduce health risks such as those associated with air pollution.” However, it is unclear whether the uplift of 2% is still appropriate. It is notable that it was first developed before the economic crash of 2008, and so does not account for any change in growth since that time. However, the present analysis is based on a long time-frame, so short-term perturbations to growth seem likely to be factored out in the longer term.

Inequality is not factored explicitly into the economic analysis, beyond the acceptance of a national average estimate for mortality valuation (in other words, the values of disadvantaged groups are not down rated to reflect a likely lower WTP linked to reduced ability to pay).

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1. Birmingham air quality annual status report (2018) shows that Birmingham has been in breach of both the national air quality objective for NO2 and the World Health Organization guideline for PM2.5.

   <https://www.birmingham.gov.uk/downloads/file/11938/air_quality_annual_status_report_2018_containing_data_for_2017> [↑](#footnote-ref-2)
2. COMEAP – the Committee on the Medical Effects of Air Pollutants is a national expert Committee advising Government on the health effects of air pollution. Their recommendations for quantification are usually used in Government cost-benefit analysis of policies to reduce air pollution. [↑](#footnote-ref-3)
3. Mortality burden calculations for the UK, England, Wales, Scotland and Northern Ireland can be found in the COMEAP (2018) report itself. [↑](#footnote-ref-4)
4. It is not possible to calculate the full result for gains in life expectancy until everyone in the initial population has died (105 years from 2030), necessitating follow-up for a life-time even if the pollution changes are only for the next decade or so. [↑](#footnote-ref-5)
5. 2011 and 2015 concentrations representing current reference years and any future years up to 2030 have been estimated from the 2015 baseline. Note that the government data projections to 2030 were produced before the Birmingham Clean Air Zone was proposed [↑](#footnote-ref-6)
6. The range is according to whether indicator pollutant is taken as PM2.5 or NO2, whether or not there is a cut-off concentration below which no effects are assumed and gender (Table 4 in report). [↑](#footnote-ref-7)
7. From 2030, so the total time period was 2011-2134. [↑](#footnote-ref-8)
8. The original studies were analysed in terms of ‘time to death’ aggregated across the population. Strictly, it is unknown whether this total change in life years was from a smaller number of deaths fully attributable to air pollution or a larger number of deaths to which air pollution partially contributed. The former is used with the phrase ‘equivalent’ to address this issue. See COMEAP (2010) for a fuller discussion. [↑](#footnote-ref-9)
9. Cut-off is a term used for the concentration below which it is unclear whether or not epidemiological evidence supports the existence of an effect. This does not mean there is no effect below the cut-off, just that the numbers of data points are too small to be sure one way or the other. [↑](#footnote-ref-10)
10. Defra (2019) Impact Pathways Approach Guidance for Air Quality Appraisal [↑](#footnote-ref-11)
11. HM Treasury (2018) The Green Book [↑](#footnote-ref-12)
12. <https://www.birmingham.gov.uk/downloads/file/4604/map_birmingham_constituencies> [↑](#footnote-ref-13)
13. Note that the government data projections to 2030 were produced before the Birmingham Clean Air Zone was proposed [↑](#footnote-ref-14)
14. It is possible that this cut-off will be defined at a value lower than 7 μg m-3 in the future as this is based on a 2002 study. The concentration-response function and its confidence intervals have been updated using a 2013 meta-analysis (the central estimate happened to remain the same). The cut-off has not so far been updated to reflect the range of the data in the meta-analysis. [↑](#footnote-ref-15)
15. This was not the case for the cut-off, where NO2 rather than PM2.5 gives the larger result. But this may be mostly to do with the value of the cut-off. [↑](#footnote-ref-16)
16. This is certainly true for estimates based on the interquartile range within an individual study. However, application to situations where the ratio between the interquartile ranges for the two pollutants differs from that in the original study may exaggerate the contribution of one pollutant over another. The views of COMEAP members differed on how important this issue might be in practice, with the majority considering that a recommended approach on the basis of combined multi-pollutant model estimates could still be made provided caveats were given. [↑](#footnote-ref-17)
17. Burden life years lost represent a snapshot of the burden in one year and are not to be confused with the full calculation of the life years lost for the health impact of air pollution concentration changes over time as presented in the next section. [↑](#footnote-ref-18)
18. Some further cohort studies were omitted because of high correlations between pollutants (see COMEAP (2018a) [↑](#footnote-ref-19)
19. From the 95% confidence interval around the coefficient. [↑](#footnote-ref-20)
20. From the 95% confidence interval around the coefficient. [↑](#footnote-ref-21)
21. More fully ‘results equivalent to xx attributable deaths at typical ages’. [↑](#footnote-ref-22)
22. Acknowledgement to Dr Daniela Fecht (Imperial College London) for formatting Carstair Quintiles data by Wards

    <https://www.researchgate.net/publication/6817786_Measuring_deprivation_in_England_and_Wales_using_2001_Carstairs_scores> [↑](#footnote-ref-23)
23. [https://webarchive.nationalarchives.gov.uk/20130329125326/http://www.lho.org.uk/viewResource.aspx?id=8943&sUri=http%3a%2f%2fwww.sepho.org.uk%2f](https://webarchive.nationalarchives.gov.uk/20130329125326/http:/www.lho.org.uk/viewResource.aspx?id=8943&sUri=http%3a%2f%2fwww.sepho.org.uk%2f) [↑](#footnote-ref-24)
24. Much of this section is sourced from text written by Mike Holland in Williams et al (2018b). [↑](#footnote-ref-25)