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Estimating Local Mortality Burdens associated with Particulate Air Pollution

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ABSTRACT

The increase in mortality risk associated with long-term exposure to particulate air pollution is one of the most important, and best-characterised, effects of air pollution on health. This report presents estimates of the size of this effect on mortality in local authority areas in the UK, building upon the attributable fractions reported as an indicator in the public health outcomes framework for England. It discusses the concepts and assumptions underlying these calculations and gives information on how such estimates can be made. The estimates are expected to be useful to health and wellbeing boards when assessing local public health priorities, as well as to others working in the field of air quality and public health.

The estimates of mortality burden are based on modelled annual average concentrations of fine particulate matter ($PM_{2.5}$) in each local authority area originating from human activities. Local data on the adult population and adult mortality rates is also used. Central estimates of the fraction of mortality attributable to long-term exposure to current levels of anthropogenic (human-made) particulate air pollution range from around 2.5% in some local authorities in rural areas of Scotland and Northern Ireland and between 3 and 5% in Wales, to over 8% in some London boroughs. Because of uncertainty in the increase in mortality risk associated with ambient $PM_{2.5}$, the actual burdens associated with these modelled concentrations could range from approximately one-sixth to about double these figures.

Thus, current levels of particulate air pollution have a considerable impact on public health. Measures to reduce levels of particulate air pollution, or to reduce exposure of the population to such pollution, are regarded as an important public health initiative.

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Changes made to this document since its first publication are as follows.

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The text of Appendix C, section C6, has been amended to provide clarification of the methods used for mortality burden estimates for combinations of individual local authority areas.

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1 INTRODUCTION

1.1 Health effects of air pollution

Much of outdoor air pollution arises from the burning of fossil fuels to generate heat and electricity, and to power vehicles. Combustion of fossil fuels emits gases such as sulphur dioxide (SO_2), nitrogen oxides [NO_x: nitrogen dioxide (NO_2) and nitric oxide (NO)] and other chemical species, as well as small particles. The gases can react with other pollutants in the air, such as solvents released by industry or ammonia emissions from agriculture, to form secondary pollutants including ozone and secondary particles (eg ammonium nitrate). Particles in the air can also arise from other sources, such as the resuspension of road dust by vehicles or soil blown by the wind.

Both population-based epidemiological time-series studies of the effects of short-term variations in air pollutant concentrations and studies on volunteers have shown that short-term exposure to high levels of various air pollutants can cause a range of adverse effects. These include exacerbation of asthma, effects on lung function, increases in hospital admissions for respiratory and cardiovascular conditions, and increases in mortality (COMEAP, 1998, 2001; WHO, 2006). Cohort studies, following people's health over several years, have shown that long-term exposure to air pollution also increases mortality risk. The relative risks associated with long-term exposure to particulate air pollution are higher than those reported from time-series studies examining the health effects associated with short-term variations in air pollution concentrations.

Outdoor air pollution has decreased considerably in the UK in recent decades, due to a combination of legislation and technological advances. These include measures such as banning the burning of coal in urban areas and the development and application of abatement technology to reduce emissions from industry and vehicles. Member states of the European Union (EU) are required to comply with legally binding limit values for ambient concentrations of some air pollutants, including PM_{10}*, $PM_{2.5}$† and NO_2. Within the UK, local authorities are required, under local air quality management (LAQM), to identify areas where national objectives for several air pollutants (benzene, 1,3-butadiene, carbon monoxide, lead, NO_2, PM_{10} and SO_2) are exceeded or are at risk of being exceeded, and to develop action plans to reduce air pollution in order to work towards meeting the objectives.

The results of large cohort studies of adults (eg Dockery et al, 1993; Pope et al, 2002) suggest that the effect of long-term exposure to air pollution on mortality is most closely associated with ambient levels of fine particulate matter ($PM_{2.5}$) and that there is no evidence for a threshold below which effects would not be expected (COMEAP, 2009). This means that current levels of particulate air pollution in the UK, and elsewhere in Europe, have a significant impact on the life expectancy of the population. Because of this, EU member states are required to achieve a reduction in population exposure to $PM_{2.5}$, as indicated by concentrations monitored at background locations in major urban areas, averaged over a

* PM_{10} is defined as the mass per cubic metre of airborne particles passing through the inlet of a size selective sampler with a transmission efficiency of 50% at an aerodynamic diameter of 10 µm. In practice, PM_{10} represents the mass concentration of all particles of generally less than 10 µm aerodynamic diameter. This fraction can pass the thorax and enter the conducting airways.

† $PM_{2.5}$ is the mass concentration of particles of generally less than 2.5 µm aerodynamic diameter. This fraction can penetrate deep into the lungs.

period of three years. In the UK, a 15% reduction in this average exposure indicator (AEI) is required over a period of 10 years from 2010. Although local authorities do not have direct responsibilities to control $PM_{2.5}$ concentrations, many of the measures that local authorities can use to reduce levels of PM_{10} and NO_2 will also reduce emissions of $PM_{2.5}$.

1.2 Background

The Committee on the Medical Effects of Air Pollutants (COMEAP) produced its report *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom* in December 2010 (COMEAP, 2010). As well as predicting the reduction in mortality that would result from specified improvements in air quality, the report included an estimate of the mortality burden of existing levels of air pollution on the population of the UK: an effect on mortality in 2008 equivalent to 29,000 deaths and an associated loss to the population of 340,000 life-years.

COMEAP's national estimate of the mortality burden attributable to long-term exposure to particulate air pollution is considered to be useful in communicating about the public health significance of air pollution. Local estimates of the mortality burden associated with particulate air pollution in London were already published in the *Report on Estimation of Mortality Impacts of Particulate Air Pollution in London* for the Mayor of London (Miller, 2010). In order to assess the need for other local mortality burden estimates, the Health Protection Agency (HPA)* sought views from some individual local authorities as well as running discussion sessions at workshops organised by Environmental Protection UK (April 2011) and the London Air Quality Network (July 2011). These confirmed that local estimates were viewed as desirable and potentially helpful for communication, both with the public and with local elected representatives and professionals. Local estimates were considered to be particularly relevant in the context of the greater responsibilities for public health being given to local authorities.

Because local mortality burden estimates may be more uncertain than national figures, the HPA asked COMEAP to comment on the technical considerations that may be particularly relevant to local assessments and to advise on possible approaches to such calculations. COMEAP's statement on this topic was published in August 2012 (COMEAP, 2012).

COMEAP's opinion that mortality burden estimates could be calculated at the local authority level informed the Department of Health's decision to include the mortality effect associated with particulate air pollution as an indicator in its public health outcomes framework (PHOF) for England (indicator 3.1). The indicator adopted is the 'fraction of all-cause adult mortality attributable to long-term exposure to current levels of anthropogenic particulate air pollution' (DH, 2012).

It was thought that local authorities (and possibly others) may wish to generate their own mortality burden estimates in various metrics. COMEAP (2012) therefore recommended methods that were defensible scientifically but sufficiently simple to be undertaken by those without specialist expertise of the use of actuarial life-table approaches. COMEAP also advised that the centralised production of mortality estimates for all local authorities would be cost-beneficial.

* In April 2013, the Health Protection Agency was abolished and its functions transferred to Public Health England (PHE).

Following from the COMEAP advice, this report includes:

a Guidance on how to estimate the mortality burden of long-term exposure to particulate air pollution at the local authority level (see Appendix A)

b Estimates of the mortality burden of long-term exposure to particulate air pollution for all unitary, upper tier and lower tier local authorities in the UK as well as for some combinations of local authorities that were thought to be useful for administrative reasons (eg local health boards in Wales)

1.3 Use of this report

This report is intended to inform public health professionals and air quality specialists, particularly those within local authorities, who will find the figures in the report helpful in raising awareness of the mortality burden of air pollution within their local area. By raising awareness of the effect of air pollution on public health, the figures should also encourage advocacy of the need for local – and also regional, national and international – actions to reduce air pollution. Individual authorities can implement measures to encourage and achieve reductions in local emissions and population exposure to air pollutants. However, more significant reductions in pollution will require action at all these levels.

Local health and wellbeing boards have a particularly important role to play under the new public health arrangements for England. These boards are established at upper tier and unitary authority levels, and are under a statutory duty to involve local people in the preparation of joint strategic needs assessments (JSNA) and the development of joint health and wellbeing strategies. These will enable public health strategies to be developed that meet the needs of the whole local community, in particular for the most vulnerable individuals and the groups with the worst health outcomes. Staff within PHE centres and Public Health Wales, and local authority specialists, will be able to use the figures within this report to brief their directors of public health on the need to consider the importance of the effects of air pollution on health when prioritising local needs. In Wales the estimates of mortality have been produced for both local authorities and health boards to help raise awareness of the relative importance of air pollution within relevant health and wellbeing strategies. It is expected that the figures will also be useful to staff within the different local structures that apply in Scotland and Northern Ireland.

Air pollution affects mortality from cardiovascular and respiratory conditions, including lung cancer. Measures implemented to reduce exposure to air pollution will, therefore, also deliver benefits for other indicators within the PHOF, including those reflecting premature mortality from these causes (indicators 4.4, 4.5 and 4.7). As well as reducing polluting emissions, encouragement of active travel – ie walking or cycling on journeys for which a car would previously have been used – will also have wider public health benefits associated with increased physical fitness. These benefits will contribute towards progress on other PHOF indicators: for example, indicators related to excess weight at various ages (indicators 2.6 and 2.12), as well as indicator 2.13, which reflects the proportion of physically active adults (DH, 2012).

Thus, the estimates of mortality burdens in this report can be viewed primarily as a tool for communication about the importance of good air quality for public health, and for raising awareness of the need to consider air pollution – alongside other local public health concerns – when establishing priorities for coherent action to improve public health locally.

It should be noted that the aim of this work is to scope the scale of the public health problem associated with air pollution: the methods used are not intended for the quantitative evaluation of the health impacts of local measures to reduce air pollution. Actuarial life-table methods are regarded as the most appropriate for predicting the mortality benefits from long-term changes in particulate air pollution, as they allow changes in the size and age structure of the population resulting from the change to be taken into account (described in COMEAP, 2010). Information on how the health benefits of anticipated reductions in air pollutant concentrations can be predicted and valued is available from the Interdepartmental Group on Costs and Benefits (Air)* and HM Treasury†.

The estimates within this report are most appropriately used within a local authority area for comparison with health burdens from other risk factors. Comparisons of mortality burdens between local authorities are not an appropriate basis to assess good or poor practice. This is because modelled population-weighted annual average concentrations of anthropogenic fine particulate matter ($PM_{2.5}$) are dependent upon characteristics of the area, such as the proportion of the population living in urban and rural areas, and the extent to which concentrations are influenced by pollution from sources elsewhere.

2 MORTALITY BURDEN ESTIMATES – METHODS, METRICS AND UNCERTAINTIES

2.1 Background

2.1.1 Size of effect and levels of pollutants

The results of epidemiological studies of the effects of air pollution are typically reported as an increase in the risk of an adverse health outcome (such as incidence of a disease or death) associated with a certain increment of air pollution: for example, a relative risk (RR) per 10 µg m^{-3} increase in $PM_{2.5}$. The results of such studies can be used to quantify the effects of current levels of air pollutants (ie the health or mortality *burden* on the population), or of changes in air pollution levels (ie the health or mortality *impacts* of the changes).

In its report *Long-Term Exposure to Air Pollution: Effect on Mortality*, COMEAP (2009) recommended a concentration-response coefficient for use in quantifying the mortality effect of long-term exposure to particulate air pollution, based on the results of a study by Pope et al (2002): an RR of 1.06 for all-cause mortality per 10 µg m^{-3} increase in fine particulate matter ($PM_{2.5}$). This coefficient was used in COMEAP's quantification of mortality effects (COMEAP, 2010).

COMEAP's calculations of national mortality burdens attributable to particulate air pollution (COMEAP, 2010) were based on population-weighted modelled annual mean concentrations at background locations‡ of $PM_{2.5}$ arising from human activities. COMEAP chose to develop

* https://www.gov.uk/air-quality-economic-analysis

† https://www.gov.uk/government/organisations/hm-treasury/series/the-green-book-supplementary-guidance

‡ The pollution climate mapping (PCM) model is used to estimate annual mean concentrations at 'background' locations in both urban and rural areas, representative of the exposure of the general population, as defined in EU Directive 2008/50/EC on ambient air quality: ie locations that (a) are not within a steep concentration gradient influenced by a single source such as a road or an industrial installation and (b) integrate all local sources.

estimates of the burden associated with anthropogenic (human-made), rather than total, particulate pollution as this would be the theoretical maximum that could potentially be influenced by policy interventions: there is little that can be done to reduce levels of particulates from natural sources (eg sea salt), but these generally make up only a small fraction of the total airborne concentration.

The modelling of annual average background $PM_{2.5}$ concentrations used methods developed by the Department for Environment, Food and Rural Affairs (Defra) to assess compliance with (and reporting under) EU directives. An additional step was included to apportion various sources/components of particulate air pollution as being either the result of human activity or naturally occurring. The pollution climate mapping (PCM) model uses dispersion modelling based on emissions data from the national atmospheric emissions inventory (NAEI), chemical transport modelling and measurement data for specific PM components to estimate the concentration of $PM_{2.5}$ at background locations in each 1 km x 1 km grid square. These modelled concentrations are then calibrated against monitoring data. Population statistics were applied to the modelled concentrations to calculate the population-weighted annual average modelled anthropogenic $PM_{2.5}$ concentrations for each local authority area. The derivation of these figures is explained in more detail in Appendix B.

2.1.2 Conceptual issues

The burden of mortality attributable to long-term exposure to particulate air pollution can be thought of as the difference between two scenarios (COMEAP, 2010):

a Baseline scenario: a population that experiences current age-specific death rates (which are influenced by air pollution)

b Alternative scenario: a population with the same age structure that experiences age-specific death rates that would be the case if anthropogenic air pollution were not present (ie death rates that are reduced by an amount implied by current levels of air pollution)

Such mortality burden estimates are based on a number of underlying assumptions and approximations. These have been discussed in detail by COMEAP (2010) which noted that the assumptions (for example, using population data and death rates in a specific year) are the same as those typically used by international experts in calculations of the health burden of air pollution. COMEAP also noted that, because of the complex effects of air pollution on population dynamics (ie the size and age structure of the population) and the lag between exposure and effect, there are different ways of interpreting what the burden represents. Perhaps the most straightforward interpretation is to think of a burden estimate as the effect on mortality, in a given year, of long-term exposure of the current population to current levels of particulate air pollution*.

* The estimates are calculated using concentration-response coefficients from epidemiological studies. Exposure assessments in these studies are typically based on annual average concentrations in a given year, or concentrations averaged over a few years, while the coefficients reported are understood to reflect the risk associated with long-term exposure over many years. Therefore, the concentration-response coefficients also reflect the effects of historical exposure of the study participants to air pollution. Historical exposures are likely to be correlated with current levels and current concentrations can, therefore, also be viewed as a proxy for long-term exposure history.

2.2 Metrics and methods

In its *Statement on Estimating the Mortality Burden of Particulate Air Pollution at the Local Level* COMEAP (2012) recommended three metrics for calculating local estimates of mortality burden associated with particulate air pollution: 'attributable fraction', 'attributable deaths' and 'years of life lost to the population'. These are outlined below. Guidance on how to undertake such calculations, and where to obtain the input data required, are provided in Appendix A. The methods used to calculate the estimates of the mortality burden attributable to long-term exposure to particulate air pollution presented in this report are detailed in Appendix C.

2.2.1 Attributable fraction

In this context, the attributable fraction (AF) is the proportion of local deaths attributable to long-term exposure to anthropogenic particulate air pollution.

For population exposure to air pollution, the attributable fraction is calculated from a relative risk estimate (RR) using the formula:

$$AF = (RR - 1)/RR$$

Attributable fraction is often expressed as a percentage and, therefore, calculated as

$$100 \times (RR - 1)/RR$$

For example, the proportion of deaths attributable to 10 μg m^{-3} $PM_{2.5}$, assuming an associated relative risk of 1.06, would be 100 × 0.06/1.06 = 5.7%. The relative risk applicable locally is derived by scaling the concentration-response function of 1.06 per 10 μg m^{-3} $PM_{2.5}$ according to the local air pollution concentrations (population-weighted modelled annual average anthropogenic $PM_{2.5}$ concentrations). Log (multiplicative) scaling can be used (see Appendix A) or the RR can be approximated by linear scaling (ie by assuming that if 10 μg m^{-3} leads to a 6% change in risk, then concentrations which differ by 1 μg m^{-3} should lead to differences of 0.6% in risk). Log scaling has been used in developing the estimates in this report.

2.2.2 Attributable deaths

An estimate of deaths attributable to long-term exposure to air pollution in a local area can be made by multiplying the attributable fraction by the total number of deaths annually in the local area.

COMEAP (2010, 2012) recognised that the 'number of deaths' was a metric widely used in communicating about public health risks. Nonetheless, COMEAP stressed that a calculated figure of 'attributable deaths' does not represent the number of individuals whose length of life has been shortened by air pollution. Long-term exposure to air pollution is understood to be a contributory factor to deaths from respiratory and, particularly, cardiovascular disease, ie unlikely to be the sole cause of deaths of individuals. This means that it is likely that air pollution contributes a small amount to the deaths of a larger number of exposed individuals rather than being solely responsible for a number of deaths equivalent to the calculated figure of 'attributable deaths', although the distribution of the mortality effect within the population is unknown.

Reporting the burden simply in terms of attributable deaths gives no feel for the loss of life associated with these deaths. Long-term exposure to air pollution increases the risk of dying at ages typical for deaths from respiratory and cardiovascular diseases, and there is no clear evidence that the increase in risk differs between different adult age groups (though, of course, the underlying mortality risk is highly dependent on age). Similar considerations apply to other risk factors that contribute to mortality from chronic respiratory and cardiovascular diseases, such as obesity or exposure to environmental tobacco smoke. This means that the loss of life associated with deaths affected by these risk factors is different from that associated with risks which may cause deaths at an unusually young age and disproportionately affect particular age groups (eg road traffic accidents). For these reasons, COMEAP (2010, 2012) considers it most appropriate to express the results of these calculations of attributable deaths as 'an effect on mortality equivalent to '*X*' deaths at typical ages'.

Estimates of mortality attributable to long-term exposure to particulate air pollution are usually based on the number of deaths in adults aged 30 years or more, reflecting the age of the subjects in the study (Pope et al, 2002) from which the concentration-response coefficient used in the calculations is derived. However, the Office for National Statistics (ONS) in England and Wales publishes data on adult mortality in 10-year age groups of 25–34, 35–44, etc. As there are relatively few deaths in those aged 25–29, using deaths in those aged 25+ as the basis of the calculation will make little difference to the burden estimate, and this is the approach adopted in generating the estimates in this report. COMEAP (2012) suggested that even including deaths at all ages in the calculation (ie the total number of local deaths) would make only a small difference to the estimate, as there are few deaths in those under 30.

2.2.3 Years of life lost by the local population

The mortality burden can, additionally, be calculated as the loss of life associated with the attributable deaths, and expressed as years of life lost to the population. COMEAP (2012) considered this a particularly useful metric to support decision-making, as it combines information on both attributable deaths and age at death. It also allows an exploration of the individual loss of life that would be associated with different distributions of the mortality effect across the population (see COMEAP, 2010).

The mortality burdens in this report, expressed in terms of years of life lost to the population, have been calculated by multiplying the numbers of attributable deaths at each age by estimates of their age-specific remaining life expectancies; this requires the use of actuarial life-tables (see COMEAP, 2010, for further discussion). For calculations being undertaken by those without experience in this technique, COMEAP (2012) suggested that a reasonable estimate could be made by multiplying the calculated figure for attributable deaths by an average loss of life of 12 years – this was the figure calculated in its national estimates (COMEAP, 2010).

2.3 Uncertainties

Estimation of the mortality burden attributable to long-term exposure to particulate air pollution is subject to a number of uncertainties. These include (COMEAP, 2010, 2012):

a Uncertainties in applying, in the UK, the relative risk coefficient of 1.06 per 10 µg m^{-3} increase in $PM_{2.5}$ which was reported from a study in the US (Pope et al, 2002)

b COMEAP (2009) used an expert elicitation exercise to express the likely range of the mortality risk associated with an increase in $PM_{2.5}$ of 10 µg m^{-3}, taking account of factors such as the strength of evidence for causality, and confidence in the transferability of the concentration-response coefficient from the US to the UK, as well as the 95% statistical sampling confidence interval (CI) reported in the study. This exercise gave a 75% plausibility interval of 1.01–1.12 and a 95% plausibility interval of 1.00–1.15, which were recommended for use in sensitivity analyses

c Uncertainty when extrapolating beyond the lowest annual average concentration (7 µg m^{-3}) of $PM_{2.5}$ in the American Cancer Society study (Pope et al, 2002) from which the coefficient recommended by COMEAP (2009) is derived

d Uncertainties in the modelling of annual average $PM_{2.5}$ concentrations, and in classifying particular sources as anthropogenic

The uncertainties relating to the estimated risk coefficient, and its application within the UK and to concentrations outside the range of the study, reflect the uncertainty in the relationship between ambient $PM_{2.5}$ concentrations and effects on mortality. Thus, whilst they are important in terms of the size of the absolute effect, they would not affect comparisons between local authority areas. Since COMEAP's (2009) consideration of this topic, evidence of associations of long-term exposure to $PM_{2.5}$ with mortality risk has continued to accumulate. A recent systematic review reported a pooled effects estimate for all-cause mortality associated with $PM_{2.5}$ of 1.06 (95% CI 1.04–1.08) from a meta-analysis of cohort studies, which included studies in Europe and Canada as well as the US (Hoek et al, 2013).

Calculations of estimates for local authorities are all generated using the same relative risk, and the variation in the attributable fraction between local authorities is predicted by the variation in $PM_{2.5}$ concentration in the local authority areas. Uncertainties in the modelling of pollutant concentrations would affect the relative size of burdens in different local authority areas.

There are additional uncertainties in generating burden estimates at a local, rather than national, level. COMEAP (2012) discussed some of these under three headings: 'representativeness', 'variability and instability of small datasets' and 'approximation introduced by the simplified methods recommended'. These uncertainties are summarised below.

2.3.1 Representativeness

In local assessments, there is an increased likelihood of differences between the local situation and the conditions of the study from which the relative risk coefficient (concentration-response function) is derived:

a Additional uncertainty is introduced if the contributions of different sources (and, hence, components) to the total anthropogenic $PM_{2.5}$ concentrations are not the same in the locality assessed as in the country as a whole

b Modelled background $PM_{2.5}$ concentrations at the residential address are used as a proxy for exposure of the resident population. The relationship between personal exposure to air pollution and modelled residential background $PM_{2.5}$ concentration depends on a number of factors, including the variety of conditions locally and how widely people travel. The relative risk coefficient used in the calculations is from a study relating differences in mortality to differences in city-wide background $PM_{2.5}$ concentrations. It can be expected that the further an assessment differs from this basis, the greater the uncertainty in the resulting estimate, due to differences in the relationship between background $PM_{2.5}$ concentrations at the residential address and the range of personal exposures experienced by the population under consideration

2.3.2 Variability in small datasets

Year-on-year variations in local annual numbers of deaths are typically larger (in percentage terms) than in the national statistics. This can lead to greater uncertainties if baseline mortality data from a single year is used for local estimates. The variability can be reduced by averaging data from several years.

2.3.3 Approximation introduced by the recommended methods

When recommending methods for estimating burden at the local level, COMEAP (2012) suggested a number of approximations that could be applied. These include:

- **a** Linear scaling of the relative risk coefficient
- **b** Use of deaths in those aged 25+, or the total number of deaths, rather than those at ages 30+
- **c** Universal application of an average loss of life per attributable death of 12 years

2.3.4 Modelling uncertainties

In addition, there are other uncertainties associated with the modelling of background $PM_{2.5}$ concentrations at a local level, including those relating to the accuracy, at a local level, of national atmospheric emissions inventory (NAEI) emissions factors and activity data. The uncertainty in the modelled $PM_{2.5}$ concentration for individual local authorities is likely to be greater than the uncertainty in the modelled overall UK average concentration.

3 MORTALITY BURDEN ESTIMATES AT A LOCAL AUTHORITY LEVEL – RESULTS

Tables 1 to 4 present estimates of the mortality burden on the local population attributable to anthropogenic particulate air pollution for each local authority area in the UK for 2010. For England (Table 1), regional estimates are also presented, as are estimates for the local health boards in Wales (Table 2). Estimates for council areas in Scotland and local government districts of Northern Ireland are presented in Tables 3 and 4, respectively. Estimates of attributable deaths and years of life lost to the population can be generated for different combinations of local authorities, if required, by addition. National estimates for the UK and each of its constituent countries are presented in Table 5.

These tables present central estimates. Based on the 75% plausibility interval recommended by COMEAP (2009), the actual burden could vary from about a sixth to double these central estimates. This plausibility interval reflects the uncertainty in the relationship between ambient $PM_{2.5}$ concentrations and effects on mortality. Thus, while it is important in terms of the size of the absolute effect, it does not reflect uncertainties which would affect comparisons over time or between areas. There is no accepted way of fully quantifying the uncertainty associated with modelled concentrations of $PM_{2.5}$ (see Appendix B).

Text continues on page 22

TABLE 1 England: baseline population, modelled population-weighted mean concentrations (µg m^{-3}) and estimated effects on annual mortality in 2010 of anthropogenic $PM_{2.5}$ air pollution

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (µg m^{-3})*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
ENGLAND	**35878.0**	**458743**	**9.9**	**5.6**	**25002**	**264749**
NORTH EAST	**1795.3**	**26090**	**8.1**	**4.6**	**1199**	**12336**
County Durham UA	355.3	5231	7.5	4.3	223	2268
Darlington UA	70.6	1044	8.0	4.5	47	481
Hartlepool UA	62.3	920	8.3	4.7	43	451
Middlesbrough UA	91.4	1363	8.8	5.0	68	695
Northumberland UA	227.0	3254	6.9	3.9	128	1284
Redcar and Cleveland UA	96.9	1368	7.8	4.5	61	664
Stockton-on-Tees UA	131.0	1662	8.2	4.6	77	872
Tyne and Wear (Met C)						
Gateshead	135.3	2031	8.6	4.9	99	962
Newcastle upon Tyne	180.6	2553	8.6	4.9	124	1320
North Tyneside	141.5	2112	8.4	4.8	101	998
South Tyneside	107.4	1675	8.8	5.0	84	864
Sunderland	196.1	2874	8.7	5.0	143	1477
NORTH WEST	**4733.0**	**67871**	**8.9**	**5.1**	**3427**	**35855**
Blackburn with Darwen UA	87.9	1244	8.9	5.1	63	667
Blackpool UA	98.5	1838	7.5	4.3	79	808
Cheshire East UA	260.8	3565	8.7	4.9	175	1764
Cheshire West and Chester UA	230.5	3119	8.2	4.7	146	1473
Halton UA	80.6	1131	9.7	5.5	62	659
Warrington UA	138.1	1746	9.6	5.4	95	1012
Cumbria CC	359.8	5367	6.4	3.6	195	1993
Allerdale	68.8	1073	6.0	3.4	37	359
Barrow-in-Furness	49.8	724	6.8	3.9	28	320
Carlisle	74.4	1121	6.7	3.8	43	446
Copeland	50.5	715	6.0	3.4	24	263
Eden	38.5	534	6.2	3.5	19	185
South Lakeland	77.9	1201	6.4	3.7	44	419
Greater Manchester (Met C)						
Bolton	178.3	2476	9.6	5.5	135	1511
Bury	125.3	1749	9.7	5.5	96	947
Manchester	298.1	3708	10.4	5.9	219	2508
Oldham	144.1	2059	10.1	5.7	118	1263
Rochdale	136.8	1905	9.6	5.5	104	1137
Salford	150.8	2321	10.5	5.9	138	1390
Stockport	200.2	2649	10.1	5.7	151	1636
Tameside	147.7	2185	10.3	5.8	127	1312
Trafford	150.5	1863	9.9	5.6	105	1138
Wigan	214.1	2952	9.2	5.2	153	1610

TABLE 1 ***Continued***

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (μg m^{-3})*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
Lancashire CC	808.7	11738	8.1	4.6	540	5582
Burnley	57.6	893	8.7	4.9	44	481
Chorley	74.8	954	8.7	5.0	47	498
Fylde	57.5	959	7.3	4.2	40	370
Hyndburn	54.3	842	9.0	5.1	43	447
Lancaster	94.9	1457	7.3	4.2	61	615
Pendle	60.4	809	8.2	4.7	38	440
Preston	86.9	1224	8.7	5.0	61	639
Ribble Valley	41.6	557	7.5	4.3	24	233
Rossendale	46.1	665	8.3	4.7	31	322
South Ribble	76.6	935	8.6	4.9	46	490
West Lancashire	76.3	1097	8.3	4.7	52	506
Wyre	81.4	1347	7.0	4.0	54	542
Merseyside (Met C)						
Knowsley	99.9	1406	9.7	5.5	77	862
Liverpool	289.3	4388	9.6	5.4	239	2440
Sefton	193.9	3128	8.1	4.6	145	1464
St Helens	123.8	1792	9.7	5.5	98	1027
Wirral	215.1	3543	8.2	4.7	166	1652
YORKSHIRE AND THE HUMBER	**3584.3**	**48534**	**9.3**	**5.3**	**2567**	**26636**
East Riding of Yorkshire UA	245.2	3485	8.7	4.9	172	1702
Kingston upon Hull, City of UA	173.5	2360	10.5	5.9	140	1512
North East Lincolnshire UA	107.6	1620	9.9	5.6	91	936
North Lincolnshire UA	114.0	1596	9.7	5.5	88	948
York UA	135.8	1706	8.5	4.8	82	833
North Yorkshire CC	431.0	5954	7.6	4.3	257	2590
Craven	41.3	620	6.9	3.9	24	225
Hambleton	63.6	790	7.5	4.3	34	368
Harrogate	114.1	1543	7.8	4.4	68	678
Richmondshire	35.8	444	6.8	3.9	17	180
Ryedale	39.3	558	7.3	4.2	23	232
Scarborough	78.9	1336	7.4	4.2	56	559
Selby	58.1	664	9.0	5.1	34	349
South Yorkshire (Met C)						
Barnsley	158.6	2320	9.5	5.4	124	1249
Doncaster	201.1	2874	9.8	5.6	160	1706
Rotherham	176.0	2539	10.1	5.7	145	1406
Sheffield	361.4	4882	9.7	5.5	269	2664
West Yorkshire (Met C)						
Bradford	325.1	4233	9.3	5.3	222	2318
Calderdale	139.7	1843	8.9	5.0	93	1018
Kirklees	271.4	3629	9.5	5.4	196	2051
Leeds	516.7	6347	9.7	5.5	350	3825
Wakefield	227.1	3147	10.0	5.7	178	1878

TABLE 1 *Continued*

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (μg m^{-3})*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
EAST MIDLANDS	**3087.2**	**40806**	**10.1**	**5.7**	**2314**	**24016**
Derby UA	163.3	2146	10.8	6.1	131	1425
Leicester UA	189.5	2448	11.7	6.6	162	1736
Nottingham UA	183.2	2332	11.4	6.4	150	1559
Rutland UA	26.5	333	9.1	5.1	17	183
Derbyshire CC	546.5	7469	9.5	5.4	402	4041
Amber Valley	87.3	1219	9.6	5.5	67	656
Bolsover	52.7	823	10.0	5.6	46	440
Chesterfield	72.4	1098	9.5	5.4	59	572
Derbyshire Dales	52.5	716	8.2	4.7	33	306
Erewash	79.0	1010	10.7	6.1	61	647
High Peak	65.6	824	8.4	4.8	39	451
North East Derbyshire	72.0	1017	9.5	5.4	55	529
South Derbyshire	65.0	763	9.6	5.4	42	439
Leicestershire CC	450.3	5499	10.1	5.7	313	3322
Blaby	66.9	759	10.5	5.9	45	517
Charnwood	108.8	1332	10.4	5.9	78	829
Harborough	59.9	681	9.6	5.4	37	403
Hinckley and Bosworth	76.1	906	9.9	5.6	51	529
Melton	35.5	425	9.3	5.3	23	241
North West Leicestershire	64.8	846	9.9	5.6	47	487
Oadby and Wigston	38.3	550	10.5	5.9	33	316
Lincolnshire CC	500.8	7407	9.2	5.2	387	3966
Boston	42.1	674	9.3	5.3	36	356
East Lindsey	105.7	1796	8.6	4.9	88	898
Lincoln	56.5	825	9.8	5.6	46	495
North Kesteven	76.5	1029	9.4	5.4	55	546
South Holland	61.7	991	9.1	5.2	51	487
South Kesteven	94.4	1219	9.6	5.4	66	683
West Lindsey	63.9	873	9.1	5.1	45	501
Northamptonshire CC	473.8	5613	10.2	5.7	323	3513
Corby	37.5	515	9.9	5.6	29	330
Daventry	55.5	608	9.7	5.5	33	349
East Northamptonshire	59.4	771	9.7	5.5	42	390
Kettering	63.2	807	10.2	5.8	47	493
Northampton	141.8	1665	10.8	6.1	102	1168
South Northamptonshire	63.5	636	9.5	5.4	34	384
Wellingborough	52.9	611	10.4	5.9	36	400
Nottinghamshire CC	553.3	7558	10.1	5.7	430	4270
Ashfield	82.0	1175	10.2	5.7	68	662
Bassetlaw	80.0	1149	9.4	5.3	61	620
Broxtowe	80.6	1022	10.8	6.1	62	612
Gedling	81.3	1077	10.3	5.8	63	628
Mansfield	70.0	1013	9.9	5.6	57	594
Newark and Sherwood	80.5	1149	9.6	5.4	63	626
Rushcliffe	79.0	972	10.2	5.8	56	528

TABLE 1 ***Continued***

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ ($\mu g\ m^{-3}$)*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
WEST MIDLANDS	**3714.5**	**50110**	**10.0**	**5.7**	**2837**	**29897**
Herefordshire, County of UA	131.1	1895	7.8	4.5	85	870
Shropshire UA	210.8	3075	7.4	4.2	130	1289
Stoke-on-Trent UA	162.2	2450	9.9	5.6	138	1420
Telford and Wrekin UA	109.2	1299	8.5	4.8	63	712
Staffordshire CC	588.8	7879	9.2	5.2	410	4197
Cannock Chase	65.8	841	9.4	5.3	45	476
East Staffordshire	76.0	1004	9.4	5.3	53	556
Lichfield	71.0	981	9.5	5.4	53	503
Newcastle-under-Lyme	86.5	1205	9.2	5.2	63	662
South Staffordshire	77.4	1087	9.2	5.2	57	562
Stafford	90.2	1210	8.9	5.0	61	608
Staffordshire Moorlands	70.3	1012	8.4	4.8	48	475
Tamworth	51.6	539	9.9	5.6	30	355
Warwickshire CC	378.9	4861	9.8	5.5	269	2782
North Warwickshire	44.5	599	10.1	5.7	34	343
Nuneaton and Bedworth	84.6	1116	10.1	5.7	64	676
Rugby	64.8	852	9.7	5.5	47	481
Stratford-on-Avon	87.5	1160	9.1	5.2	60	588
Warwick	97.5	1134	10.0	5.7	64	694
West Midlands (Met C)						
Birmingham	643.6	8122	11.4	6.4	520	5707
Coventry	202.6	2684	11.1	6.2	168	1882
Dudley	215.5	2923	10.5	5.9	173	1808
Sandwell	194.8	2883	12.2	6.9	198	2073
Solihull	143.2	1771	10.7	6.0	107	1152
Walsall	172.2	2431	11.3	6.4	155	1684
Wolverhampton	161.8	2412	10.2	5.8	139	1451
Worcestershire CC	400.0	5424	9.2	5.2	283	2871
Bromsgrove	67.4	987	9.9	5.6	55	477
Malvern Hills	55.0	919	8.4	4.8	44	378
Redditch	54.9	613	10.0	5.6	35	401
Worcester	65.4	803	9.5	5.4	43	485
Wychavon	85.7	1101	9.0	5.1	56	594
Wyre Forest	71.6	1001	8.8	5.0	50	536
EAST	**4042.9**	**51211**	**9.9**	**5.6**	**2844**	**29096**
Bedford UA	109.0	1325	9.8	5.5	73	802
Central Bedfordshire UA	178.3	1928	9.7	5.5	106	1158
Luton UA	123.3	1336	11.4	6.4	86	1004
Peterborough UA	114.3	1382	10.1	5.7	79	829
Southend on Sea UA	115.5	1873	10.8	6.1	115	1022
Thurrock UA	105.5	1131	11.5	6.5	73	821

TABLE 1 ***Continued***

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (μg m^{-3})*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
Cambridgeshire CC	421.1	4721	9.6	5.5	257	2762
Cambridge	75.8	808	10.2	5.8	47	468
East Cambridgeshire	59.9	643	9.1	5.1	33	378
Fenland	66.3	1012	9.4	5.3	54	562
Huntingdonshire	117.6	1212	9.7	5.5	67	743
South Cambridgeshire	101.4	1045	9.5	5.4	57	611
Essex CC	986.9	12681	10.1	5.7	724	7386
Basildon	119.6	1449	11.0	6.2	90	940
Braintree	100.5	1293	9.6	5.5	71	651
Brentwood	52.6	667	10.6	6.0	40	398
Castle Point	63.8	878	10.6	6.0	53	536
Chelmsford	118.4	1239	10.2	5.8	72	796
Colchester	121.4	1352	9.7	5.5	75	811
Epping Forest	88.2	1183	10.7	6.0	71	681
Harlow	54.8	648	10.7	6.0	39	465
Maldon	45.4	573	9.5	5.4	31	316
Rochford	59.4	772	10.1	5.7	44	431
Tendring	110.0	2027	9.3	5.3	107	1039
Uttlesford	52.8	599	9.5	5.4	32	322
Hertfordshire CC	759.0	8842	10.3	5.8	514	5258
Broxbourne	62.3	651	10.6	6.0	39	448
Dacorum	99.1	1129	9.9	5.6	63	675
East Hertfordshire	96.8	1024	10.0	5.6	58	602
Hertsmere	68.8	902	10.7	6.1	55	526
North Hertfordshire	88.7	1234	9.8	5.6	69	613
St Albans	95.2	1012	10.3	5.8	59	612
Stevenage	54.9	626	10.2	5.8	36	399
Three Rivers	62.1	725	10.4	5.9	43	440
Watford	57.7	648	11.2	6.3	41	387
Welwyn Hatfield	73.3	891	10.4	5.9	53	555
Norfolk CC	618.2	8997	8.8	5.0	450	4479
Breckland	95.1	1397	8.8	5.0	70	633
Broadland	91.3	1355	8.8	5.0	68	591
Great Yarmouth	68.9	1091	8.6	4.9	53	558
King's Lynn and West Norfolk	105.2	1568	8.8	5.0	79	797
North Norfolk	78.0	1310	8.3	4.7	62	591
Norwich	92.3	1101	9.7	5.5	61	720
South Norfolk	87.3	1174	8.7	5.0	58	591
Suffolk CC	511.8	6995	9.3	5.3	366	3577
Babergh	62.3	901	9.4	5.3	48	429
Forest Heath	42.8	469	9.2	5.2	25	258
Ipswich	86.8	1117	10.0	5.6	63	653
Mid Suffolk	68.7	858	9.1	5.2	45	448
St Edmundsbury	74.6	921	9.5	5.4	50	491
Suffolk Coastal	91.6	1372	9.1	5.2	71	651
Waveney	85.1	1357	8.5	4.8	66	648

TABLE 1 ***Continued***

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (μg m^{-3})*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
LONDON	**5330.6**	**47998**	**12.7**	**7.2**	**3389**	**41404**
Inner London						
Camden	165.5	1126	13.8	7.7	87	1157
Hackney and City of London¶	151.9	1097	14.0	7.9	86	1397
Hammersmith and Fulham	121.9	907	14.1	7.9	72	1070
Haringey	156.0	1142	12.7	7.1	81	1215
Islington	135.3	1069	14.1	7.9	84	1084
Kensington and Chelsea	128.0	824	14.9	8.3	68	1164
Lambeth	200.8	1454	13.7	7.7	112	1520
Lewisham	181.5	1628	12.7	7.2	116	1331
Newham	147.2	1302	13.5	7.6	98	1322
Southwark	197.0	1426	14.1	7.9	113	1651
Tower Hamlets	151.8	1047	14.5	8.1	85	1121
Wandsworth	212.3	1587	13.1	7.3	116	1331
Westminster	182.5	1061	14.9	8.3	88	1403
Outer London						
Barking and Dagenham	109.7	1317	12.6	7.1	93	1027
Barnet	235.8	2397	12.0	6.8	162	1701
Bexley	154.7	1846	11.8	6.6	122	1255
Brent	178.3	1530	12.9	7.2	111	1561
Bromley	217.9	2571	11.1	6.3	161	1621
Croydon	233.4	2391	11.5	6.5	155	1749
Ealing	219.4	1905	12.8	7.2	137	1773
Enfield	195.5	2000	11.8	6.6	133	1509
Greenwich	150.1	1658	12.7	7.2	119	1312
Harrow	155.8	1410	11.3	6.4	90	1100
Havering	163.2	2174	11.1	6.3	137	1397
Hillingdon	172.4	1794	11.6	6.5	118	1335
Hounslow	159.0	1382	12.7	7.1	99	1167
Kingston upon Thames	113.1	1023	11.9	6.7	68	730
Merton	146.6	1186	12.3	6.9	82	974
Redbridge	177.9	1757	12.4	7.0	123	1376
Richmond upon Thames	133.5	1144	12.0	6.8	77	897
Sutton	133.6	1424	11.4	6.4	92	949
Waltham Forest	149.0	1420	12.9	7.3	103	1205
SOUTH EAST	**5884.6**	**74124**	**9.7**	**5.5**	**4034**	**41729**
Bracknell Forest UA	79.1	690	9.8	5.6	38	493
Brighton and Hove UA	176.2	2131	9.5	5.4	115	1333
Isle of Wight UA	103.3	1689	8.1	4.6	78	764
Medway UA	171.6	2044	10.9	6.1	125	1359
Milton Keynes UA	159.7	1534	10.2	5.8	89	1047
Portsmouth UA	132.5	1607	10.5	5.9	95	1059
Reading UA	99.1	1045	10.5	5.9	62	703
Slough UA	84.7	744	12.1	6.8	51	714
Southampton UA	151.9	1761	11.1	6.2	110	1280
West Berkshire UA	106.3	1074	9.7	5.5	59	669

TABLE 1 ***Continued***

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ ($\mu g\ m^{-3}$)*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
Windsor and Maidenhead UA	101.1	1169	10.5	5.9	69	677
Wokingham UA	110.9	1006	10.1	5.7	58	648
Buckinghamshire CC	344.1	3792	9.9	5.6	214	2295
Aylesbury Vale	120.9	1283	9.6	5.4	70	723
Chiltern	63.8	757	9.7	5.5	42	462
South Bucks	47.3	586	10.9	6.2	36	342
Wycombe	112.1	1165	10.1	5.7	66	768
East Sussex CC	372.7	6160	8.4	4.8	294	2786
Eastbourne	69.2	1261	8.5	4.8	61	565
Hastings	60.3	951	9.0	5.1	49	491
Lewes	70.7	1035	8.2	4.6	48	503
Rother	67.4	1322	8.3	4.7	62	537
Wealden	105.1	1591	8.2	4.7	74	689
Hampshire CC	912.5	11351	9.4	5.3	601	6211
Basingstoke and Deane	115.0	1149	9.9	5.6	64	718
East Hampshire	78.8	1045	8.9	5.1	53	482
Eastleigh	85.6	966	10.0	5.7	55	587
Fareham	79.9	1047	9.9	5.6	59	602
Gosport	55.4	748	9.4	5.3	40	434
Hart	63.8	560	9.3	5.3	30	348
Havant	83.3	1222	9.2	5.2	64	680
New Forest	130.6	2002	8.5	4.9	97	899
Rushmoor	61.2	641	10.3	5.8	37	434
Test Valley	80.8	969	9.3	5.3	51	508
Winchester	78.2	1000	9.0	5.1	51	520
Kent CC	984.5	13466	9.8	5.6	745	7436
Ashford	78.8	928	9.4	5.4	50	539
Canterbury	98.6	1516	9.4	5.3	81	748
Dartford	64.3	811	11.8	6.7	54	518
Dover	75.9	1184	9.1	5.2	61	602
Gravesham	67.9	846	10.9	6.2	52	563
Maidstone	105.0	1332	10.0	5.6	75	769
Sevenoaks	81.2	988	10.1	5.7	57	572
Shepway	72.5	1119	9.2	5.2	58	565
Swale	91.0	1194	10.0	5.7	68	700
Thanet	92.0	1697	9.4	5.3	90	830
Tonbridge and Malling	81.6	930	10.0	5.7	53	569
Tunbridge Wells	75.6	920	8.9	5	46	462
Oxfordshire CC	437.2	4967	9.8	5.6	276	2944
Cherwell	97.4	1090	9.9	5.6	61	638
Oxford	91.3	920	10.6	6.0	55	673
South Oxfordshire	92.4	1077	9.6	5.4	59	608
Vale of White Horse	83.1	936	9.8	5.6	52	557
West Oxfordshire	73.0	944	9.2	5.2	49	468

TABLE 1 ***Continued***

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (μg m^{-3})*	Attributable fraction[†] (%)	Attributable deaths[‡] age 25+	Associated life-years lost[§]
Surrey CC	786.5	9286	10.1	5.7	527	5337
Elmbridge	93.7	1058	10.5	5.9	63	643
Epsom and Ewell	51.1	538	10.4	5.9	32	348
Guildford	91.9	969	10.1	5.7	55	577
Mole Valley	60.7	820	9.6	5.4	44	446
Reigate and Banstead	97.5	1225	9.9	5.6	69	596
Runnymede	58.7	657	10.9	6.1	40	427
Spelthorne	66.5	793	11.1	6.3	50	538
Surrey Heath	59.0	635	10.3	5.8	37	373
Tandridge	58.7	754	9.5	5.4	41	416
Waverley	83.1	1115	8.9	5.0	56	554
Woking	65.6	721	9.8	5.5	40	419
West Sussex CC	570.5	8608	8.8	5.0	429	3975
Adur	44.2	704	9.0	5.1	36	335
Arun	111.4	2061	8.4	4.8	98	880
Chichester	82.2	1320	8.7	4.9	65	584
Crawley	72.0	740	9.7	5.5	41	497
Horsham	93.2	1157	8.7	4.9	57	553
Mid Sussex	93.2	1255	8.8	5.0	63	549
Worthing	74.2	1370	8.9	5.0	69	577
SOUTH WEST	**3705.6**	**52000**	**8.2**	**4.7**	**2389**	**23779**
Bath and North East Somerset UA	120.3	1618	8.7	4.9	80	765
Bournemouth UA	113.7	1969	9.0	5.1	100	911
Bristol, City of UA	289.0	3406	10.2	5.8	196	2048
Cornwall and Isles of Scilly UAs**	387.8	5802	6.7	3.8	221	2181
North Somerset UA	151.5	2129	8.1	4.6	98	998
Plymouth UA	169.1	2329	7.9	4.5	105	1094
Poole UA	100.8	1572	9.1	5.2	81	754
South Gloucestershire UA	181.1	1963	9.6	5.4	107	1136
Swindon UA	137.6	1492	10.2	5.8	86	973
Torbay UA	97.8	1717	7.0	4.0	69	662
Wiltshire UA	321.2	4117	8.7	4.9	203	2056
Devon CC	544.4	8115	6.8	3.9	314	2994
East Devon	100.1	1775	6.8	3.9	69	586
Exeter	80.2	981	7.4	4.2	42	438
Mid Devon	54.7	719	7.0	4.0	29	292
North Devon	66.5	1024	6.6	3.8	38	366
South Hams	61.4	886	6.6	3.8	34	312
Teignbridge	93.9	1482	6.8	3.9	58	562
Torridge	48.5	687	6.4	3.6	25	243
West Devon	39.1	561	6.1	3.5	20	194

TABLE 1 ***Continued***

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (μg m^{-3})*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
Dorset CC	299.1	4686	7.8	4.4	207	2002
Christchurch	35.4	637	8.3	4.7	30	275
East Dorset	65.7	992	8.2	4.6	46	451
North Dorset	46.2	622	7.8	4.4	28	274
Purbeck	33.6	467	7.7	4.4	20	214
West Dorset	72.0	1238	7.4	4.2	52	461
Weymouth and Portland	46.1	729	7.4	4.2	31	327
Gloucestershire CC	415.7	5527	8.9	5.0	278	2848
Cheltenham	78.4	1000	9.6	5.5	55	579
Cotswold	61.1	856	8.6	4.9	42	405
Forest of Dean	58.7	814	8.0	4.5	37	368
Gloucester	79.3	991	9.3	5.3	52	575
Stroud	79.7	1101	8.5	4.8	53	497
Tewkesbury	58.5	766	9.0	5.1	39	424
Somerset CC	376.6	5558	7.7	4.4	244	2356
Mendip	76.8	1024	7.8	4.4	45	466
Sedgemoor	80.9	1193	7.9	4.5	54	521
South Somerset	114.4	1651	7.8	4.4	73	706
Taunton Deane	77.5	1217	7.8	4.5	54	488
West Somerset	27.0	473	6.5	3.7	17	174

Abbreviations used in Table 1
UA: unitary authority
CC: county council
Met C: metropolitan county

Notes to Table 1

* **Mean anthropogenic $PM_{2.5}$:** modelled population-weighted annual mean concentrations of fine particulate matter ($PM_{2.5}$) arising from human activities. The pollution climate mapping (PCM) model uses dispersion modelling based on emissions data from the national atmospheric emissions inventory (NAEI), chemical transport modelling and measurement data for specific PM components to estimate the concentration of $PM_{2.5}$ at background locations in each 1 km x 1 km grid square. The modelled concentrations are calibrated against monitoring data. Population statistics are applied to the modelled concentrations to calculate the population-weighted annual average modelled anthropogenic $PM_{2.5}$ concentrations for each local authority area.

† **Attributable fraction:** the proportion of deaths estimated as due to long-term exposure to anthropogenic particulate air pollution.

‡ **Attributable deaths:** long-term exposure to anthropogenic particulate air pollution is estimated to have an effect on mortality risks equivalent to the number of attributable deaths. Air pollution is likely to contribute a small amount to the deaths of a larger number of exposed individuals rather than being solely responsible for the number of deaths equivalent to the calculated figure of attributable deaths.

§ **Associated life-years lost:** the years of life lost to the population due to increased mortality risk attributable to long-term exposure to particulate air pollution.

¶ The City of London has been grouped with Hackney by the ONS because of the very small numbers of deaths in this area.

** The Isles of Scilly are administered separately by an Isles of Scilly council and do not form part of Cornwall UA but, for the purposes of the presentation of statistical data by the ONS, they have been combined with Cornwall UA.

TABLE 2 Wales: baseline population, modelled population-weighted mean concentrations (μg m^{-3}) and estimated effects on annual mortality in 2010 of anthropogenic $PM_{2.5}$ air pollution

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (μg m^{-3})*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
WALES	**2075.4**	**31041**	**7.5**	**4.3**	**1320**	**13549**
Betsi Cadwaladr LHB	481.6	7462	6.7	3.8	280	2836
Isle of Anglesey	49.4	815	5.5	3.2	26	251
Gwynedd	81.2	1347	5.5	3.1	42	408
Conwy	81.6	1479	6.0	3.4	51	489
Denbighshire	69.6	1154	6.4	3.7	42	422
Flintshire	106.1	1366	8.0	4.5	62	670
Wrexham	93.5	1301	7.6	4.3	56	595
Powys LHB	96.5	1445	6.2	3.6	51	509
Powys	96.5	1445	6.2	3.6	51	509
Hywel Dda LHB	264.5	4190	6.6	3.7	157	1562
Ceredigion	51.8	745	5.8	3.3	25	273
Pembrokeshire	83.8	1347	6.6	3.8	51	500
Carmarthenshire	128.8	2098	6.9	3.9	82	789
Abertawe Bro Morgannwg LHB	349.0	5362	7.4	4.2	227	2314
Swansea	157.1	2405	7.4	4.2	102	1048
Neath Port Talbot	97.3	1573	7.4	4.2	66	662
Bridgend	94.6	1385	7.5	4.3	59	604
Cardiff and Vale LHB	299.1	3843	9.0	5.1	196	2100
Vale of Glamorgan	86.5	1190	7.9	4.5	53	557
Cardiff	212.6	2653	9.5	5.4	143	1543
Cwm Taf LHB	198.5	3081	7.7	4.4	135	1399
Rhondda, Cynon, Taff	160.4	2491	7.8	4.4	110	1130
Merthyr Tydfil	38.1	590	7.5	4.3	25	269
Aneurin Bevan LHB	386.4	5658	8.5	4.8	273	2829
Caerphilly	118.7	1687	8.3	4.7	80	822
Blaenau Gwent	47.4	797	7.9	4.5	36	356
Torfaen	62.8	951	8.5	4.8	46	473
Monmouthshire	63.6	874	7.9	4.5	39	404
Newport	93.8	1350	9.4	5.4	72	774

Abbreviation used in Table 2
LHB: local health board

Notes to Table 2

* **Mean anthropogenic $PM_{2.5}$:** Modelled population-weighted annual mean concentrations of fine particulate matter ($PM_{2.5}$) arising from human activities. The pollution climate mapping (PCM) model uses dispersion modelling based on emissions data from the national atmospheric emissions inventory (NAEI), chemical transport modelling and measurement data for specific PM components to estimate the concentration of $PM_{2.5}$ at background locations in each 1 km x 1 km grid square. The modelled concentrations are calibrated against monitoring data. Population statistics are applied to the modelled concentrations to calculate the population-weighted annual average modelled anthropogenic $PM_{2.5}$ concentrations for each local authority area.

† **Attributable fraction:** the proportion of deaths estimated as due to long-term exposure to anthropogenic particulate air pollution.

‡ **Attributable deaths:** long-term exposure to anthropogenic particulate air pollution is estimated to have an effect on mortality risks equivalent to the number of attributable deaths. Air pollution is likely to contribute a small amount to the deaths of a larger number of exposed individuals rather than being solely responsible for the number of deaths equivalent to the calculated figure of attributable deaths.

§ **Associated life-years lost:** the years of life lost to the population due to increased mortality risk attributable to long-term exposure to particulate air pollution.

TABLE 3 Scotland: baseline population, modelled population-weighted mean concentrations (µg m^{-3}) and estimated effects on annual mortality in 2010 of anthropogenic $PM_{2.5}$ air pollution

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ (µg m^{-3})*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
SCOTLAND	**3660.5**	**53800**	**6.8**	**3.9**	**2094**	**22474**
Council areas						
Aberdeen City	150.6	2049	7.4	4.2	86	936
Aberdeenshire	172.3	2198	5.6	3.2	70	749
Angus	79.8	1233	6.0	3.4	42	436
Argyll & Bute	66.1	1087	4.7	2.7	29	302
Clackmannanshire	35.3	483	6.5	3.7	18	195
Dumfries & Galloway	109.1	1790	5.8	3.3	60	597
Dundee City	97.9	1677	7.3	4.1	69	774
East Ayrshire	84.9	1312	6.1	3.5	45	497
East Dunbartonshire	73.8	941	6.8	3.9	37	424
East Lothian	67.6	995	7.0	4.0	40	400
East Renfrewshire	61.5	847	6.8	3.9	33	339
Edinburgh, City of	339.5	4169	8.6	4.9	205	2269
Eilean Siar	19.4	349	4.2	2.4	8	85
Falkirk	107.4	1518	7.5	4.3	65	667
Fife	253.7	3770	6.8	3.9	146	1569
Glasgow City	408.3	6508	8.3	4.7	306	3333
Highland	160.2	2296	4.3	2.5	57	641
Inverclyde	56.9	989	5.7	3.3	32	339
Midlothian	56.2	794	7.5	4.3	34	352
Moray	62.6	904	4.7	2.7	25	261
North Ayrshire	95.7	1552	5.7	3.2	50	540
North Lanarkshire	224.6	3351	7.5	4.3	142	1573
Orkney Islands	14.6	212	4.7	2.7	6	56
Perth & Kinross	104.8	1492	6.1	3.5	52	533
Renfrewshire	120.0	1915	7.0	4.0	77	803
Scottish Borders	82.0	1251	6.1	3.5	44	427
Shetland Islands	15.6	210	4.8	2.8	6	63
South Ayrshire	81.4	1387	5.9	3.4	47	466
South Lanarkshire	219.1	3236	7.3	4.1	134	1450
Stirling	59.8	813	6.2	3.5	29	304
West Dunbartonshire	63.5	1067	6.5	3.7	39	413
West Lothian	116.4	1407	7.4	4.2	59	682

Notes to Table 3

* **Mean anthropogenic $PM_{2.5}$:** Modelled population-weighted annual mean concentrations of fine particulate matter ($PM_{2.5}$) arising from human activities. The pollution climate mapping (PCM) model uses dispersion modelling based on emissions data from the national atmospheric emissions inventory (NAEI), chemical transport modelling and measurement data for specific PM components to estimate the concentration of $PM_{2.5}$ at background locations in each 1 km x 1 km grid square. The modelled concentrations are calibrated against monitoring data. Population statistics are applied to the modelled concentrations to calculate the population-weighted annual average modelled anthropogenic $PM_{2.5}$ concentrations for each local authority area.

† **Attributable fraction:** the proportion of deaths estimated as due to long-term exposure to anthropogenic particulate air pollution.

‡ **Attributable deaths:** long-term exposure to anthropogenic particulate air pollution is estimated to have an effect on mortality risks equivalent to the number of attributable deaths. Air pollution is likely to contribute a small amount to the deaths of a larger number of exposed individuals rather than being solely responsible for the number of deaths equivalent to the calculated figure of attributable deaths.

§ **Associated life-years lost:** the years of life lost to the population due to increased mortality risk attributable to long-term exposure to particulate air pollution.

TABLE 4 Northern Ireland: baseline population, modelled population-weighted mean concentrations ($\mu g\ m^{-3}$) and estimated effects on annual mortality in 2010 of anthropogenic $PM_{2.5}$ air pollution

Area	Population age 25+ (x 10^3)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ ($\mu g\ m^{-3}$)*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
NORTHERN IRELAND	**1174.6**	**14243**	**6.6**	**3.8**	**553**	**6063**
Local government district						
Antrim	34.8	359	6.0	3.5	12	138
Ards	54.3	645	6.8	3.9	25	278
Armagh	37.4	451	5.8	3.3	15	164
Ballymena	42.8	507	6.2	3.5	18	202
Ballymoney	20.3	231	5.4	3.1	7	77
Banbridge	31.6	332	6.3	3.6	12	138
Belfast	172.7	2693	9.2	5.2	141	1494
Carrickfergus	27.3	331	6.6	3.8	12	136
Castlereagh	46.4	610	7.9	4.5	28	295
Coleraine	38.4	483	5.3	3.1	15	170
Cookstown	23.2	264	5.4	3.1	8	90
Craigavon	60.0	661	7.1	4.1	27	327
Derry	68.9	751	6.2	3.5	26	339
Down	46.1	526	5.7	3.3	17	189
Dungannon	35.9	406	5.4	3.1	13	127
Fermanagh	41.9	497	4.3	2.5	12	126
Larne	21.8	288	6.4	3.6	10	115
Limavady	22.0	213	4.9	2.8	6	74
Lisburn	75.5	831	7.5	4.2	35	378
Magherafelt	28.3	261	5.3	3.0	8	89
Moyle	11.5	144	5.0	2.9	4	45
Newry and Mourne	61.4	662	5.7	3.3	22	249
Newtownabbey	56.0	690	7.0	4.0	28	292
North Down	56.5	779	7.6	4.4	34	331
Omagh	34.0	342	5.2	3.0	10	122
Strabane	25.7	286	4.5	2.6	7	82

Notes to Table 4

* **Mean anthropogenic $PM_{2.5}$:** Modelled population-weighted annual mean concentrations of fine particulate matter ($PM_{2.5}$) arising from human activities. The pollution climate mapping (PCM) model uses dispersion modelling based on emissions data from the national atmospheric emissions inventory (NAEI), chemical transport modelling and measurement data for specific PM components to estimate the concentration of $PM_{2.5}$ at background locations in each 1 km x 1 km grid square. The modelled concentrations are calibrated against monitoring data. Population statistics are applied to the modelled concentrations to calculate the population-weighted annual average modelled anthropogenic $PM_{2.5}$ concentrations for each local authority area.

† **Attributable fraction:** the proportion of deaths estimated as due to long-term exposure to anthropogenic particulate air pollution.

‡ **Attributable deaths:** long-term exposure to anthropogenic particulate air pollution is estimated to have an effect on mortality risks equivalent to the number of attributable deaths. Air pollution is likely to contribute a small amount to the deaths of a larger number of exposed individuals rather than being solely responsible for the number of deaths equivalent to the calculated figure of attributable deaths.

§ **Associated life-years lost:** the years of life lost to the population due to increased mortality risk attributable to long-term exposure to particulate air pollution.

TABLE 5 National estimates: baseline population, modelled population-weighted mean concentrations ($\mu g\ m^{-3}$) and estimated effects on annual mortality in 2010 of anthropogenic $PM_{2.5}$ air pollution

Area	Population age 25+ ($x\ 10^3$)	Deaths age 25+	Mean anthropogenic $PM_{2.5}$ ($\mu g\ m^{-3}$)*	Attributable fraction† (%)	Attributable deaths‡ age 25+	Associated life-years lost§
UNITED KINGDOM	42788.6	557828	9.4	5.3	28969	306835
ENGLAND	35878.0	458743	9.9	5.6	25002	264749
WALES	2075.4	31041	7.5	4.3	1320	13549
SCOTLAND	3660.5	53800	6.8	3.9	2094	22474
NORTHERN IRELAND	1174.6	14243	6.6	3.8	553	6063

Notes to Table 5

* **Mean anthropogenic $PM_{2.5}$:** Modelled population-weighted annual mean concentrations of fine particulate matter ($PM_{2.5}$) arising from human activities. The pollution climate mapping (PCM) model uses dispersion modelling based on emissions data from the national atmospheric emissions inventory (NAEI), chemical transport modelling and measurement data for specific PM components to estimate the concentration of $PM_{2.5}$ at background locations in each 1 km x 1 km grid square. The modelled concentrations are calibrated against monitoring data. Population statistics are applied to the modelled concentrations to calculate the population-weighted annual average modelled anthropogenic $PM_{2.5}$ concentrations for each local authority area.

† **Attributable fraction:** the proportion of deaths estimated as due to long-term exposure to anthropogenic particulate air pollution.

‡ **Attributable deaths:** long-term exposure to anthropogenic particulate air pollution is estimated to have an effect on mortality risks equivalent to the number of attributable deaths. Air pollution is likely to contribute a small amount to the deaths of a larger number of exposed individuals rather than being solely responsible for the number of deaths equivalent to the calculated figure of attributable deaths.

§ **Associated life-years lost:** the years of life lost to the population due to increased mortality risk attributable to long-term exposure to particulate air pollution.

4 DISCUSSION

The mortality burden estimates in the tables provide information on the scale of the effect of particulate air pollution on public health in local populations. They are intended to inform local decision-makers as an aid to the evaluation of local public health priorities, and in communicating about the health effects of air pollution. They are based on evidence from large epidemiological studies (the study by Pope et al, 2002, included hundreds of thousands of individuals), but should be regarded as approximations when applied to local populations; some of the reasons for this are discussed below.

4.1 Influence of population characteristics on the mortality burden estimates

One of the benefits of attributable fraction as a metric is that, because its calculation does not use mortality statistics, it is independent of age and mortality characteristics of the local population. This is one of the reasons why it was considered a suitable metric for an indicator in the DH PHOF for England (DH, 2012). Being expressed as a percentage, it is also a metric that people are likely to be familiar with and it may be quite readily understood.

The local mortality burden estimates presented in terms of attributable deaths and years of life lost are calculated using local mortality statistics and are not age standardised. This means that, if there were two areas with the same $PM_{2.5}$ concentrations (ie with the same attributable fraction) whose populations were the same size and had the same age-specific death rates but with different age distributions, the deaths and associated years of life lost attributable to air pollution would be different. This is because mortality rates increase with age, so the overall mortality rate within a population depends on both the age-specific mortality rates and the age distribution of the population. If two populations have the same age-specific mortality rates but one has a younger age distribution (perhaps because of inward and outward migration), the average age at which the deaths occur there is lower, and the loss of life expectancy per attributable death is higher. This is because there will be fewer deaths at older ages, due to the smaller proportion of residents in older age groups. Therefore, for the same $PM_{2.5}$ concentrations, the number of deaths attributable to particulate air pollution will be lower in the area with the younger age distribution, but the associated loss of life to the population may not be.

For example, London has considerably higher concentrations of $PM_{2.5}$ than the North East region of England, meaning that the contribution of air pollution to the age-specific mortality rate is higher in London. This is reflected in London having a higher attributable fraction (and, hence, PHOF indicator). However, the adult population in London is, on average, younger than that in the North East. When calculated using the methods used to generate the mortality burden estimates in this report (described in Appendix C) and then expressed on a per 100,000 population basis, an estimated 64 deaths per 100,000 population (aged 25+) and an associated 777 years of life lost in 2010 were attributable to particulate air pollution in London. In the North East, despite the attributable fraction being lower, the number of attributable deaths per 100,000 population aged 25+ was slightly higher than in London (67 deaths per 100,000 population), while the associated loss of life was lower than in London (687 years of life lost). The differences in both aspects reflect the difference in age distribution, death rates and life expectancy between the two regions. Therefore, the age distribution of the local population is one of the factors that will determine the extent to which a mortality burden estimate calculated using the simplified method recommended in Appendix A, which assumes an average loss of 12 years per attributable death, might overestimate or underestimate the years of life lost to the local population.

4.2 Sensitivity of mortality burden estimates to local conditions affecting $PM_{2.5}$ concentrations and exposure

The mortality burden estimates in this report were calculated using concentrations of $PM_{2.5}$ modelled nationally on a 1 km by 1 km grid square basis using information from the national atmospheric emissions inventory (NAEI) (see Appendix B for details). For point sources, reported emissions were used. For other sources, such as roads, a combination of emission factors and activity data was used to predict emissions. Because a national inventory of these factors is used, very local initiatives affecting these sources (for example, measures affecting vehicle age or technology) will not be reflected in the local modelled $PM_{2.5}$ concentrations. The NAEI only captures information that it is practical to include in a national assessment. This means that large schemes, such as the low emission zone in London, will be reflected in modelled concentrations, but that traffic characteristics in smaller schemes will not. The impact of measures that affect the amount of traffic on major roads will be reflected in the NAEI, although there may be a lag of several years before this information is incorporated because traffic count data on any specific road is collected only infrequently. Thus, local mortality burden estimates based on this modelling approach are rather insensitive to local conditions affecting emissions from traffic sources unless the policy measures have been reflected in the NAEI, even though reductions in the actual mortality burden would be expected.

Regional background concentrations of particulate matter make a substantial contribution to concentrations of $PM_{2.5}$ at urban background locations. The Air Quality Expert Group (AQEG, 2012) noted that the regional background contributes at least 60–80% of the urban background at UK monitoring stations, with secondary inorganic aerosols making the largest single contribution to this regional background. Contributions from more local sources (those within about 15 km) make up the remainder of the urban background concentration. This is another reason why both actual and estimated burdens of mortality attributable to long-term exposure to air pollution are relatively insensitive to individual local air pollution control measures; larger gains will be achieved when measures are implemented on a wider scale.

In addition, differences in the personal exposure of members of the local population to existing levels of pollution are not reflected in the burden estimates. The concentration-response coefficient used in the calculations relates increased mortality risk to background $PM_{2.5}$ concentrations, as this was the population exposure metric used in the relevant epidemiological studies. However, it can be assumed that the mortality risk associated with air pollution within a city (or local authority area) is governed by the range of personal exposures experienced by individuals and that background $PM_{2.5}$ concentrations are a proxy measure for this. Therefore, although initiatives to reduce personal exposure to $PM_{2.5}$ (eg by encouraging the use of low-pollution walking routes or providing cycling lanes away from roads carrying large volumes of traffic) would be anticipated to be beneficial to public health, they would not, in the short-term, be reflected in the estimates of local mortality burden attributable to air pollution. However, over time, health benefits from, for example, active travel would be expected to lead to lower age-specific death rates and eventually also affect the population age distribution, both of which would influence the burden calculations.

4.3 Approach to $PM_{2.5}$ modelling

In producing these local mortality burden estimates, the same approach to modelling background levels of $PM_{2.5}$ has been used as that used by COMEAP in developing its national estimates (COMEAP, 2010). This uses information from the national atmospheric emissions inventory (NAEI) and monitoring data from Defra's national automatic urban and rural network (AURN). The modelling is undertaken on a 1 km by 1 km scale, and is intended to provide an estimate of 'background' (eg not roadside) concentrations of $PM_{2.5}$ resulting from human activities. The modelled concentrations are then weighted according to the population resident in each grid square to produce an average for the local area.

Other approaches to modelling $PM_{2.5}$ concentrations have been used elsewhere to calculate local mortality burdens attributable to particulate air pollution. For example, finer scale modelling undertaken by King's College, London, was used as the basis of the estimates of mortality attributable to air pollution undertaken for the Mayor of London (Miller, 2010). Other differences in the methods used by Miller (2010) were that these estimates were based on total (rather than anthropogenic) $PM_{2.5}$ concentrations, in 2006, and used data on mortality in all age groups. These types of methodological differences will lead to differences in the mortality burdens estimated as being attributable to particulate air pollution.

4.4 Other issues to consider

Estimates of mortality burden provide a measure for communicating about the effect of air pollution on public health. In addition to the calculated estimates of local mortality burden, the following points may be helpful when the possible effects of air pollution on a local population are considered.

There is considerable consensus around the effects on mortality of long-term exposure to particulate air pollution, and in methods for quantifying these effects. Nonetheless, as noted by COMEAP (2012), air pollution also affects morbidity, meaning that air-pollution-related illness is an additional burden on the population. In addition, short-term variations in levels of pollutants are associated with both increased mortality and hospital admissions. Thus, while the mortality effect of long-term exposure to particulate pollution is one of the most significant public health effects of air pollution, it is not the only one. COMEAP (2012) suggested that mention should be made of the other effects of air pollution on health, in addition to estimates of the mortality burden of long-term exposure to particulate air pollution, in communicating about the public health significance of air pollution. Sources of further information on the health effects of air pollutants include the COMEAP website[*] and publications by the World Health Organization (eg WHO, 2006, 2013) and the United States Environmental Protection Agency (eg US EPA, 2009).

Within any local authority area, there will be some areas with higher concentrations of air pollution than others, notably near busy roads. This means that some individuals will experience higher levels of air pollution than others. People likely to experience higher exposures include those who live close to busy roads (who tend to be in lower socioeconomic groups) and others who might spend more time than average in micro-environments with higher levels of air pollution (for example, commuters on busy routes).

Measured concentrations of $PM_{2.5}$ vary from year to year as a result of the weather conditions. This year-to-year variation is generally greater than the year-to-year $PM_{2.5}$ concentration changes resulting from changes in emissions, and this should be borne in mind when reviewing and interpreting figures for different years.

Defra's air quality information resource, *UK-AIR*[†], includes data on levels of air pollutants in the UK. Defra's LAQM resources[‡] provide information on measures which local authorities can use to reduce air pollution. A report is also available, in the form of case studies, on local authority projects to improve air quality (Beattie et al, 2013). This report is intended to allow other local authorities to see the type of work that is being carried out to improve air quality, and to understand some of the issues that arise and the ways that they can be overcome.

[*] www.comeap.org.uk

[†] http://uk-air.defra.gov.uk/

[‡] http://laqm.defra.gov.uk/

5 CONCLUSIONS

Long-term exposure to particulate air pollution contributes to deaths from respiratory and cardiovascular causes, in combination with other risk factors.

This report discusses methods for calculating the burden of mortality attributable to current levels of particulate air pollution in three metrics: ‘attributable fraction’, ‘attributable deaths’ and ‘years of life lost to the population’.

Central estimates of the fraction of mortality attributable to long-term exposure to current levels of anthropogenic particulate air pollution range from around 2.5% in some local authorities in rural areas of Scotland and Northern Ireland with low levels of air pollution, and between 3 and 5% in Wales, to over 8% in some of the most polluted London boroughs. Because of uncertainty in the mortality risk associated with ambient $PM_{2.5}$, the burdens could range from approximately one-sixth to about double these figures. Thus, current levels of particulate air pollution have a considerable impact on public health.

Although subject to more sources of uncertainty than national figures, the local estimates of mortality presented here are likely to be reasonable estimates of the mortality burden of long-term exposure to current levels of anthropogenic particulate air pollution on local populations. It is not known how the mortality burdens are distributed across the local populations: the number of individuals affected is likely to be greater than the calculated number of ‘attributable deaths’. The figures are best viewed as representing the increased risk to the local population, as a whole, associated with current levels of air pollution.

The age structure of the local population influences the estimates of mortality burden associated with particulate air pollution levels, when expressed in terms of attributable deaths and associated loss of life. This has implications for the interpretation of burden estimates in an area with an atypical population, and for the accuracy of estimation of years of life lost to the population in these areas using the simplified method, assuming a loss of 12 years per attributable death.

Measures to reduce local $PM_{2.5}$ concentrations, or to reduce exposures of the population to particulate air pollution, are expected to have a public health benefit including on mortality, even though this benefit will not be directly reflected in changes of local mortality burden estimates such as those published here. Larger gains will be achieved when actions to reduce $PM_{2.5}$ are implemented over wider areas, eg through the concerted action of several local authorities.

6 ACKNOWLEDGEMENTS

This report builds upon on the work of the Committee on the Medical Effects of Air Pollutants (COMEAP) on quantifying the mortality effects of long-term exposure to particulate air pollution. The approaches used to undertake the calculations are those used, or recommended, by COMEAP and the report includes summaries of discussions of this topic previously published in its reports and statements.

The calculation of the local mortality burdens published in this report, and the drafting of Appendices A and C, was undertaken by Brian Miller (Institute of Occupational Medicine) and was funded by the Policy Research Programme in the Department of Health.

The production of modelled annual average concentrations of anthropogenic $PM_{2.5}$ for each local authority area, and the drafting of Appendix B, was undertaken by John Stedman (Ricardo-AEA) and was funded by the Department for Environment, Food and Rural Affairs (Defra).

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APPENDIX A Guidance on Estimating Mortality Attributable to Long-term Exposure to Particulate Air Pollution at the Local Authority Level

B G Miller, Institute of Occupational Medicine

This appendix shows how, if desired, it is possible to estimate the burden of local mortality due to long-term exposure to local particulate air pollution using the methods used and/or recommended by the Committee on the Medical Effects of Air Pollutants (COMEAP, 2009, 2010, 2012). These methods can be applied to any local area for which the necessary data is available, which generally implies local authorities or groupings of those, and the results can be aggregated across any combination of authorities.

The calculations described below will produce an estimate of the proportion (and number) of adult deaths within the area that are attributable to long-term exposure to the local concentration of anthropogenic $PM_{2.5}$. Years of life lost to the population associated with these attributable deaths can also be estimated.

A1 Deaths

The first step is to obtain the total number of annual deaths in the local area. These are published separately for England and Wales, for Scotland and for Northern Ireland by the relevant national statistical authorities. At the time of writing, MS Excel spreadsheets containing this data, broken down by local area, could be accessed via the following web references:

For England and Wales, broken down by age (10-year groups), sex and administrative area: Table 2 within the reference tables (MS Excel files) available at

http://www.ons.gov.uk/ons/rel/vsob1/deaths-registered-area-usual-residence/index.html

For Scotland, broken down by age (5-year groups), sex and administrative area: Table 5.2 within the vital events reference tables available at

http://www.gro-scotland.gov.uk/statistics/theme/vital-events/general/ref-tables/index.html

For Northern Ireland, broken down by age (5-year groups), sex and administrative area: Table 5.2 available at

http://www.nisra.gov.uk/demography/default.asp10.htm

Because of the variability in small datasets, it is recommended that an average of three to five years' mortality data is used, rather than just the data for the year of interest (which will usually be the most recent year available).

It is customary to calculate mortality attributable to air pollution only for adults aged 30 years or more (30+). For data published in standard 10-year age groups, mortality data for ages 25+ can be used and, in fact, the proportion of deaths below the age of 30 is so small that even using the total across all ages leads to only a slightly larger estimate. The numbers of deaths used should be combined across the sexes unless there is reason to keep them separate.

A1.1 Particulate pollution concentrations

Modelled concentrations of annual average anthropogenic $PM_{2.5}$ at background locations for local authority areas for the year of interest can be obtained from

http://uk-air.defra.gov.uk/data/pcm-data

A1.2 Concentration-response function

The quantitative relationship between additional mortality risk and long-term exposure to specific concentrations of particulate air pollution is described by a concentration-response function. Currently, it is customary to assume that an increment of 10 µg m^{-3} in the annual concentration of $PM_{2.5}$ will increase the mortality risk by 6%, ie multiply risk by a factor of 1.06.

A1.3 Relative risk

The relative risk (RR) corresponding to an air pollution increment or difference other than 10 µg m^{-3} is calculated by scaling the 1.06 according to the modelled $PM_{2.5}$ concentration, say *x*. If a scientific calculator or spreadsheet is available, this can be calculated as

$$RR = 1.06^{(x/10)}$$

An approximation that may be easier to calculate assumes linear rather than multiplicative scaling:

$$RR = 1 + (0.06 \times x/10)$$

For example, for a concentration of 5 µg m^{-3}, the first version gives RR = 1.0296 while the second gives RR = 1.03. The difference is trivial.

A1.4 Attributable fraction

The attributable fraction (AF) of mortality is calculated from the RR by the formula

$$AF = (RR - 1)/RR$$

Thus an RR of 1.0296 yields an AF of 0.029, or 2.9%.

A1.5 Attributable deaths

The burden of deaths in the specified year attributable to long-term exposure to particulate air pollution is the product of the AF and the total number of (adult or total) deaths. The interpretation of this figure is that the air pollution has increased mortality risk in the local population to an amount equivalent to this number of deaths.

A1.6 Associated loss of life

As well as deaths attributable to air pollution, it is also of interest to know the years of life lost to the population associated with this increased mortality; ie if the mortality had been at the lower level that would be implied if air pollution had not been present, how many more years of life would have been lived by the population. Estimates of remaining life expectancy can be obtained from life-table calculations; COMEAP (2012) suggested that a simplified approach of assuming an average loss of 12 years of life per attributable death could be used to estimate this loss of life to the local population.

A2 References

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COMEAP (2010). *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom*. Committee on the Medical Effects of Air Pollutants. Available at http://www.comeap.org.uk/documents/reports

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APPENDIX B Modelling of Ambient $PM_{2.5}$ Concentrations: Population-weighted Annual Average Anthropogenic $PM_{2.5}$ at Background Locations

J R Stedman, Ricardo-AEA

B1 Modelling of ambient $PM_{2.5}$ concentrations

Annual mean $PM_{2.5}$ concentrations across the UK are estimated each year as part of the annual assessment of ambient air quality required by the EU air quality directive (EC, 2008). Full details of the pollution climate mapping (PCM) model that is used to calculate the maps of concentrations for 2010 have been provided by Brookes et al (2011).

The PCM model provides estimates of concentrations for 1 km x 1 km grid squares across the UK and these estimates are representative of background locations, as defined in the AQD to be representative of the exposure of the general population. Concentrations at traffic locations (within 10 m of the kerb) will generally be greater but this local variation in concentrations has not been included in the model for background locations. The model has been calibrated using annual mean $PM_{2.5}$ concentrations measured at background air quality monitoring stations within the UK national monitoring network*.

The modelling approach adopted is a pragmatic attempt to include contributions from the known sources of ambient concentrations of $PM_{2.5}$ and provide good agreement with measured concentrations. The model includes contributions from a number of different sources. The resulting ambient concentrations are then summed to calculate the total at each location. These components are listed below:

a Area sources of primary particles (calculated using dispersion kernels derived using an air dispersion model and maps of emissions from the national atmospheric emissions inventory (NAEI) and calibrated using measurements from the UK national monitoring networks). This includes emissions (arising from brake and tyre wear and road abrasion as well as from exhaust) from local traffic sources

b Large point sources of primary particles (explicitly modelled using an air dispersion model and estimates of the emissions from the NAEI)

c Small point sources of primary particles (calculated using a small points model using dispersion kernels derived using an air dispersion model and estimates of the emissions from the NAEI)

d Secondary inorganic aerosol (interpolated from sulphate, nitrate and ammonium measurements and scaled for counter-ions and bound water and size fractions)

e Secondary organic aerosol (estimated using a chemical transport model)

f Regional primary particles (calculated using a chemical transport model using NAEI emissions for the UK and emissions estimates for the rest of Europe)

g Rural calcium rich dusts from soil resuspension (estimated using a resuspension model, emission rates depend on land cover and hour-by-hour meteorology)

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* http://uk-air.defra.gov.uk/interactive-map

h Urban calcium rich dusts (modelled using a surrogate spatial distribution based on population)

i Regional iron rich dusts (assumed constant 0.33 µg m^{-3} $PM_{2.5}$)

j Iron rich dusts from vehicle related resuspension (estimated using a resuspension model, emission rate depends on heavy goods vehicle flow on major roads and hour-by-hour meteorology)

k Sea salt (interpolated from chloride measurements and scaled for counter-ions)

l Residual (assumed constant 1.0 µg m^{-3} $PM_{2.5}$ for 2010). This represents the contribution to ambient concentrations from sources that have not been explicitly included in the model

Figure B1 shows the resulting map of annual mean ambient $PM_{2.5}$ concentrations for 2010.

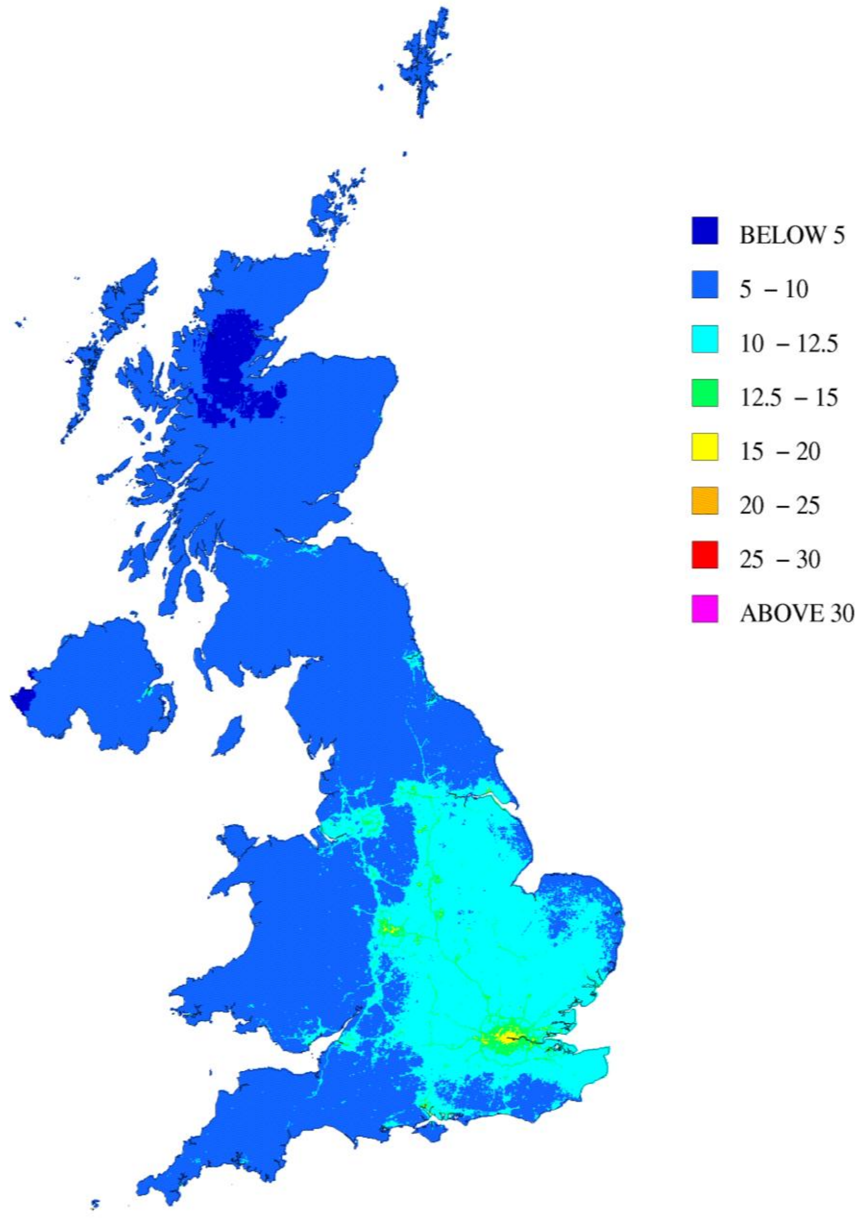

FIGURE B1 Modelled annual mean background $PM_{2.5}$ concentration 2010 (µg m^{-3}) (Brooks et al, 2011)

B2 Calculation of anthropogenic $PM_{2.5}$

The model results can be used to estimate the contributions to total concentrations from anthropogenic and non-anthropogenic sources. For many sources the distinction is reasonably clear cut. The contribution from sea salt is clearly non-anthropogenic, while the contribution from point source emissions from industries is clearly anthropogenic. It is less clear for some other sources such as dusts from soil resuspension, which could be considered as non-anthropogenic but are strongly influenced by land use and have therefore not been considered as non-anthropogenic in this analysis. The only contributions assigned as non-anthropogenic are sea salt and the residual. The composition of the residual is by definition not known but has been included in this category since other components which could arguably have been described as non-anthropogenic have been excluded.

B3 Calculation of population-weighted mean

The population-weighted mean is a useful summary statistic, which is related to human health impacts if the dose-response function is assumed to be linear with no threshold. The population-weighted mean has been calculated by multiplying the 1 km x 1 km concentration values by 1 km x 1 km population statistics from the 2001 census. The values for all of the grid squares are summed and then divided by the total population to calculate the population-weighted mean for each local authority area.

To do this, polygons using population data at output area (OA) level are overlaid on a 1 km x 1 km grid using GIS, to give the population resident within each 1 km x 1 km square. Information from this intersection is used to estimate the allocation of population to the 1 km x 1 km grid squares. Where an OA spans two (or more) grid squares, area-weighting is used to allocate a proportion of the population in the OA to each grid square, taking into account GIS information on un-populated area as appropriate.

Local authority boundaries are compared with and approximated to the 1 km by 1 km population/pollution grid and the annual average concentration of anthropogenic $PM_{2.5}$ in each 1 km x 1 km grid square within the local authority area is multiplied by the resident population. The sum of all these products is divided by the total population resident in the local authority area to give the population-weighted annual average for the local authority.

The modelled population-weighted annual mean anthropogenic $PM_{2.5}$ concentrations can be found at http://uk-air.defra.gov.uk/data/pcm-data.

B4 Uncertainty

The measurement and modelling of ambient $PM_{2.5}$ concentrations is subject to considerable uncertainty. The AQD sets a data quality objective for the measurement uncertainty of 25%. The uncertainty of modelled estimates additionally includes uncertainties associated with emission inventory estimates and the spatial distribution of emissions and the various model components. The data quality objective for modelled annual mean $PM_{2.5}$ is 50%. Both the measured and modelled concentrations have been shown to be within the uncertainty requirements of the AQD.

B5 Discussion

Measured concentrations of $PM_{2.5}$ vary from year to year as a result of the weather conditions. This year to year variation is generally greater than the year to year changes resulting from changes in emissions. The inter-annual variability of average concentrations measured at background monitoring stations in the years 2009, 2010, 2011 and 2012 was about 10%.

Air quality modelling at a finer spatial resolution than the 1 km x 1 km data used in this study would tend to predict somewhat higher average concentrations as a result of including the higher concentrations very close to roads. The coefficients used to estimate the mortality burden of ambient $PM_{2.5}$ have been derived from measurements at urban background locations (Pope et al, 2002). Thus it is difficult to say whether modelling at a finer spatial resolution would give a more accurate estimate of the mortality burden of $PM_{2.5}$ or not.

B6 References

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APPENDIX C Mortality Burden Estimates at a Local Authority Level – Methods Used in this Report

B G Miller, Institute of Occupational Medicine

C1 Mortality rates

All-cause mortality data for England and Wales, Scotland and Northern Ireland was obtained from the relevant websites presenting published national statistics (see Appendix A). The data obtained was in the form of MS Excel tables containing the numbers of deaths and population sizes, for the years 2008, 2009 and 2010, broken down by local authority, sex and age. Some data was only available in tables of 10-year age groups and, for consistency, those with 5-year groups were converted to 10-year groups to correspond.

The figures of population and deaths were averaged over the three years, to provide a less variable set of rates for the calculations.

C2 Pollution concentrations

Modelled population-weighted annual mean background concentrations of anthropogenic $PM_{2.5}$ in 2010 were provided by Ricardo-AEA. Details of the modelling are provided in Appendix B.

C3 Attributable deaths

The annual burden of mortality attributable to anthropogenic $PM_{2.5}$ was generated in several steps.

The numbers of deaths in the adult age groups – aged 25 and above – were extracted from the spreadsheet, and the data for the sexes combined to provide a total.

The local annual mean concentration (x) of $PM_{2.5}$ was used to estimate a relative risk (RR) for each local area, from a base relative risk of 1.06 per 10 µg m^{-3} of $PM_{2.5}$. The formula used for this logarithmic (multiplicative) scaling was

$$RR(x) = 1.06^{x/10}$$

The attributable fraction of risk AF (expressed as a percentage) was calculated

$$AF(x)\ \% = 100 \times [RR(x) - 1] / RR(x)$$

This percentage was applied by multiplication to the number of deaths per year in each local population, to estimate a number of attributable deaths in each adult age group.

C4 Estimation of remaining life expectancy

Remaining life expectancy is a function of achieved age, and the values are estimated using life-table methods. The formulae used were as follows.

Given a table of age-specific all-cause mortality hazard rates h_i in n = 10-year age groups i = [25–34], [35–44], etc), then the probability of survival s from the birthday beginning the ith age group to the birthday beginning the next is estimated by

$$s_{i+1} = \frac{1 - c_i \times h_i}{1 + (n_i - c_i) \times h_i}$$

Here the n_i are the widths in years (not necessarily all the same) of the age groups, and the values c_i are weights that allow for the fact that mortality occurs through the calendar interval that mirrors the age group. These can usually be taken as half of the interval width, ie $n_i/2$, which equals 5 for 10-year groupings*.

Cumulative survival from birth to the birthday $k_i + n$, denoted by ${}_0S_{k+n}$, was then calculated (denoting by Π the operator that multiplies together a set of values) as

$${}_0S_{k+n} = \prod_{i=0}^{k} s_i = \prod_{i=0}^{k} \frac{1 - c_i \times h_i}{1 + (n_i - c_i) \times h_i}$$

Joining these values describes an approximation to the underlying continuous survival function, and the probability d_i of death in the ith interval given survival to that interval's start is

$$d_i = {}_0S_{i+1} - {}_0S_i$$

Life expectancy *E(L)*, in units of 'life-years' (or just 'years'), is the area under the survival function defined by the ${}_0S_i$. The following is obtained (using Σ to denote addition)

$$E(L) = \sum_{i=0}^{A} (n_i \times {}_0S_{i+1} + c_i d_i)$$

where ${}_0S_0 = 1.0$, and A is the highest age achieved in the population so that ${}_0S_{A+1} = 0$. It can therefore be seen that the survival function and the life expectancy it implies are defined uniquely by the set of hazard rates h_i and the weights c_i (and quantities calculated from them).

This equation estimates the life expectancy from birth, but for the burden calculations remaining life at a given age is needed. ${}_0S_a$ is the proportion of the original population surviving to the ath birthday, and remaining expected life given an achieved age a, $E(L¦a)$, may be estimated by adapting the above formula to

$$E(L ¦ a) = \frac{1}{{}_0S_a} \left[\sum_{i=a}^{A} (n_i \times {}_0S_{i+1} + c_i d_i) \right]$$

The above formulae are appropriate when every age group is of known width, but not in the common situation of an open-ended last interval. In that case, however, the estimated contribution of life-years from the open-ended interval beginning at age A is given by ${}_0S_A / h_A$, the proportion surviving to the start of the interval divided by their subsequent hazard rate.

* The group aged 0 is often quoted separately, because of perinatal mortality; because the majority of deaths at this age occur early rather than uniformly, $c_0 = 0.1$ was used; for the 1–4 year age group the value $c_1 = 2$ was used.

Thus

$$E(L) = \sum_{i=0}^{A-1} (n_i \times {}_0S_{i+1} + c_i d_i) + {}_0S_A / h_A$$

and, conditional on reaching age *a*,

$$E(L \mid a) = \frac{1}{{}_0S_a} \left[\sum_{i=a}^{A-1} (n_i \times {}_0S_{i+1} + c_i d_i) + {}_0S_A / h_A \right]$$

C5 Attributable loss of life expectancy

Calculating age-specific remaining life expectancy for attributable deaths within each age group allows aggregation over the attributable deaths in a way that accommodates their age distribution. This gives an estimate of years of life lost to the population. The attributable deaths in each age group were assigned expected remaining life (as if they had not occurred) according to their age. Because the life-table gives expected remaining life from the start of each age group, and deaths will occur at all ages within the group, the value assigned to each death was the expectation at the starting age less half the width of the age group; for most age groups that was 10/2 = 5 years.

The same weights c_i used in the above calculations (and for the same reason) were therefore used to estimate the average age-conditional life expectancy for deaths within the age group g_i beginning at age a_i as

$$E(L \mid g_i) = E(L \mid a_i) - c_i$$

and these were cumulated over the age-distributed attributable deaths in adults.

C6 Combinations of local areas

Results were required for a number of combinations of individual local authority areas. For these combined areas, the total attributable deaths and years of life lost have been calculated by summing over the relevant local authorities. In addition, modelled population-weighted annual average anthropogenic $PM_{2.5}$ concentrations for the combined areas have been calculated from the pollution and population data for relevant local authorities.

The estimates of attributable deaths and years of life lost obtained by summing figures generated for individual local authority areas are different from those that would be generated by applying the attributable fractions for the combined areas to the mortality data from the combined areas. The differences in estimates obtained by the two methods are small compared with the other uncertainties affecting these calculations, which are discussed elsewhere in the report. Estimates based on summing figures for local authorities are likely to be a more accurate reflection of the total mortality burden because they are based on pollution concentrations and mortality statistics matched at a finer scale.

APPENDIX D Glossary of Terms and Abbreviations

Air dispersion model: A mathematical model simulating dispersion of air pollutants in the ambient atmosphere

Ambient air: Outdoor air

Anthropogenic: Arising from human activities

AQD, air quality directive: Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

AQEG: Air Quality Expert Group. An expert committee of Defra which considers current knowledge on air pollution and provides advice on such things as the levels, sources and characteristics of air pollutants in the UK

Attributable deaths: The number of deaths attributable to population exposure to a particular factor (ie the number of deaths fewer that would have been expected had the population been unexposed to that factor)

Attributable fraction: A measure of the association between exposure to a particular factor and the risk of a particular outcome. It indicates the amount of the incidence that can be attributed to one particular factor and the amount by which the incidence would have been lower if the population had been unexposed to that factor. In this case, it represents the proportion of local deaths that can be attributed to long-term exposure to particulate air pollution

AURN, automatic urban and rural network: An automatic air pollution monitoring network funded by Defra and used to report compliance against the ambient air quality directives

Cardiovascular disease: Disorders of the heart and circulatory system

Chemical transport model: A model simulating atmospheric chemistry as well as pollutant movement

COMEAP: Committee on the Medical Effects of Air Pollutants. COMEAP is an expert committee that provides advice to government departments and agencies, via the Department of Health's Chief Medical Officer, on all matters concerning the effects of air pollutants on health

Concentration-response coefficient: A quantitative relationship between the concentration of a pollutant and an increased risk of an effect on health (in this case, mortality)

Confidence interval: If it is possible to define two statistics t_1 and t_2 (functions of sample values only) such that, θ being a parameter under estimate,

$$p\ (t_1 \leq \theta > t_2) = \alpha$$

where α is some fixed probability (eg 0.95 or 95%), the interval between t_1 and t_2 is called a confidence interval. The assertion that θ lies in this interval will be true, on average, in a proportion α of the cases when the assertion is made. For example, 95% confidence intervals are calculated in such a way that, in the absence of bias, 95% of such intervals will include the parameter that is being estimated

Defra: Department for Environment, Food and Rural Affairs

DH: Department of Health

Dispersion kernels: A matrix describing the way that air pollutants disperse from a source into the surrounding atmosphere. Calculated using an air dispersion model by releasing unit emissions

Epidemiological studies: Investigations of diseases conducted at a population level

European (EU) directives: The European Union has been legislating to control emissions of air pollutants and to establish air quality objectives since the early 1970s. European directives on ambient air quality require the UK to undertake air quality assessment, and to report the findings to the European Commission on an annual basis

Interpolated: Estimated based on known values (in this case, estimation of concentrations of a pollutant based on measured concentrations at monitoring sites)

LAQM, local air quality management: Duties of local authorities under Part IV of the Environment Act 1995 to review and assess air quality and put in place plans to ensure compliance with relevant national objectives

Logarithmic scaling: Scaling based on a linear relationship between one parameter and the log of another (in this case, between ambient $PM_{2.5}$ concentrations and the log of the relative risk)

Morbidity: Ill-health

Mortality: Death

Mortality burden of air pollution: The effect on mortality that is attributable to air pollution at current levels; in this case the mortality attributable to long-term exposure to current levels of anthropogenic particulate air pollution

$\mu g\ m^{-3}$: Micrograms per cubic metre. 1 μg = 1 millionth of a gram

NAEI, national atmospheric emissions inventory: The NAEI compiles estimates of emissions to the atmosphere from UK sources such as power stations, traffic, household heating, agriculture and industrial processes

ONS: Office for National Statistics. Executive office of the UK Statistics Authority. Main responsibilities include the collection, compilation, analysis and dissemination of a range of economic, social and demographic statistics

Particle: A minute portion of matter – frequently a very small solid or liquid particle (or droplet) of micrometre or nanometre dimensions

PCM model, pollution climate mapping model: A collection of models designed to fulfil part of the UK's requirements to report on the concentrations of particular pollutants in the atmosphere under EU Directive 2008/50/EC

Plausibility interval: A representation of combined views of experts on the plausibility of different concentration-response coefficients. The 75% plausibility interval represents the range between the 12.5th and 87.5th percentiles of the overall plausibility distribution (ie of the cumulative average probabilities assigned to a range of coefficients)

PM: Particulate matter

$PM_{2.5}$: Mass per cubic metre of particles passing through the inlet of a size selective sampler with a transmission efficiency of 50% at an aerodynamic diameter of 2.5 micrometres (μm)

PM_{10}: As above, with 10 micrometres

Population-weighted mean: A summary statistic representing ambient concentrations experienced by the population, calculated to give proportionally more weight to the concentration of pollutant in areas with higher resident populations. It can be used in the calculation of human health impacts if the concentration–response function used is linear with no threshold

Primary particles: Particles emitted directly to the air

PHOF, public health outcomes framework: A Department of Health framework for England intended to focus public health action on increasing healthy life expectancy and reducing differences in life expectancy and healthy life expectancy between communities

Relative risk (RR): Relative risk is the risk of an event (or of developing a disease) related to exposure. It is a ratio of the probability of the event occurring in the exposed group versus that in a non-exposed group. Relative risk is used in this report to compare age-specific death rates in two groups that differ in terms of exposure or other characteristics, eg in terms of their average annual exposure to $PM_{2.5}$. It is derived as the ratio of age-specific death rates in the two groups (assuming other factors are equal) because exposure is expected to increase age-specific death rates by some multiplicative factor, to be estimated from epidemiological studies

Secondary inorganic aerosol: Inorganic particulate matter, such as ammonium nitrate, formed in the atmosphere from gaseous pollutants

Secondary organic aerosol: Organic particulate matter formed in the atmosphere from vapour phase organic compounds

Secondary particles: Particulate matter formed in the atmosphere from gaseous pollutants

US EPA: United States Environmental Protection Agency

WHO: World Health Organization

Years of life lost to the population: The loss of life attributable to population exposure to a particular factor (ie the years of lost life expectancy associated with the attributable deaths)