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PM_{10} QUESTION TIME

PROFESSOR MARTIN WILLIAMS reviews the challenges within the air quality sector

Air quality and associated policies in the UK have reached a key stage in their development. The successes of the 1956 Clean Air Act are now far behind us; unlike the stark images of the earlier smogs, the emergence of new problems from particulate matter (PM) in the early 1990s arose from increasingly sophisticated statistical epidemiology but nonetheless led to a resurgence of interest in urban air quality and the associated health problems. The UK was at the forefront of action here through the 1995 Environment Act and the first Air Quality Strategy in 1997, both of which emerged before the suite of air quality Directives in the European Union (EU) in the late 1990s. In parallel, activities addressing wider scale problems of ozone, acidification and eutrophication (excess nutrient nitrogen) led to the signing of the Gothenburg Protocol within the Convention on Long Range Transboundary Air Pollution and subsequently the EU National Emissions Ceilings Directive. These activities together offered the prospect of a couple of decades of significant improvements in air quality, in human health and in impacts on the environment, not simply because of the setting of standards and targets but because these were also accompanied by source-related regulation on motor vehicles through the 'Euro standards', and on major industrial emitters in the IPPC (Integrated pollution prevention and control) Directive and related legislation.

There have been some notable successes. Sulphur dioxide emissions have reduced significantly and the acidification problem in Europe has in essence been solved – although some areas currently remain affected and some water bodies will take a long time to show recovery. In terms of human health, the introduction of the three-way catalyst on petrol cars in the so-called 'Euro 1' level of legislation has made large improvements in urban air quality since the early 1990s. This coupled with legislation on evaporative emissions and releases from the petrol retail chain, together with measures on solvents, has also reduced volatile organic compound (VOC) emissions such that many toxic and carcinogenic compounds have declined markedly and peak ozone concentrations in 'summer smogs' have decreased significantly from the 1970s and 1980s, when peak ozone levels were 200 ppb or more (258 ppb in the famous 1976 summer)-such peaks are now rarely above 100 ppb in northern Europe.

However, it is now becoming apparent that levels of some pollutants, including particulate matter (PM) (probably the most important in health terms) and nitrogen dioxide (NO_2) (the most difficult in terms of achieving compliance with EU legislation) are not reducing to the level expected and in some areas may even be increasing. What is the reason for this? Analyses in recent years have shown that this is attributable to the road vehicle sector. In the last seven or eight years there has been a large increase in the proportion of diesel cars in the UK, and European, fleet. Diesel cars emit more NOx and PM than petrol cars equipped with catalysts. Moreover, in order to meet successively stringent emission limits on PM from diesel cars, oxidation catalysts have been fitted and these have had the effect of increasing the proportion of NO_2 in the primary emission of NOx. At the same time heavy duty diesel vehicles, particularly some bus fleets such as in London, have fitted particle traps which work by using enhanced NO_2 in the exhaust to oxidise the particles in the trap to regenerate it. This too has led to increased primary NO_2 emission. Even more significantly, recent remote sensing data (Carslaw *et al.*, 2011) has suggested that the Euro standards from

Euro 1 to Euro 5 have had very little effect on NOx emissions from diesel cars and light vans. All these factors have resulted in fairly flat trends in NO_2 concentrations at urban locations influenced by traffic in the UK and also in most European countries. This is causing problems for compliance with the EU limit value for NO_2 but the consequences for public health are much less clear-the health effect evidence for NO_2 appears to be less convincing than for PM for example, particularly in the vicinity of the limit value. It is interesting to note that the United States Environmental Protection Agency has promulgated a standard 2.5 times less stringent than the EU value, despite a recent review of the health effects.

Perhaps a more significant issue is the fact that levels of PM_{10} (particles measuring 10 µm or less) are reducing less than might have been expected (Harrison *et al.*, 2008). This is partly due to the complexities of the atmospheric chemistry where reductions in the secondary aerosol components (sulphates, nitrates etc) are not necessarily 1:1 with reductions in precursor emissions, and the fact that the directly controlled primary emissions make up a relatively small fraction of the total PM mass. This means the estimates of the public health burden have not improved much in the past five years or more, with the current estimate being that levels of $PM_{2.5}$ currently reduce life expectancy by around six months across the whole UK population with an associated economic cost of roughly £15 billion. Clearly more action is needed on PM, but this is constrained by the fact that there is still no clear identification of the most harmful components of the PM mix, despite around 15 years or more of research.

So what will initiate further action beyond a 'business as usual' approach? Some of the papers in this issue address this question. In many ways the economic case is self-evident-the damage costs of approximately £15 billion per annum are similar to those associated with obesity. On the other hand, public perception and opinion on the two issues is widely different. It seems unlikely that a theoretical economic damage cost alone is sufficient to galvanise action; indeed the damage costs have been on the table for the past five or more years without appreciable new actions. The one pressure which appears likely to generate activity, and some investment, is the threat of non-compliance with EU legislation, despite the fact that putative fines (described in the media as being of the order of £300 million with no apparent evidence for such a figure) are much less than the economic damage costs. The UK has never suffered a full infraction judgement on an environmental issue, and recent announcements suggest that such considerations carry some weight – incentives for cleaner HGVs in last year's budget, the announcement in the past two weeks of a £5 million fund to promote short-term actions in London as requested by the European Commission in relation to the UK's time-extension application are cases in point.

These actions, designed as they are to achieve legal compliance, will do little to improve the overall impact of air pollution on public health. One further notable success which has been achieved in the recent past has been the inclusion of the 'exposure reduction' concept into EU legislation which is designed to align legislative pressures with improvements in health impacts – which the current standards-based system does not do adequately. Actions to achieve more effective measures in the short term however will come if public opinion is behind them. Environmental Protection UK is working actively to promote such developments, as detailed in this issue. Apart from encouraging public awareness of the problems of air quality, further improvements (as noted in this issue) will come from aligning policies to mitigate climate change and air quality, seeking optimal win-win solutions. The UK has a great opportunity to do this as it is the only country with an ambitious greenhouse gas reduction target set in domestic law. The Department for Environment, Food and Rural Affairs began this process of optimal alignment last year (Defra, 2010) and the recent publication of advice to local authorities 'at the sharp end' will help to translate this strategic direction into reality.

Air pollution problems are becoming increasingly global, both in the sense of intercontinental transport of pollutants and the need to share experiences, science and policies on a world-wide basis. This will help to increase communication and spread awareness and this is a welcome development.

In summary, there have been some important success stories in recent years, but there have also been failures, and there remain significant public health challenges to air quality managers and policy makers in the UK, in Europe and world-wide. The papers in this timely and welcome edition of Environmental Scientist summarise the key issues admirably.

Martin Williams is a Professor in Air Quality Research at the Environmental Research Group, King's College. He was previously Head of the Air and Environmental Quality Division of the Department for Environment, Food and Rural Affairs (Defra) and is currently chairman of the Executive Body of the UNECE Convention on Long Range Transboundary Air Pollution. Professor Williams is an Honorary Fellow of the IES and gave the 2007 Burntwood Lecture.

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AIR QUALITY - THE UNSEEN PUBLIC HEALTH CRISIS?

The invisible health risk of poor air quality needs greater recognition by decision-makers and the public, according to DR TIM CHATTERTON

Throughout the first decade of the 21st century, mainstream public health discussions often dwelt on three key issues: obesity, alcohol and smoking. These issues were often characterised as problems of individual choice, but some of the key debates were around wider issues, including the introduction of the concept of 'obesogenic environments' and the impact of passive smoking in the workplace. Meanwhile air quality failed to receive such a high public profile, despite the fact that over the last decade air quality in much of the UK failed to improve. Over 60 per cent of the UK's local authorities have declared one or more Air Quality Management Areas (AQMAs), places where air quality objectives are not likely to be achieved. By 2010 the UK was facing legal challenges from the European Union over its breach of Directive 2008/50/EC for particulate matter (PM_{10}) and nitrogen dioxide (NO_2).

Why has there been such a failure to secure a place for air quality on the wider public health agenda? Is it because there is less of a health risk associated with these, than with obesity and smoking or are there other reasons for its low public profile? To address this, a comparison is drawn of the costs of a number public health issues presented in government policy documents, which should be driving forward government action.

Urban Health Risks

In attempting to manage air quality in the UK over the last 15 years it has been clear that air pollution is no longer able to remain a standalone subject (even if it ever really could). With the majority of UK air quality problems associated directly with industrial and domestic sources resolved, road transport has become the main cause of air quality problems, with well over 90 per cent of AQMAs related to transport. The problem is, however, not simply related to transport emissions; it is also to do with the topography of the streets, with buildings constraining air flow and inhibiting the dispersion of pollution. This is just the simple, direct influence of urban form though; the whole design, layout and operation of UK cities have led to a ubiquitous set of health problems, many of which are related to fundamentally unsustainable travel practices.

The University of the West of England (UWE), Bristol, recently undertook a review of *Spatial Determinants of Health for the World Health Organisation* (WHO) (Grant *et al.*, 2010). In attempting to categorise the range of threats posed by the modern urban jungle, the report identified five key 'Urban Health Risks':

- Physical inactivity
- Social impacts (including mental health)
- Noise
- 'Unintentional injuries' including road traffic accidents, heat, flooding and falls
- Air pollution

This provides a comparative framework for the relative impacts of different health risks to judge whether air quality has received unduly low priority. Climate change does not appear within the list as it does not itself pose a direct risk but rather exacerbates existing risks.

> *the impact of $PM_{2.5}$ on life expectancy was around seven months whilst the effects of road accidents and passive smoking were "of the order of between two and three months"*

Physical Inactivity

The UWE/WHO study reported that "across Europe levels of moderate-intensity physical activity are generally low and fail to comply with recommendations. Over 40 per cent of adults in the 15 European member countries reported no moderate level of physical activity in the past week. Only 18 per cent participated in a moderate level of physical activity per day, the frequency WHO suggests is required to reduce cardiovascular disease" (Grant *et al.*, 2010).

What, however, are the effects of this in terms of quantifiable health outcomes? The 2004 Chief Medical Officer's Report reported the annual costs of physical inactivity in England as £8.2 billion, including the rising costs of treating chronic diseases such as coronary heart disease and diabetes (Department of Health, 2004). In addition, the cost of inactivity due to obesity (an estimated further £2.5 billion) gives a total of £10.7 billion. The report found that "It is not possible to estimate the number of deaths attributable to inactivity as this is not a documented cause of death" (Department of Health, 2004).

Considering obesity, the 2007 Foresight report uses a baseline cost for obesity based on the 2004 Health Select Committee report of £7 billion per year (of which £1 billion is the direct health service costs attributable to obesity alone) (Department for Innovation, Universities and Skills, 2007). From this, it predicted that by 2050 the National Health Service (NHS) costs attributable to overweight and obesity would reach £10 billion per year, with wider costs to society and business estimated to reach £49.9 billion per year. Although the contemporary concept of the 'obesogenic environment' may suggest an overwhelming effect of the physical environment, it is important to remember that this also includes mental and cultural environments (the Foresight report lists appetite control in the brain, dietary habits and psychological ambivalence as other key determinants).

In making a qualitative judgement on these costs, the Department of Health (DH) website stated "Obesity has serious economic costs. It has been estimated that the cost of obesity to the NHS is approximately £1 billion per year, with an additional £2.3 billion - £2.6 billion per year to the economy as a whole" (Department of Health, 2007).

Social Impacts (including mental health)

The UWE/WHO report considered 'social impacts' as being effects of the urban environment that "lead to a host of social, economic and psychological problems at the individual or community level which then can be detrimental to physical and psychological well-being" (Grant *et al.*, 2010). These included vandalism, crime, abuse, discriminatory behaviours, isolation and stigmatism, and direct impacts of urban form such as community severance due to road building or heavy road traffic.

Assessing the effects of such a wide and amorphous set of impacts is challenging. A starting place might be to consider the costs of depression. The 2007 King's Fund report, *Paying the Price*, (Crone *et al.*, 2008) cited the cost of depression to the UK in 2007 as £7.5 billion, comprised of £1.68 billion in service costs and £5.82 billion in lost earnings. An alternative view might be to look at the costs of crime. The Home Office estimated the economic and social costs of crime against individuals and households for 2003/4 to be £36.2 billion (Home Office, 2004).

Noise

Whilst previously noise was generally considered a nuisance rather than a significant health risk, over the last decade or so the evidence has been mounting in relation to its impacts, particularly through physical stress reactions leading to cardiovascular impacts such as high-blood pressure, heart disease and strokes. A 2008 report for Defra estimated that the 'total disutility' of noise in the UK was over £7 billion, consisting of £2-3 billion of health costs, productivity costs of £2 billion and amenity impacts in the range of £3-5 billion (Defra, 2008).

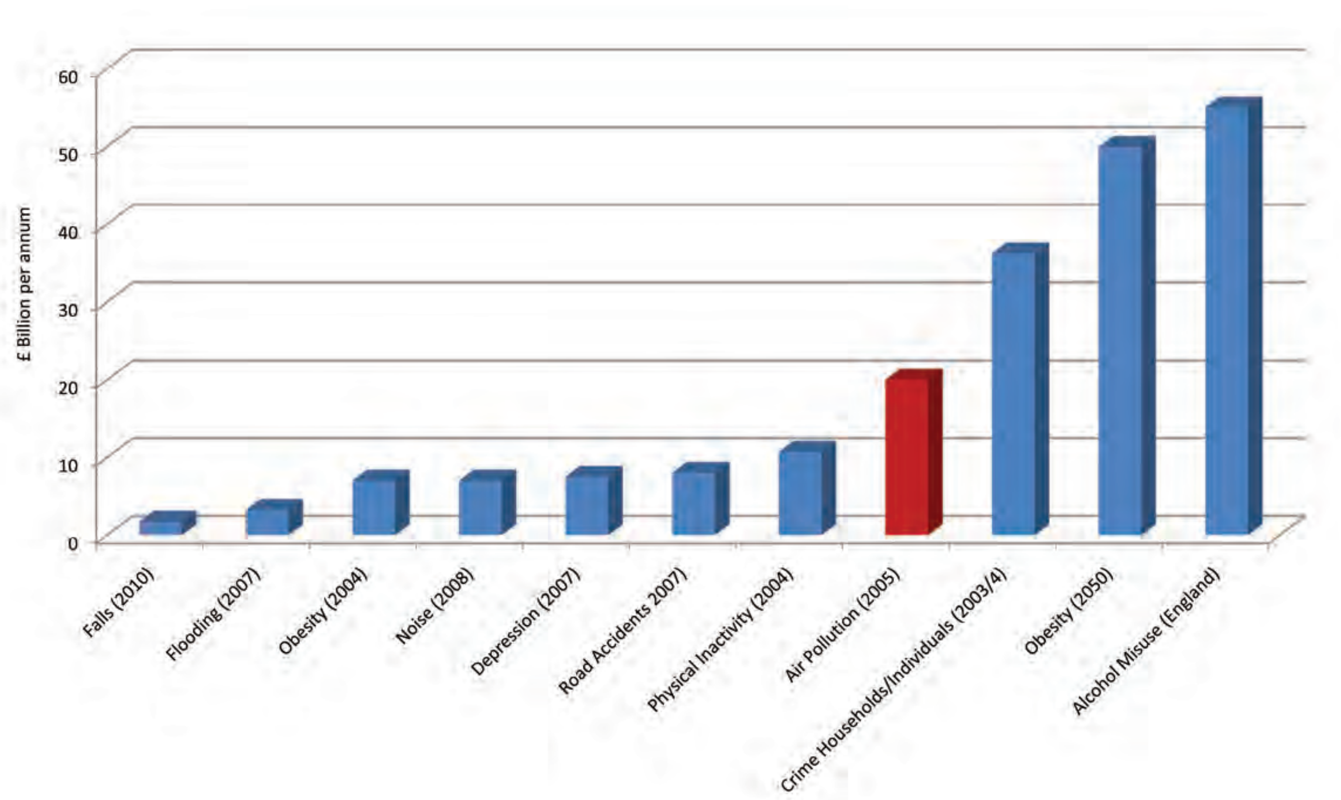

Figure 1: Indicative costs to society of threats to public health

'Unintentional Injuries' (including road traffic accidents, heat, flooding and falls)

Due to the varied nature of this category an indicative range of impacts will be given for them, as many of them do not readily aggregate into regular annual costs.

- Road Traffic Accidents: The Audit Commission report, *Changing Lanes*, found that almost 3,000 people die each year on the roads in England, with 240,000 injuries (around 10 per cent of which are classed as serious) (Audit Commission, 2007). This costs the economy £8 billion per year (£470 million of which are direct costs to the NHS).

- Heat: In response to a Parliamentary Question from Andrew Lansley in 2006 (Healey, 2006), the government reported that the August 2003 and July 2006 heatwaves caused 2,139 and 680 "excess deaths", respectively.

- Flooding: A 2010 Environment Agency report calculated that the widespread flooding cost the UK £3.2 billion (Environment Agency, 2007) Most of this related to property and infrastructure damage and loss of earnings. The specific impacts on public health (including school education) were calculated as £287 million, most of which was associated with mental health costs based on people's willingness to pay to avoid exposure to the distress caused by flooding.

- Falls: No government costing on the impact of falls could be found, however, a 2003 study by the University of York estimated the cost to the government of falls in over 60s in 1999 to be £981 million (Scuffham *et al.*, 2003). A more recent 2010 study by Age UK put the cost at £1.7 billion per year (Age UK, 2010). Amongst the younger population, the Health and Safety Executive have estimated that 'slips, trips and falls' in the workplace cost society £800 million per year (HSE, 2010).

Air pollution

1998 was a landmark year for air quality and health in the UK. On the 1st January, the DH published the Committee on the Medical Effects of Air Pollutants (COMEAP) report, *Quantification of the effects of air pollution on health in the United Kingdom* (COMEAP, 1998). The widely reported COMEAP conclusions were that up to 24,000 people per year might be dying as a result of air pollution in the UK (or more specifically, having their deaths 'brought forward'). Whilst this figure drew much attention at the time, it became increasingly questioned. This was partly because the UK was no longer suffering from regular smogs and other extreme short-term pollution episodes, making it difficult, outside complex epidemiological studies, to actually identify these deaths. The work was also undertaken very early in the UK air quality management regime (established by the 1995 Environment Act) leading to suggestions that the government should repeat the work on the basis of the better evidence now being gathered across the country. As time passed, it became harder to credibly cite a figure from a report over ten years old, and many people began to assume that 24,000, even if originally accurate, would be an overestimate of effects a decade later.

> 'air pollution is currently estimated to reduce the life expectancy of every person in the UK by an average of 7-8 months with estimated equivalent health costs of up to £20 billion each year'

2007 Air Quality Strategy

The standard health costs for air pollution impacts cited in the UK over the last few years have been taken from the 2007 Air Quality Strategy (AQS) (Defra, 2007). This stated that "air pollution is currently estimated to reduce the life expectancy of every person in the UK by an average of 7-8 months with estimated equivalent health costs of up to £20 billion each year" (from the Minister's Foreword). Volume 2 of the AQS, which presents the evidence base, clarifies this as being based on anthropogenic $PM_{2.5}$ (PM less than 2.5 microns) alone for a baseline of 2005, with a range of costs from £8.6 – 20.2 billion, and resulting in the loss of a total of 38.7 million life-years across the 2005 population.

This figure of £20 billion puts air pollution way ahead of most of the contemporary health costs. From the figures cited above, it is only exceeded by the full costs of obesity projected for 2050 (£49.9 billion), and by the total (i.e. not health-related) costs of crime against households and individuals (£36.2 billion). As another comparator, a 2008 report on alcohol misuse cites reports of costs of between £20 and £55.1 billion for total annual societal cost of alcohol misuse in England (BMA, 2008).

Passive Smoking

Considering the impacts of passive smoking also puts things in perspective. This led to the smoking ban covering all enclosed public places and workplaces in England under the 2006 Health Act – one of the most widespread public health measures in UK history. A 2006 Institute for Occupational Medicine report looked at the effects of 10 µg m^{-3} $PM_{2.5}$ (somewhat lower than the 2005 UK population weighted mean $PM_{2.5}$ concentration of 13.5 µg m^{-3} used in the AQS calculations) and compared them to road traffic accidents and passive smoking. The report found that the impact of the $PM_{2.5}$ on life expectancy was around seven months (similar to the AQS work) whilst the effects of road accidents and passive smoking were "of the order of between two and three months" (Miller & Hurley, 2006).

Critical Reviews

In 2010, two significant reviews were published of the air quality management process in the UK: one by the government's In-House Policy Consultancy (IHPC), looking specifically at the Local Air Quality Management Process, and the second slightly broader review by the Environmental Audit Committee (EAC). Both reviews strongly picked up on the failure to effectively convey the known health impacts of air pollution.

The IHPC report recommended that:

"Defra and the [devolved administrations] work with their respective health departments to develop a stronger story about the health impact of air quality for communication to decision takers in central and local government, and to the general public. We would like to see the publication of more information endorsed by the Government which compares air pollution health impacts with other well understood health threats, and the inclusion of additional appropriate measures, possibly including estimated numbers of premature deaths per year as a result of man-made pollution, and of years of life lost to victims" (Faulknet & Russell, 2010).

The EAC report stated that:

"The Government's assessment of the costs and benefits of action on air quality does not account for all the health effects of poor air quality, the damage to ecosystems and potential fines. The Government should improve the assessment of the costs and benefits of better air quality. The Government must therefore urgently:

- *quantify the impact on morbidity and the cost to the NHS of poor air quality;*
- *improve understanding of the health effects of exposure to nitrogen dioxide;*
- *estimate the cost of the damage to ecosystems and the environment from poor air quality;*
- *fund the research necessary to fill the gaps in the evidence base; and*
- *take account of the likely fines from missed EU targets in its air policy appraisal" (EAC, 2010).*

The enquiries made in the course of the two reviews highlighted a range of evidence suggesting that, rather than being an overestimate, the 24,000 deaths brought forward from the 1998 COMEAP report may have been a significant underestimate. New estimates for the numbers of premature deaths quoted in reviews show a wide range of estimates, reaching up to over 50,000 per year (European Environment Agency, 2009).

Conclusions and Thoughts

The weight of evidence seems to firmly show that air pollution is one of the most costly and damaging public health risks, and yet it does not seem to have a significant political profile at either national or local government level, and it receives very little media coverage compared to other issues such as smoking, obesity and even alcohol.

Air quality is often perceived as solely an environmental problem, and therefore is not recognised by the health community as a major public health issue. This is problem manifests itself not only in government silos (for example between Defra and DH, or between local authority environmental health departments and NHS primary care trusts), but also in approach to the problem. The establishment of clear, health-based air quality standards through the EU Framework Directive and UK AQS can lead to the assumption that any air quality health issues have been resolved. These standards however continue to be exceeded. The efforts to meet the air quality standards are frequently put in second or third place, or sometimes even lower, compared to other pressures such as protecting economic activity or combating congestion.

The other problem resulting from the air quality standards approach is that it has removed the human dimension to air quality. Although the standards are based on human health effects it can be argued that they have led to air quality becoming a technical discipline in environmental management and not one that focuses first and foremost on people. This makes it hard, not only to effectively communicate some of the health risks, but also to develop effective management strategies that need to be completely integrated with the human, social world.

What about air pollution's political profile? Why are national and local politicians not more concerned about it? Despite a lack of media coverage or major campaigning by non-governmental organisations the public have often shown significant concern about air pollution. For example, a 2001 survey of the general public by Defra (before they stopped asking about air quality!) found that air quality was the most important of the government's environmental sustainability indicators, with 73 per cent of respondents stating that air quality was 'very important', and another 22 per cent pronouncing it was 'fairly important' (Defra, 2001). Air quality was considered a more important environmental issue than climate change by the public, in contrast with the fact that in recent years climate change has surged up the political agenda (certainly in terms of rhetoric if not always action).

Why has public concern surrounding air quality not been acknowledged by decision-makers? One possible issue is that today's air pollution is not a visible problem, in comparison with the episodes of smog in previous decades. The 2008 National Census of Local Authority Councillors indicated that over 70 per cent of councillors in England would have been alive during the 1952 Great Smog (Local Government Association, 2008). The average age of an elected MP In the 2005 general election was 51 (House of Commons, 2011), meaning the majority of decision-makers too young to have experienced such events. Whilst still capable of understanding the significant risks of air pollution, most decision-makers have therefore not grown up in a society experiencing such visible air pollution episodes. Within this context, the largely invisible air pollution problems today may simply not appear as significant compared to other public health risks – whatever the numbers may indicate.

Dr Tim Chatterton is a Senior Research Fellow in the Air Quality Management Resource Centre at the University of the West of England, Bristol. He has recently spent a year on an RCUK Fellowship based in the Department of Energy and Climate Change, and has also carried out work for Defra, Department for Tranport and a wide range of Local Authorities, and he is also a trustee of the UK Public Health Association.

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BREATHING DIFFICULTIES: AIR QUALITY, CLIMATE & HEALTH

CLARE HEAVISIDE considers current and future trends in air pollutants and their health effects in the UK

Air quality in the UK today has improved greatly since the infamous smog events of the 1950s which were largely caused by domestic burning of coal, the most serious of which was the Great Smog of December 1952 associated with thousands of excess deaths in London over a single week. In 1956, the Clean Air Act signalled the beginning of a period of change in government regulations to reduce the impacts of air pollution on the health of the UK population, and in general air quality has continued to improve to the present day. However, advances in epidemiology in recent decades have shown that some pollutants in the UK are sufficiently high to have a detrimental effect on health, with air pollution still contributing to the deaths of thousands each year in the UK (Department of Health, 2010).

Air pollutants have a variety of sources, depend on man-made emissions and are often influenced by weather conditions. The World Health Organisation lists six pollutants of concern to health: sulphur dioxide, lead, nitrogen dioxide, ozone, carbon monoxide, and particles. Of these, sulphur dioxide, lead and carbon monoxide levels have all fallen considerably in recent decades in the UK, and do not pose a great risk to public health. In addition to these pollutants, the UK National Air Quality Strategy lists benzene, 1,3-butadiene and Polycyclic Aromatic Hydrocarbons as hazards, although concentrations of these have also decreased in recent years. Particles, nitrogen dioxide and ozone concentrations however, regularly exceed levels identified as harmful to health (see figure 1). This is likely to remain the case in the coming decades.

The Role of the Health Protection Agency

In the UK the Department for Environment, Food and Rural Affairs (Defra) leads on policy regulating emissions which lead to air pollution. The role of the Health Protection Agency (HPA) is to inform government, through the Department of Health (DH) and Defra, of the health effects of air pollution. HPA also supports COMEAP (the Committee on the Medical Effects of Air Pollution), on behalf of the DH, to advise government on the quantification of health benefits of policies, which influences recommendations for Defra's Air Quality Strategy. The Air Pollution Unit at Centre for Chemical, Radiation and Environmental Hazards (CRCE) works with the COMEAP Standards Advisory Subgroup (CSAS), established to advise on Air Quality Standards and, in particular, communicating the risks of carbon monoxide poisoning to health professionals and the public. The Health Protection Units of the HPA and Local and Regional Services advise on local air quality and health. As well as advice, the HPA is involved in research to investigate aspects of air pollution exposure and climate change, and their effects on health.

Sources and Health Effects of Air Pollutants

Air pollution is mainly associated with respiratory and cardiovascular illness, particularly in vulnerable people such as the elderly, the very young and those with pre-existing health conditions including asthma and cardiovascular disease. Acute health effects are usually associated with peak air pollution episodes where people are exposed to high levels of pollution for short periods of time. Chronic health effects are associated with long-term exposure to air pollution and evidence of these effects is accumulating. Variation can be seen in the origins and health effects of the main pollutants in the UK.

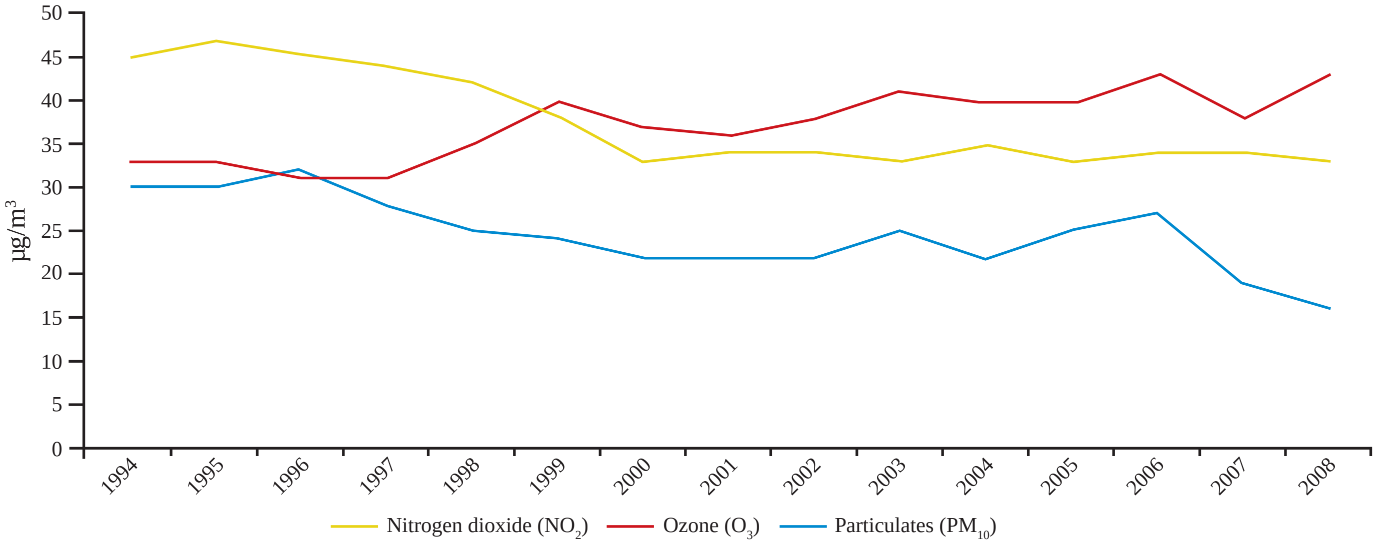

Figure 1: Recent trends in annual mean concentrations of nitrogen dioxide, ozone and particulates at the Birmingham Centre (Automatic Urban and Rural Network Station) Source: Defra, 2010.

Nitrogen dioxide

The main health effects of nitrogen dioxide (NO_2) are inflammation of the airways and reduced lung function, with children and those with asthma being the most vulnerable. There is evidence of health effects from both long-term and short-term exposure. NO_2 originates mainly from road traffic, and is therefore present at higher concentrations in cities and near roads than in the countryside, with peaks coinciding with rush hour traffic. Nitrogen oxides (NO and NO_2) also contribute to the formation of ozone, another pollutant and a greenhouse gas. Generally emissions of NO_2 have decreased since the late 1980s due to reductions in emissions from power stations and the introduction of catalytic converters, lowering road traffic contributions. Despite this, peak levels in heavily trafficked parts of cities still regularly exceed air quality limit values, and some roadside sites are reporting increases. For example, in 2010 Marylebone Road, a very busy road in central London, had 537 exceedances of the Air Quality Standard (2005) for hourly mean values greater than 200 µg m^{-3}. The hourly objective is that this limit should not be exceeded more than 18 times in a year.

> *Exposure to particles can contribute to a range of cardiovascular and respiratory illness, exacerbate existing conditions, decrease lung function and is associated with increased lung cancer deaths*

Ozone

Detrimental health effects of ozone (O_3) include reduced lung function, irritation and inflammation of airways. People particularly vulnerable to O_3 exposure are those exercising outdoors when O_3 levels are highest. There is some recent evidence of a long-term respiratory effect (Jerrett *et al.*, 2009) as well as short-term effects, and O_3 exposure has also been linked with cardiovascular disease. O_3 is a secondary pollutant; it is not emitted directly but is formed by chemical reactions in the presence of sunlight involving precursors including carbon monoxide, methane, nitrogen oxides and volatile organic compounds. Without a single source, prediction and regulation of O_3 are complex tasks, particularly because O_3 is heavily influenced by meteorology. The processes leading to its formation and destruction depend on factors such as temperature, humidity, winds, sunlight and land surface type. Levels are almost always higher in suburban or rural areas rather than urban centres, due to the destructive effect of NO on O_3 in heavily trafficked areas. Over the last few decades, long-term average levels in Europe have increased steadily, especially in cities. O_3 episodes are associated with hot, sunny weather causing increased photochemical production of O_3. Although the size of the O_3 peaks during summer air pollution episodes in the UK are decreasing due to the regulation of precursors, the frequency of the episodes is increasing. An increase in the frequency of heat waves (often associated with elevated O_3) as a result of climate change and a slow increase in hemispheric O_3 background levels is likely to lead to increased health risks from O_3 exposure in the future.

Particles

Particulate matter, comprising the ambient aerosol, is usually classed by size and the main classifications relevant to health are PM_{10} (particulates up to an aerodynamic diameter of 10 microns) and $PM_{2.5}$ (2.5 microns and below). Particles smaller than 100 nanometres are usually classed as ultrafine particles. The composition of particles is varied and includes wind-blown dust, organic and inorganic material (sulphate and nitrate) and can be natural or man-made. The size of a particle determines where it is deposited in the airways after being inhaled. A small percentage of ultrafine particles may pass into the blood stream and be transported to other organs. Exposure to particles (PM_{10} and $PM_{2.5}$) can contribute to a range of cardiovascular and respiratory illness, exacerbate existing conditions (such as asthma), decrease lung function and is associated with increased lung cancer deaths. The main man-made sources in the UK are road transport (particularly diesel vehicles) and industrial processes. There has been a reduction in PM_{10} in the UK since the 1970s, mainly due to a decline in coal use and tighter regulation of vehicle emissions.

Climate & Weather Effects on Air Pollution

Weather conditions, from large-scale weather systems to local meteorological factors, can have a considerable effect on air pollution levels. Certain meteorological conditions (e.g. anticyclones leading to air stagnation) often result in high pollution episodes which can be harmful to health. On the largest scales, pollutants and precursors can be transported to the UK over great distances (e.g. from continental Europe) along the edges of high pressure systems. These conditions are usually associated with light winds, meaning there is often little natural ventilation to disperse pollution once it builds up.

The Great Smog of London in 1952 was a result of many factors. The winter was particularly cold, leading to excess smoke and particles from increased burning of coal, domestically and in power stations. At the same time, an anticyclone was present over London, trapping cold, polluted air under a layer of warm air with little wind to aid dispersion. The Smog lasted a few days and is thought to be responsible for up to 12,000 excess deaths, mainly through respiratory infection (Bell *et al.*, 2003). Nowadays, fortunately, our greatly improved air quality prevents such events happening, although winter air pollution episodes can still be exacerbated by anticyclonic weather systems, temperature inversions and the transport of pollution from outside the UK on prevailing winds.

During the summer, hot weather can also often exacerbate air pollution levels in the UK. The 2003 European heat wave was a major natural hazard resulting in an estimated excess of 30,000 fatalities across Europe throughout August, with France and Germany among the worst affected (UNEP, 2004).

Temperatures and air pollution are often positively correlated. This was certainly the case in Europe in August 2003, where O_3 and PM_{10} levels peaked with the high temperatures and anticyclonic conditions. Health impacts in the UK were notable, from both heat and air pollution exposure, during that period (see figure 2). Over 2,000 excess deaths were reported during this month compared with expected numbers for August (Johnson *et al.*, 2005). The level of pollution was such that of the estimated 2,045 excess deaths in the UK, 207 deaths were thought to be associated with PM_{10} and between 225 and 593 associated with O_3 (Stedman, 2004). Larger effects may have occurred during the summer of 1976 when ozone concentrations reached an all time high of over 200 ppb

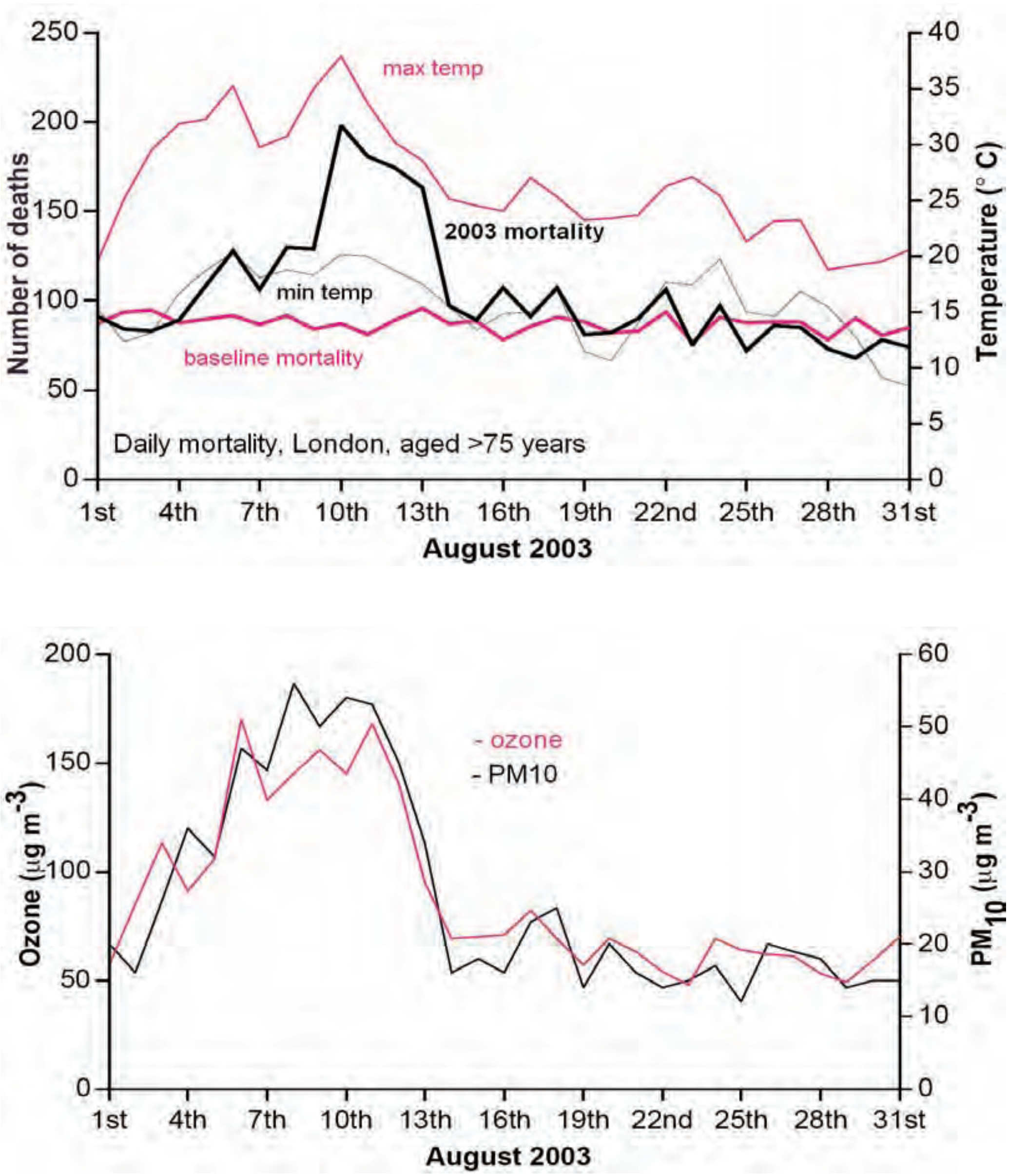

Figure 2: Comparison of temperature, mortality of the over 75-age group and air pollution levels in London during August 2005. Maximum and minimum temperature, daily mortality for people over 75 years and baseline mortality (calculated based on previous 5 Augusts) for London in August 2003 (top graph). Concentrations of ozone (daily max of running 8-hour mean) and PM_{10} (daily mean) for London in August 2003 (bottom graph). Adapted from Johnson et al., (2005).

in London and over 250 ppb in Harwell, Oxfordshire (Defra, 2011). Although concentrations of particulate matter are decreasing and the magnitude of O_3 peaks is also falling, the benefit to health is partly offset by an increase in background O_3 and an increase in the frequency of heatwaves.

Measuring Health Impacts of Air Pollution

Quantifying the health effects of air pollution is difficult and complex due to the large number of confounding factors obscuring the true effects of the pollutants. It is also difficult to assess the impact of each pollutant on health separately since they are often correlated, and there is evidence that combined health effects of a range of pollutants are greater than their individual impact. Epidemiological cohort studies can identify the health impact of long-term exposure to pollution but these studies are time-consuming, expensive, and scarce. Time-series studies of air pollution are relatively easy to perform and can highlight a relationship between daily mortality or morbidity and short-term increases in exposure, but cannot be used to identify long-term effects. Much of the evidence for health impacts of air pollution is based on increased mortality associated with an increase in exposure even though in most cases air pollution exposure is only a contributing factor to death.

Another way of expressing the health impact is to calculate Years of Life Lost (YLL), estimating the average numbers of years lost due to a person dying prematurely based on a reference population life expectancy. Life tables can be used to estimate YLL. Each year, the statistical chance of a person dying can be calculated based on age and gender. Together with exposure data, life tables enable assessment of effects of long term exposure to air pollutants at a population level. These calculations can contribute to policy development so an appropriate metric must be carefully considered (Department of Health, 2010).

The Future of Air Quality Related Health Impacts in the UK

Regulation and control strategies for air pollutants with have mainly anthropogenic sources are directly related to concentration in the atmosphere. For pollutants with a strong interaction with weather and climate, predictions for future levels must take into account climate factors. Emissions of most air pollutants in the UK are falling, although concentrations of some (e.g. NO_2, PM_{10} and O_3) still regularly exceed air quality limits. Further reduction of these pollutant levels is therefore needed.

Annual mean levels of particles such as PM_{10} are falling but daily episodes of elevated peak levels exceeding the limit value still occur. Future O_3 levels are difficult as it is a secondary pollutant, with concentrations depending on a range of precursor gases, atmospheric chemistry and meteorology modified by climate change. Currently the dominant factor is precursor emission, which most predict will fall due to regulations for the next few decades. The climate change effect on O_3 production will however, lead to increases in the northern hemisphere, largely through increased temperature. As emissions continue to fall and climate change effects become more evident, climate change is likely to become the dominant factor.

For many air pollutants, policy has succeeded in reducing concentrations to a safer level in the UK. There is still work to be done to reduce some key air pollutants such as NO_2 and PM_{10} further, especially in cities. We also have to consider the potential impacts of climate change on air quality in the future. It is clearly important to continue with research on both the health impacts of air pollution and the environmental factors determining air quality in order to inform policy and protect the public health of the UK population.

Clare Heaviside is an environmental scientist at the Health Protection Agency where she works on air pollution, climate change and health. She is also an honorary research fellow at Birmingham University, working on regional modelling of urban climate. Her first degree was in Engineering at Sheffield University and she has an MSc in Applied Meteorology from Reading University and a PhD in atmospheric and oceanic physics from Imperial College.

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THE $PM_{2.5}$ CHALLENGE

Limiting the impact of $PM_{2.5}$ exposure on the nation's health remains an important if difficult task, according to **DUNCAN LAXEN**

The headline shouts "UK air pollution causes 50,000 early deaths a year, say MPs". The sub-heading: "Minute particles from burning fuel can shorten lives by up to nine years, according to the environment audit committee", clearly focuses the problem on 'minute particles'. Scientists have known for two decades now that fine airborne particles are the key air pollutant in terms of health impacts, and that there is no known safe level for exposure to these particles. It is also now known that long-term exposure is more important than short-term exposure, and the numbers of deaths attributable to particles are more than those for passive smoking and car accidents. Exposure to particles is clearly not something to be ignored.

The initial focus of the air quality community was on particulate matter less than ten micrometres aerodynamic diameter (PM_{10}), as this was the particle size measured at the time. Subsequently the emphasis has shifted to the even smaller particles, which penetrate deeper into the lung. First in the USA, and now in Europe, standards have been introduced to limit exposure to these smaller particles, referred to as $PM_{2.5}$. To comprehend the extent of the challenge in reducing $PM_{2.5}$ it is necessary to understand where airborne particles come from, their current impacts and the necessary levels of exposure reduction (Laxen *et al.*, 2010).

> *'the numbers of deaths attributable to particles are more than those for passive smoking and car accidents'*

Where does $PM_{2.5}$ come from?

Traditionally concern focused on single compound pollutants, such as sulphur dioxide and carbon monoxide. In contrast, $PM_{2.5}$ is made up of many different constituents. Measurements at an urban background site in Birmingham over a 12-month period in 2004/05 showed the main constituents to be (Yin & Harrison, 2008): organics (27%); ammonium sulphate (24%); ammonium and sodium nitrate (21%); elemental carbon (11%); iron rich dusts (6%); sodium chloride (4%); and calcium salts (2%). There will also be a wide range of trace constituents associated with the particles, including polycyclic aromatic hydrocarbons and metals.

To add to the complexity, these constituents of $PM_{2.5}$ come from a wide range of sources. The first distinction to make is between sources contributing primary particles and those that contribute gaseous emissions that are transformed in the atmosphere to create secondary particles. Furthermore, there are anthropogenic and natural sources of both primary and secondary particles. Primary particles include combustion products, mainly elemental carbon and various organic particles, as well as sea salt and mineral particles from wind-blown dust. Secondary particles are comprised mainly of ammonium sulphate and nitrate salts, and organic particles. These secondary particles form relatively slowly in the atmosphere, and the precursor gases have often travelled hundreds of kilometres from the point of emission before the secondary particles are created. It is thus not possible to link secondary particles to particular individual sources.

The understanding of $PM_{2.5}$ levels from the different sources is essentially limited in the UK to two models: receptor modelling based on measurements made in Birmingham over a 12-month period in 2007/08 and the semi-empirical modelling of national background concentrations carried out by AEA on behalf of Defra and the devolved administrations. Further work is however required as differences exist between the two approaches. This is demonstrated through a comparison of the results from the two models for the city of Birmingham (see figure 1).

In both cases it is evident that secondary $PM_{2.5}$ dominates. There is also a significant contribution from sea salt and dust. Road traffic accounts for around 12 per cent of the $PM_{2.5}$ at this location, with a third of this traffic contribution coming from brake and tyre wear. The receptor modelling shows that diesel dominates over petrol. There is however no clear category for industrial sources, in contrast with the AEA model in which they contribute around nine per cent, with domestic sources only contributing around one per cent. The AEA model does however have a category called 'off-road machinery' that contributes seven per cent. It is possible that this links with the category 'smoking engines' identified in the receptor modelling. The receptor modelling also shows a significant organic matter contribution, but it is not immediately apparent where this would appear in the categories used in the AEA model.

An important message from this work is that only a relatively small proportion of urban background $PM_{2.5}$ is amenable to local control. Local traffic, industrial, domestic and commercial sources account for around 25 per cent of the $PM_{2.5}$ in urban areas. The role of urban dusts is less clear, but they may also be amenable to local control, thus, in combination, around one third of the $PM_{2.5}$ concentrations may be responsive to local management. This adds considerably to the challenge of using local measures taken by local authorities and the environment agencies to reduce our exposure to $PM_{2.5}$.

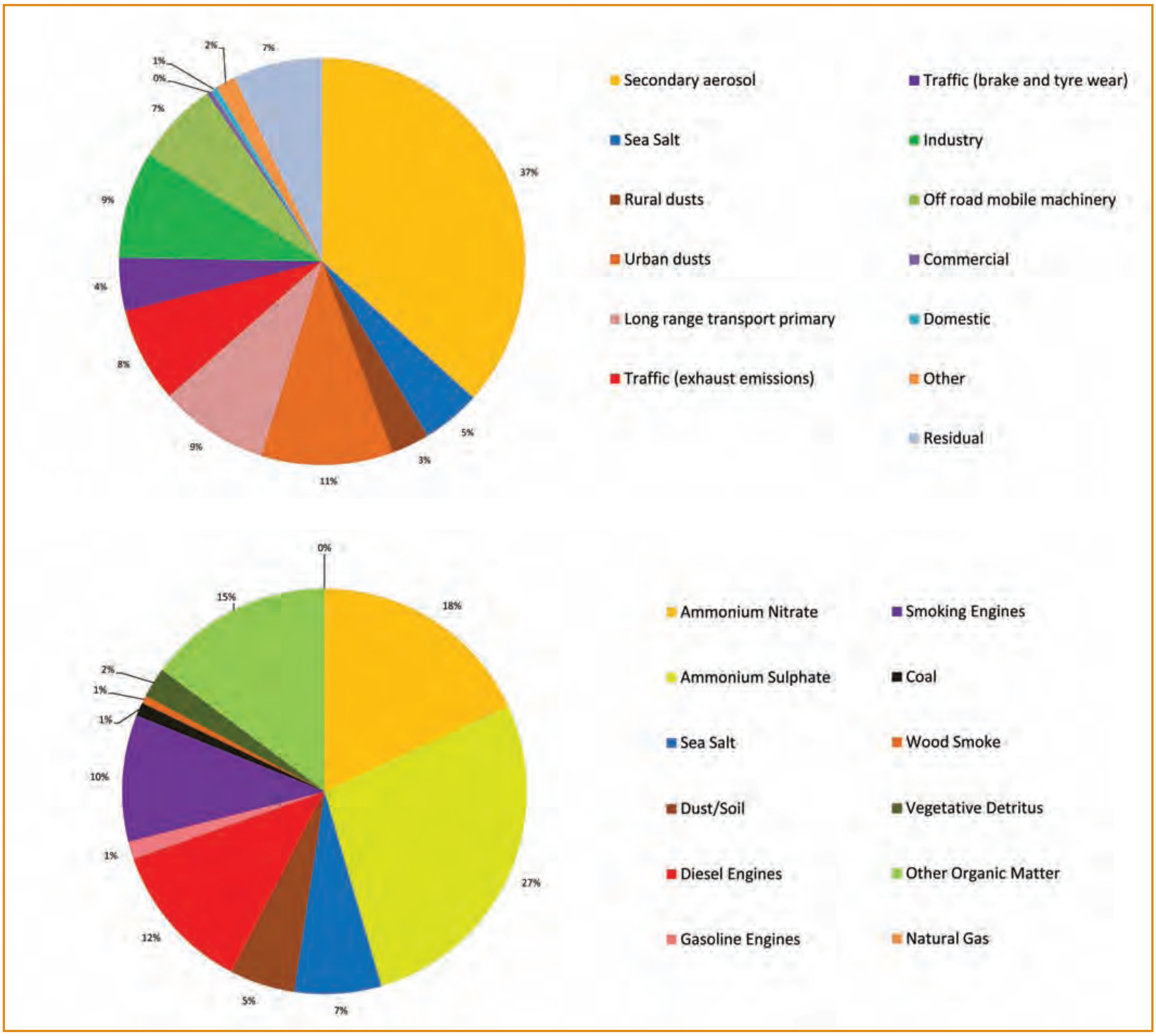

Figure 1: Sources of $PM_{2.5}$ at urban background locations in Birmingham. Top graph: results from modelling by AEA for 2009, for a location at Birmingham Tyburn (Stedman, 2011). Bottom graph: results from measurement and receptor modelling in 2007/08 by Yin *et al*. (2010).

How much $PM_{2.5}$ are we exposed to?

Secondary particles therefore dominate, even in urban areas. These particles are found across the whole of the UK, thus people are exposed everywhere. There is though a gradient in secondary particles from north to south, with the highest concentrations in the southeast of England. This is, in large part, a reflection of the importance of secondary particles transported from continental Europe.

The importance of continental sources to the east is seen in the monitoring data. Results from the national network of sites across the UK in 2009 have been analysed using OpenAir software (Open Air, 2011). Polar plots have been created using wind data appropriate to different regions of the country. These plots show average concentrations as a function of wind direction and wind speed. The patterns are remarkably similar for all urban background sites in the UK, as shown from the results for four sites across the UK (see figure 2). Concentrations above the annual average clearly occur with easterly winds, with a more northeasterly component evident in the north of the country and a more southeasterly component in the south. In most cases the highest concentrations occur with the highest wind speeds, greater than 10 m/s. This is consistent with the transport of $PM_{2.5}$ from continental Europe, mostly as secondary particles. At low wind speeds (less than 3 m/s) elevated concentrations are to some extent associated with all wind directions. This is likely to reflect the build-up of local emissions when the winds are light and dispersion limited, although there is still an easterly predominance.

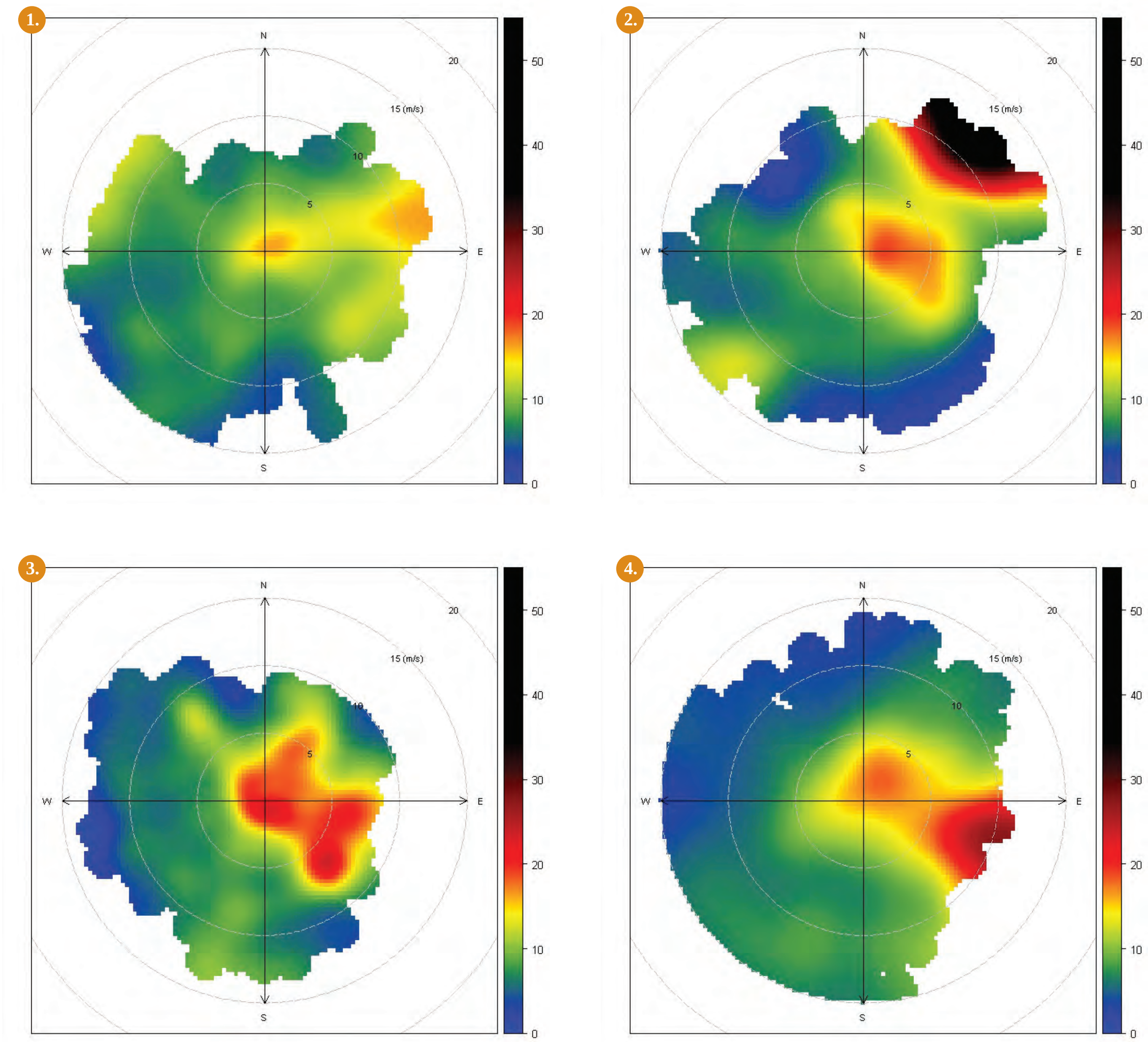

Figure 2: Polar plots of $PM_{2.5}$ concentrations (µg/m^3) at urban background sites in 2009. From left to right: 1. Glasgow Centre, 2. Manchester Piccadilly, 3. Birmingham Tyburn, 4. Portsmouth. The outer full circle represents a wind speed of 20 m/s. The concentration scale is marked 0-50 µg/m^3. Concentrations shown as yellow and above are essentially those above the annual average.

Assimilating the information from monitoring and modelling, AEA has mapped the background $PM_{2.5}$ concentrations across the UK (see Figure 3). The gradient from north to south is due to secondary $PM_{2.5}$, as discussed above. Superimposed on this are the higher concentrations associated with urban areas, with motorways and major roads also adding to the pattern. These maps have allowed population-weighted mean $PM_{2.5}$ concentrations for 2010 to be calculated; these are 5.5 µg/m^3 in Scotland, 6.4 µg/m^3 in Northern Ireland, 8.3 µg/m^3 in Wales, 10.6 µg/m^3 in England (excluding London), and up to 14.1 µg/m^3 in inner London.

Another way to look at $PM_{2.5}$ concentrations is to separate them into rural background, urban background and roadside. In this regard, the rural background concentrations range from 3.5 µg/m^3 in the north of Scotland, to 10 µg/m^3 in the south of England. Superimposed on this is an urban enhancement, which is a few µg/m^3 in major urban areas. At the roadside, concentrations will be a few µg/m^3 higher still, although levels decline rapidly on moving away from the road, such that they are indistinguishable from the local background beyond about 20-50 m.

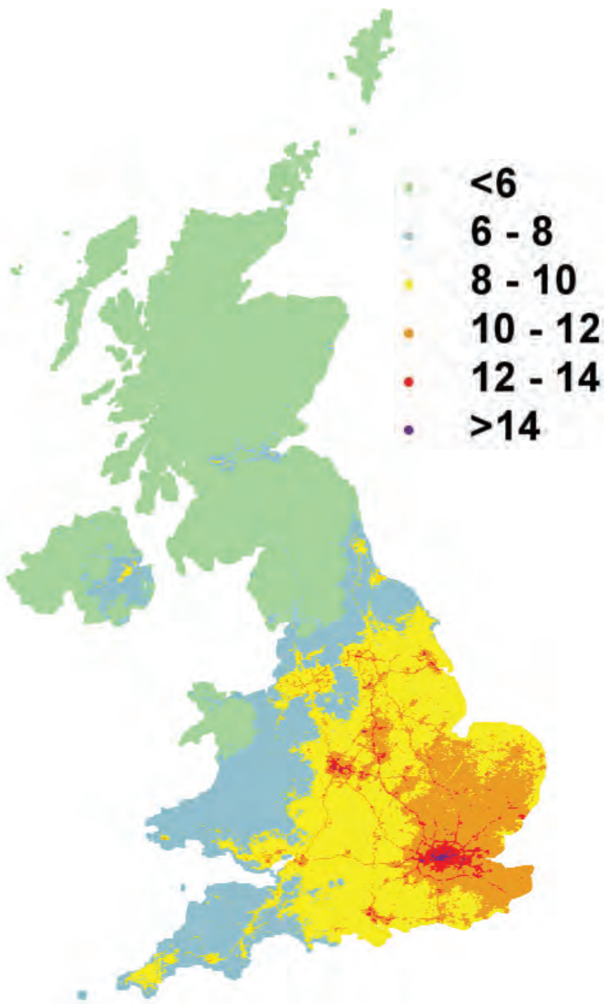

Figure 3: Background $PM_{2.5}$ concentrations (μg/m^3) in 2010. Based on data produced for Defra and the devolved administrations by AEA.

What are the $PM_{2.5}$ health effects?

There have been many studies of the health effects of exposure to airborne particles. These have shown that both short- and long-term exposure to $PM_{2.5}$ can lead to increased hospital admissions and to mortality from cardiovascular and respiratory diseases (see Box 1). It is however recognised that the effects of long-term exposure are more significant in terms of the overall impact on the nation's health. For this reason the focus of attention is now on annual mean concentrations, which reflect this long-term exposure.

It has not been possible to identify a threshold below which there are no health effects. This is important when it comes to designing programmes to control exposure. Similarly the components of $PM_{2.5}$ which give rise to the toxicity have not been identified. All components therefore have to be treated as equally capable of giving rise to the health effects.

Quantification of Health Effects

COMEAP has recently issued a detailed report quantifying the long-term effects of exposure to $PM_{2.5}$. This broadly supports the headline quoted by the House of Commons Environment Audit Committee, coming up with a figure of 29,000 deaths in the UK in 2008 being attributable to exposure to $PM_{2.5}$. The report, however, examines the different ways of calculating and expressing effects (COMEAP, 2010). Often the effects are expressed as loss of life and the report shows that if air pollution was solely responsible for these 29,000 deaths, then the loss of life for these individuals would average 11.5 years. At the other extreme, if all deaths in the UK in 2008 were influenced by air pollution then the average loss of life would be 6 months. It goes on to say that as air pollution is linked to cardiovascular deaths, it is probably more reasonable to say it contributed to the earlier deaths of up to 200,000 people, with an average loss of life of about two years per death affected.

What legislation controls exposure?

As stated, there is no threshold for the effects of exposure to $PM_{2.5}$. From the perspective of improving the nation's health it proves more effective therefore to reduce the exposure of a large number of people by a small amount, than to reduce exposure of a small number of people by a large amount. This is illustrated by considering the health benefits of reducing the average exposure of 10 million people by 1 μg/m^3, which are one hundred times greater than reducing the exposure of 10,000 people by 10 μg/m^3. The UK therefore championed the introduction of the 'exposure reduction' approach to the legislation to maximise the benefits of controlling exposure to $PM_{2.5}$ (Laxen & Moorcroft, 2005). This approach has been taken up in the Air Quality Strategy for the UK and in the EU's Clean Air for Europe Directive. To be effective it should apply to as many people as possible. Legislation is therefore focussed on background locations in the major urban conurbations. Targets have been set for an overall reduction in exposure over a ten year period, as a three-year average concentration measured at a large number of urban background monitoring sites throughout the UK.

The UK has set its own target of a 15 per cent reduction to be achieved between 2010 and 2020. The EU approach is more complicated, being dependent on the starting concentration, with a greater reduction required when this concentration is higher. In the UK it will be necessary to reduce the average concentration across all urban background monitoring sites by either 10 per cent or 15 per cent depending on the exact levels measured over the period between 2009 and 2011 at the 50 sites forming the 'official' network.

This exposure reduction approach is supported by some backstop standards, to ensure that individuals are not exposed to excessively high concentrations. There is thus an EU annual mean limit value of 25 μg/m^3 which comes into effect in 2015. The current evidence from the monitoring across the UK is that this limit value will not be exceeded anywhere. Indeed, the evidence is that the PM_{10} standards, which remain in force, are more constraining, even in Scotland where more stringent objectives have been set. Thus, if the PM_{10} standards are met, then the $PM_{2.5}$ standards should also be met.

Superficially, the exposure reduction standard is not very demanding. This will, however, not be the case in practice. A 10-15 per cent reduction represents a 1.5-2 µg/m^3 reduction in the annual mean concentration over ten years. Local sources enhance the urban background by some 3-6 µg/m^3. Meeting the reduction target by controlling local sources would therefore require a decrease of between 25 and 67 per cent, which would be challenging. An alternative approach would be to rely on the reduction in secondary $PM_{2.5}$, which accounts for some 4-6 µg/m^3 of urban background concentrations. This would require secondary $PM_{2.5}$ concentrations to be cut by 25-50 per cent, again not insubstantial. In practice, therefore, it will be difficult to meet the exposure reduction targets. The challenge will be compounded by the wide range of sources contributing to urban background concentrations, some of which are still not well understood, and by the international difficulties in agreeing emissions reductions of precursor gases to achieve a reduction in secondary particles. This, in turn, will be compounded by the non-proportional relationship between precursor gas emissions and secondary particle concentrations.

At the start of the implementation of new legislation to control exposure to $PM_{2.5}$ a number of challenges lie ahead, but all the evidence indicates that the necessary efforts will be highly beneficial in improving public health.

Prof. Duncan Laxen is Managing Director of Air Quality Consultants Ltd and a board member of the IAQM. He is a member of Defra's Air Quality Expert Group and the Department of Health's Committee on the Medical Effects of Air Pollution. He led the preparation of the SNIFFER report on $PM_{2.5}$ in the UK that is the basis for this article.

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IES: NEW MEMBERS AND RE-GRADES

Name	Occupation	Grade
Adetayo Adedeji	Senior Environmental Toxicologist	M
Declan Alder	Graduate Environmental Consultant	A
Jenny Aldred	Environmental Scientist	M
Izabela Blicharska-Moreno	Consultant	A
Nicholas Brown	Principal Consultant	M
Melanie Brown	Farm Conservation Advisor	M
Justin Cairns	PhD Researcher	A
Ayan Chakravarrtty	Student	Af
Wai Chiu	Assistant Consultant	M
Emma Collins	Environmental Scientist	M
Michael Collins	Geoenvironmental Scientist	M
Emily Connolly	Environmental Scientist	M
Laura Cunningham	Assistant Environmental Scientist	A
Ian Deans	Associate Geoenvironmental Consultan	M
George Evans	Graduate	A
Ruth Fain	Environmental Scientist	M
Hayley Farnell	Senior Environmental Scientist	M
Deborah Ferady	Contaminated Land Officer	M
Jacob Ford	Scientific Officer (Analytical Chemist)	M
Kate Fradley	Air Quality Consultant	A
Ian Fraser	Company Director	M
Victoria Griffin	Senior Environmental Scientist	M
Geraldine Guiguet-Doran	Environmental Consultant	M
Joseph Hall	Graduate	A
Charles Hall	Graduate	A
Nicholas Hampson	Student	Af
Thomas Hastings	Business Development Manager	Af

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CASE STUDY: ADVANCES IN MODELLING EXPOSURE

Modelling spatial-heterogeneity is essential to refine exposure estimates, as **VALERIE GARCIA, VLAD ISAKOV** and **TIM WATKINS** demonstrate in this case study in New York City

Concerned about the health impacts of air pollution, many environmental agencies around the world are implementing regulations to reduce emissions from various sectors, thus maintaining ambient air quality at acceptable levels. The United States Environmental Protection Agency (EPA) sets the National Ambient Air Quality Standards (NAAQS) for criteria pollutants, such as ozone, nitrogen dioxide, and particulate matter, to protect public health and the environment. As the NAAQS target pollutant concentrations in the ambient air, the impact on reducing actual human exposure to harmful air contaminants may vary significantly. Air quality management programs designed to meet the NAAQS may also vary in their effectiveness at protecting public health. It is therefore important to explicitly consider exposure to fully assess the nature and magnitude of the air pollution problem, and achieve a better understanding of how pollutants impact human health.

Numerous health studies have used measurements from a few central-site ambient monitors to characterise air pollution exposures. Relying solely on central-site ambient monitors does not account for the spatial-heterogeneity of ambient air pollution patterns or the influence of infiltration and indoor sources (Jerrett *et al.*, 2005, Sarnat *et al.*, 2006). Central-site monitoring becomes even more problematic for certain particulate matter (PM) components (e.g. metals) or size fractions (e.g. coarse, ultrafine) that exhibit significant spatial-heterogeneity. This variation may be influenced by meteorology as well as emissions from both regional and local sources. In addition, using central site monitors does not reflect personal exposure contributions, such as time in microenvironments. Given that people spend the majority of their time indoors, the infiltration of outdoor air indoors and indoor sources can greatly affect personal ambient exposure levels. Improving air pollution exposure characterisation will result in more accurate risk estimates of associated health effects to inform future development of NAAQS and other air pollution regulations.

The level of exposure characterisation required for analyses will depend on the goals of the epidemiological assessments. More advanced methods to characterise exposure are necessary in studies where intra-urban gradients of air pollutant concentrations are important. For example, while PM mass concentrations may be similar across locations, the composition may be very different, making the understanding of sources very important. In addition, health studies conducted across multiple locations require an understanding of location-specific factors, such as climate, housing stock, and commuting patterns, which impact the relationship between personal and ambient exposures. Refining exposure estimates, even for those pollutants known to be spatially homogeneous, may reveal associations not previously discernable.

Approaches for estimating exposures

Estimates of ambient concentrations have been enhanced by utilising passive monitoring methods along with modelling tools, thus providing additional spatial resolution in ambient concentration estimates. Spatio-temporal models (which integrate Geographical Information Systems data and other factors such as meteorology) have been developed to produce more resolved estimates of ambient concentrations. Models, such as the Community Multi-Scale Air Quality (CMAQ) model, estimate ambient concentrations by combining information on meteorology, source emissions, and chemical-fate and transport (Byun & Schere, 2006). In addition, hybrid modelling approaches, which integrate regional scale models (such as CMAQ) with local scale dispersion models, provide new alternatives for characterising ambient concentrations.

Publicly available data on housing characteristics and commuting patterns can be used to understand the relationships between personal and ambient exposure. The age and size of the home will affect the proportion of personal exposure due to ambient air. Commuting patterns will also influence how representative a central site ambient monitor is of ambient exposure. Since publicly available data are limited, modelling approaches to estimate personal exposure are being developed, for example the Stochastic Human Exposure and Dose Simulation Model (SHEDS) (Burke *et al.*, 2001, Özkaynak *et al.*, 2008). The SHEDS model is a population exposure model that calculates the distribution of exposures within the study population. An integrated air quality and exposure modelling system provides the means to predict the distribution of exposures for the population in various microenvironments by linking air quality modelling information to SHEDS. An integrated modelling system could also be applied in air quality management practices, such as standard setting, standard implementation, risk mitigation and accountability (Isakov *et al.*, 2006, Isakov *et al.*, 2009).

Application of Advanced Approaches in a Health Study

A case study conducted in New York City (NYC) metropolitan area illustrates the impact of spatial misalignment on health effect measures, looking in particular at the association between asthma and ozone. Three of the techniques previously described were applied to characterise ozone exposure:

1. Ozone concentration surfaces over the study area derived from monitoring data using statistical interpolation techniques;

2. Ozone concentration estimates based on emissions and meteorological data using the CMAQ model;
3. Ozone exposure estimates using the SHEDS model with inputs from CMAQ (version 4.5).

The study investigated the association between ozone exposure and respiratory-related hospital admissions for five summers (between June and August, 2001 – 2005 inclusive) in four counties of the NYC metropolitan area (Bronx, New York, Queens and Kings).

The exposure metrics produced varied between the three different approaches. Figure 1 compares spatial aspects of the exposure metrics from the first and third technique (concentrations versus personal exposure). As shown, the exposure concentration levels estimated with SHEDS is much lower than the interpolated observations. This is because individuals spend a large amount of time indoors, and also because spatial heterogeneity in exposure estimates is achieved by incorporating exposure factors, such as housing type, infiltration rates, or individual's locations and activities. This does not however address whether the more spatially resolved exposure estimate generated from the SHEDS model will result in a more significant association with the health endpoints, despite the fact that the exposure levels are lower than the spatially interpolated estimates.

The daily maximum ozone concentrations, averaged over eight hours, were calculated from the hourly measurements archived at the EPA's Air Quality System (AQS) database (EPA, 2011). Ozone observations were available from six stations and were interpolated to one kilometre horizontal grid resolution and then averaged for each of the four counties. In addition, eight-hour maximum daily averaged ozone concentrations were calculated from the hourly concentration values simulated by the CMAQ model (Byun & Schere, 2006; Appel *et al.*, 2007). The CMAQ estimates were used to generate a combined observed and modeled surface using a multiplicative adjusted bias approach, known as 'bias-corrected CMAQ' (Garcia *et al.*, 2010). Finally, output from the SHEDS model was used to estimate individual exposure by accounting for infiltration of pollutants into buildings and daily activity patterns (Burke *et al.*, 2001).

Hospital admission information was obtained from the New York State (NYS) Department of Health Statewide Planning & Research Cooperative (SPARCS), which collects inpatient information for all NYS hospitals, excluding psychiatric and federal hospitals. SPARCS is a legislatively mandated discharge database which includes at least 95 per cent of acute care hospitalisations. Respiratory diseases were based on the International Classification of Diseases, 9th Revision (US Department of Health and Human Services, 1991), and included: asthma, chronic bronchitis, emphysema, and chronic obstructive pulmonary disease. There were a total of 1,840 daily respiratory-related hospital admissions across the four NYC counties during the 460 days of the study time period.

A Generalized Additive Model (GAM) (Wood, 2010) was used to investigate potential associations between ozone and respiratory-related hospital admissions in the greater NYC metropolitan area. The model relates the number of hospital admissions to the three-day moving average of the daily eight-hour maximum ozone concentration for each day. This time-series model accounts for inter- and intra-annual variability, as well as holidays and weekend versus weekday ef-

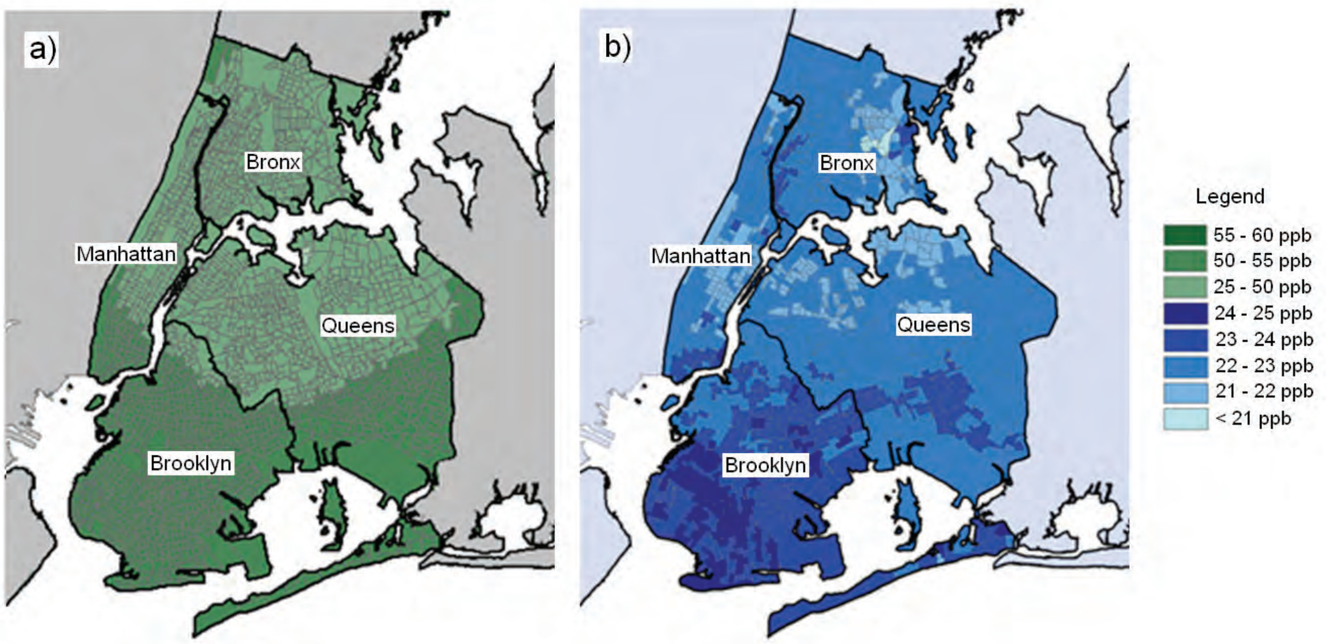

Figure 1: Spatial maps of interpolated observations of ambient ozone concentrations from technique 1 (a) and modelled personal exposures from technique 3 (b) in the greater New York City metropolitan area.

fects. Other indicator variables include average maximum temperature and average dew point. The GAM was run repeatedly, using the different exposure definitions from each technique as the main health effects variable each time: averaged observations from interpolations, bias-corrected CMAQ, and exposure model output). Using the GAM, relative risk was calculated for same-day, lag 1 day, lag 2 days, lag 3 days and 3-day simple moving average (SMA) for each exposure metric. All other variables in the GAM remained the same. In addition, a sensitivity analysis was conducted by randomly selecting and removing data points and then examining the repeatability of the results to determine the stability of the epidemiology model. In addition, residuals were examined for collinearity and autocorrelation.

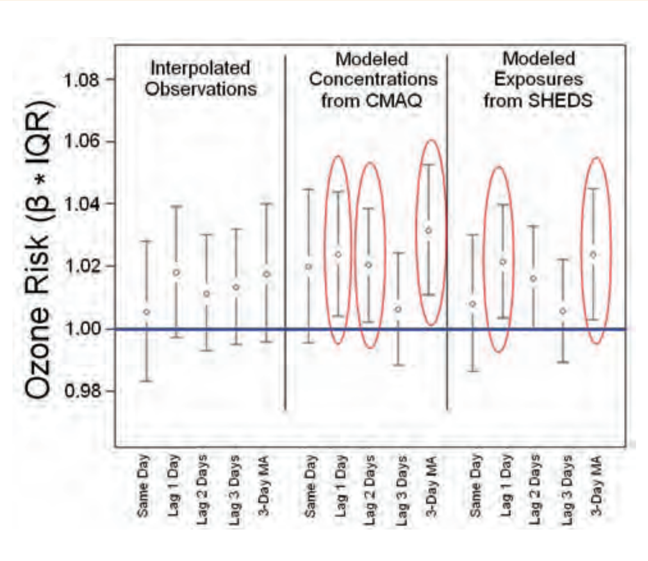

Figure 2: Risk and 95th percentile confidence intervals calculated by applying averaged observations, bias-adjusted CMAQ predictions, and exposure model output in the GAM. Significant difference for confidence intervals shown for values above the 1.0 line. Coefficients are multiplied by the inter-quartile range to account for the varying distributions of the three datasets. Ovals highlight significant findings.

Results of the Health Study Approaches

The refined exposure estimates quantifiably strengthened the relative risk (figure 2) from just under two per cent for observations, to three per cent (bias-corrected CMAQ) and over two per cent (exposure model output). The lag 1 day, lag 2 days and 3-day SMA all produce significant risk, compared to using observations alone. The use of enhanced ozone concentration surfaces (technique 3) resulted in a significant finding for the lag 1 day, lag 2 days, and 3-day SMA metrics, where no significant association was seen with observations alone. This result is consistent with the findings reported in Garcia et al. (2010) that the air quality model provides additional information regarding spatial-heterogeneity. Jerrett et al. (2005) also demonstrate the intra-urban variability and improved estimates from using approaches that consider infiltration and time in microenvironments. The results of this study therefore support previous studies showing that the estimated health effect measure was greater in magnitude for both the biased-corrected CMAQ and exposure model metrics compared to observations alone.

In addition to relative risk and confidence levels there are several issues that it is important to consider when analysing the inference of the health effect measure. These include misclassification and selection bias, differing scales and intervals at which health and air pollution data are available and aggregated, sampling bias due to data limitations, and confounding that exists between the model variables and the health outcome.

In this study, selection bias (association between exposure and disease differs for those who participate and those who do not) is moderated by the study design since the entire NYC population is included in the study. The impact of exposure misclassification (also known as information bias or Berkson error) on the inference of the health effect measure is determined by whether the error is differential (bias is different for diseased and non-diseased groups) and non-differential (bias is unrelated to disease occurrence). In this study, any information bias would likely be non-differential because the error associated with the main health effect (ozone) should be the same in both the respiratory illness and healthy groups. Thus, any bias would likely attenuate the findings toward the null making the study results conservative (under-estimation of effect).

Confounding is an issue in this study as temperature is correlated with ozone and with the health outcome. For this study, Garcia et al. (2010) provides evidence that temperature alone cannot account for the association seen between ozone and respiratory-related hospital admissions in the NYC metropolitan area. Other analyses examining the homogeneity of the health effect modifier for temperature versus ozone concentrations indicated that after accounting for temperature, the variability remaining was sufficiently explained by ozone for two groups stratify by the mean concentration. Finally, the large sample size of the study (1,840) minimises the existence of sampling bias. The change in the health effect measure resulting from the application of the more refined exposure estimates can therefore be attributed to the improvement in matching the daily change in exposures with the appropriate population.

Since environmental managers and health scientists rely on the ambient concentrations in managing air quality, it is important to have a better understanding of human exposure to air contaminants to adequately protect human health. Improving characterisation of air pollution exposures involves novel approaches using measurements and modelling tools to enhance estimates of ambient air concentrations and to gain a better understanding of the personal-ambient relationships. Creative use of publically available data and the application of personal exposure modelling tools, such as SHEDS, alone and in combination with other air quality models provide opportunities to better define and predict personal-ambient associations.

Valerie Garcia, Vlad Isakov and Tim Watkins work for the Office of Research and Development, National Exposure Research Laboratory, United State Environment Protection Agency.

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MOBILISING THE PUBLIC ON HEALTH AND AIR QUALITY

Environmental charity Environmental Protection UK is launching a major air quality and public health campaign during 2011 **ED DEARNLEY** sets out the need for this campaign and how it could be implemented

Health is at the top of most lists of concerns amongst the UK public. Other factors may cause annoyance and distress, but if we neglect our health we pay the ultimate price. The impacts of poor air on health are considerable, yet public and political awareness of the issue remains remarkably low. Does this situation need to be improved, or is the current legislative framework sufficient to address the problem of poor air quality without the public 'getting involved'? And if it is necessary to improve public awareness of air quality issues, how can this be done?

Does the public need to 'get involved'?

The first question is one that is particularly relevant at the current moment in time – there is an increasing tension between the health improvement agenda and the main drivers to improve air quality. The UK Government is currently focused on complying with limit values for the concentration of certain pollutants in the air, as prescribed in European law by the 2008 Air Quality Directive. If they fail to meet these targets large fines could potentially be imposed by the European Courts. In practice this means the current focus is on meeting limit values for particulate pollution (PM_{10}) in parts of the UK that do not officially comply: parts of London and the island of Gibraltar. Whilst this is important, targeting these areas covers only a small number of people when compared to the UK population as a whole.

After PM_{10} compliance is achieved attention will move to limit values for nitrogen dioxide (NO_2), a pollutant which is understood to have far less of a health impact than PM_{10} and its smaller, more dangerous component $PM_{2.5}$. These should have been achieved by 2010, but are widely exceeded in many parts of the UK. During 2011 the Government will be asking the European Commission for a time extension to 2015 for meeting these limit values. Targets for reducing $PM_{2.5}$ concentrations across the whole UK population (known as 'exposure reduction') were also set in the last revision of the EU Air Quality Directive. The deadline for achieving these is 2020 though, so with the pressing issue of compliance with other limit values being more imminent, there is currently little focus by the UK Government on these longer-term targets.

Compliance with EU limit values also does not necessarily mean action to improve air quality. Monitoring and reporting tweaks can be used to smooth the road to compliance, a process most recently seen in the UK Government's projections of PM_{10} concentrations in London which used every (allowable) means to massage away any exceedances of the European limit values. The UK Government can also attempt to weaken the legislation itself, with Department for Transport Minister Theresa Villiers recently making a statement (DfT, 2011) that hinted at what many suspected – that the UK Government will be trying to weaken European legislation on nitrogen dioxide when it comes up for review in 2013.

If air quality targets can be achieved by weakening legislation and monitoring 'tweaks' then what will drive national and local politicians to take meaningful action to actually improve air quality and public health? This is a pertinent question at this time of public funding cuts and an emerging localism agenda for local authorities; both factors mean that funding will increasingly focus on issues that are seen to be political priorities at the national and local level. If national and local government are to invest time and resources into air quality then significantly more in the way of bottom up pressure is needed: the public need to start placing pressure on politicians at all levels to address the issue.

How can the public be made more aware of the issues?

To engage public in air quality issues it is necessary to first identify effective drivers of public opinion. Most media stories involving air quality in recent years have focused on achieving European limit values, and the threat of EU sanctions. This is not something that chimes with the public at large: the UK is still a largely 'Eurosceptic' nation. A recent poll (Rotherham, 2009) suggested that the UK public was evenly split on whether the EU was felt to be a good or a bad thing for ordinary people. The same poll suggested that 72 per cent of the British public believes that Britain should break EU rules if it is thought to be in the 'national interest'. The message here is clear: trying to galvanise public support around a message centring on the need to address poor air quality because 'Europe says so' is bound to fail.

> *'it is essential to ensure that the public understand the impact that air quality has on their health and put pressure on their political leaders to address the problem'*

Climate change is the pre-eminent environmental issue in people's minds, so can public concerns on this issue be used to drive action on air quality? Certainly many of the possible actions to reduce greenhouse gas emissions can also improve air quality, particularly if an integrated policy approach to both sets of emissions is taken. Away from environmentally concerned enclaves, however, support for action on climate change is mixed. In a BBC poll (BBC, 2010) last year the most commonly held belief amongst those questioned was 'climate change is happening, but not yet proven to be largely man made' (38 per cent of respondents). The science is simply too complex, and the impacts too far in the future, for many people to take the issue to heart.

Health on the other hand is something all people can relate to, and the health of both ourselves and our loved ones will always be high up our list of concerns. Health can also be a powerful motivator of public opinion – witness the frequent health 'scares' in the media, and the passion with which the public defends the National Health Service against cuts. Health has therefore been identified as by far the best platform for raising public awareness of poor air quality.

Raising Public Awareness

So how can public awareness of the health impacts of poor air quality be improved? It is at this point that the jobs of scientists and campaigners start to deviate slightly – to get the public interested engaging statistics are required. Statistics on the long term impacts of air pollution produced by the well regarded Committee on the Medical Effects of Air Pollutants (COMEAP, 2010) have tended to focus on average life months lost across the whole UK population (six months for $PM_{2.5}$). These average statistics however hide the fact that the problem is concentrated in the most polluted locations – in these areas the impact on people's health is much higher than an average figure might suggest. They also drive a sense of complacency – six months off the end of life does not seem too great a loss.

To raise public attention to the issue it is necessary to use metrics people understand, the most dramatic of which is premature deaths. National figures on premature deaths are available (29,000 in 2008 due to long term exposure to $PM_{2.5}$); however with the exception of London (4,300 premature deaths in 2008 (Miller, 2010)) local statistics are not available. Local figures are important – without these people tend to assume the impacts of poor air quality are confined to the biggest cities and areas around power stations and heavy industry. A study of local health impacts is therefore the necessary bedrock of an air quality and health campaign.

Armed with the results of such a health study it is essential to engage with two key audiences, the first being local campaigners. Local environmental campaigns spring up around a wide variety of issues, although specific air quality campaigns are surprisingly thin on the ground. This kind of local action is however precisely what is needed to push air quality onto the local political agenda. National campaigns cannot engage effectively at the local level whilst grassroots action can be extremely effective in driving support amongst the public, politicians and local media. Local campaigns need guidance though, and a national campaign, such as the one being launched Environmental Protection UK (EPUK), can support and assist them with statistics, publicity materials and advice. This can guide them away from largely ineffective tactics such as targeting the private motorist, and towards applying effective pressure on local government and businesses to take action.

The media are the other key group to be targeted. Air quality does receive intermittent attention in the national media, with stories around health or potential European sanctions being the most popular. There is however little sustained interest in the issue amongst the national mainstream media. A campaign can rectify this by developing close relationships with the media through careful 'selling' of the health story. The picture at a local level is similar: the local media often run air quality stories, but there is little in the way of sustained media pressure to address the problem. Local campaigners, provided with assistance at a national level, can develop appropriate links with their local media to encourage a campaigning, rather than one off, approach to be taken.

The solutions to air quality problems can also be presented by the campaign, and here it will link in closely with actions planned to address carbon emissions. It is generally accepted that air quality improvements will increasingly be achieved thorough measures introduced to reduce carbon emissions (for example electrification of transport), and smart policy decisions can maximise the 'win-win' benefits for both areas. This type of joint approach has long been advocated by many in the air quality world, and policy approaches have been set out for both at national (Defra, 2010) and local (EPUK, 2011) level. EPUK's campaign by can build upon these excellent documents in the solutions it puts forward.

EPUK is the leading UK non-governmental (NGO) for local environmental issues, including air quality. EPUK has identified that the time is right to take forward a major push on air quality and health, and are now working hard to lay the foundations of their campaign. The first step is to establish a wide coalition of health and environmental NGOs to lend their support to the campaign. This is important to give the campaign legitimacy – a large number of respected NGOs calling for change is harder to ignore than just one. It also means that the coalition's media and political connections can be harnessed for the success of the campaign. A number of influential NGOs have already signed up to support the campaign, and EPUK hope to add several more by the time of launch. The second step is of course to fund the campaign – large national campaigns need to be adequately resourced to be effective, and EPUK are now working to secure funding from a number of sources.

Funding permitting, the campaign will launch in the second half of 2011. The time is right to reconnect health and air quality; in a year that will see attention focused on the dry, technical subject of compliance with EU air quality limit values it is essential to ensure that the public understand the impact that air quality has on their health and put pressure on their political leaders to address the problem. In an era of austerity it is only with this kind of grassroots pressure that the UK will see national and local leaders prioritise work to meaningfully improve air quality, and of course our health.

Ed is a policy officer for Environmental Protection UK, where he has led the charity's work on air quality and climate change since 2006. Prior to this he spent five years supporting local authorities in Gloucestershire to develop policy and projects around sustainable energy and climate change. Following this he took up a role at Royal Holloway, University of London to develop the College's sustainability policies and projects. If you're interested in supporting or funding the campaign contact Ed Dearnley (ed.dearnley@environmental-protection.org.uk)

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AIR QUALITY: A SOUTH AFRICAN PERSPECTIVE

CARADEE WRIGHT and her colleagues detail how air pollution and related health problems facing South Africa today are a unique blend of those faced by both developing and developed countries.

In South Africa, there are three main anthropogenic sources of air pollution: industrial combustion of fossil fuels, domestic burning of coal, wood and paraffin for cooking and heating, and exhaust fumes from motor vehicles. A unique set of spatial circumstances prevail in South Africa as a consequence of historical apartheid urban planning, leading to some residential areas being located in close proximity to industrial zones (see image 1). In addition, rural-urban migration has led to an influx of people who have established informal dwellings within or on the boundaries of urban areas. These communities tend to rely on traditional fuels such as coal, wood or paraffin for cooking and heating even after the settlement is formalised and provided with basic services, including electricity. Coupled with inadequate air quality legislation until fairly recently, this has led to the development of air pollution 'hot spots' across the country. Notable examples of these include the South Durban Industrial Basin, Secunda in the Highveld region and Zamdela in the Vaal Triangle (see figure 1). In many of these areas, the juxtaposition of industry and densely settled residential areas has led to the mobilisation of communities to act against air pollution impacts on their health. Community-led protests and air pollution campaigns in these areas have played a major role in prompting industries and government to take action to reduce air pollution emissions.

Proximity of industrial stacks and residential areas in South Durban.
Source: C Wright

Managing Air Pollution in South Africa

The first air quality legislation in the country was the Atmospheric Pollution Prevention Act (Act No. 45 of 1965) (the APPA), which was based on the best-practicable means approach of preventing pollution. As a source-based method of control, the cumulative effects on ambient air quality were not considered. These shortcomings of the APPA contributed to the deterioration of air quality and the development of 'hot spots'. The introduction of South Africa's Bill of Rights highlighted the unconstitutional nature of the APPA. This prompted the development and subsequent promulgation of the National Environmental Management: Air Quality Act (Act No. 39 of 2004) (the AQA). The AQA signalled a paradigm shift in air quality management in the country toward a receiving environment approach, which aims to control all major sources of air pollution and is managed by local government. The AQA also works to enforce every South African's constitutional right to an environment that is not harmful to their health or well-being.

There are various tools under the AQA that can be used to support these goals, including ambient air quality standards for priority pollutants, regulation of emissions from point sources and the development and implementation of air quality management plans at all spheres of government. National ambient air quality standards were established in 2009 for the priority pollutants, namely, sulphur dioxide (SO2), nitrogen dioxide (NO_2), ozone, particulate matter (PM_{10}), benzene, lead and carbon monoxide. These standards were developed based on accepted international health thresholds. $PM_{2.5}$ is considered an emerging priority pollutant with an ambient air quality standard to be established in 2011. Each local municipality is required to develop and implement an air quality management plan with the aim of maintaining ambient air quality levels below specified standards, thus minimising adverse human health impacts.

In addition, the AQA also allows for the development of priority areas for air quality management interventions to ensure compliance with national air quality management standards. To date the Vaal Triangle Air-Shed Priority Area and the Highveld Priority Area have been declared as priority areas (see Figure 1)

Examples of Studies on Human Health Impacts

Quantifying the impact of air pollution on human health in South Africa is a challenge due to limited data availability at the appropriate scale and spatial representation. In 2010, the South African Air Quality Information System (SAAQIS) was implemented to co-ordinate a national approach to air quality monitoring and management. This is however no accessible integrated health information management system at present. National burden of disease studies, together with local environmental epidemiological studies (Wichmann and Voyi, 2005) can instead provide some evidence of an association between air pollution and a range of health problems.

National Perspective

In South Africa the key air-related health impacts include

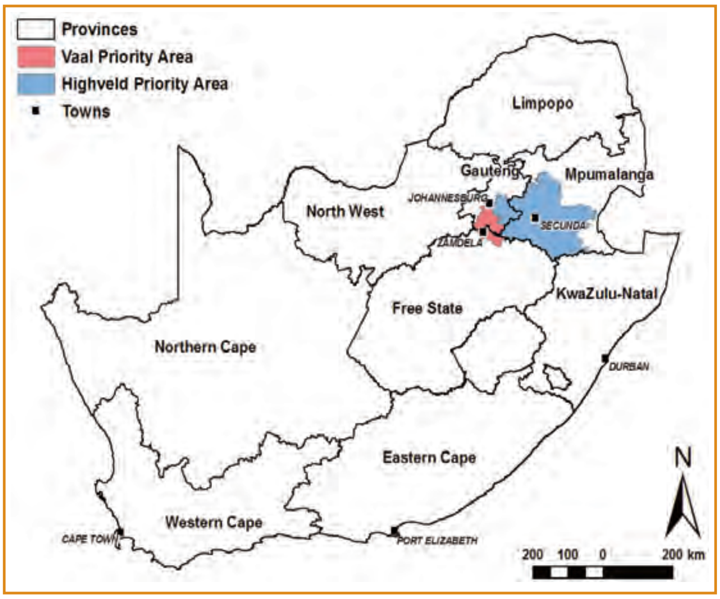

Figure 1: Air Pollution Priority Areas in South Africa. Source: Mogesh Naidoo

acute respiratory tract infections (e.g. pneumonia), chronic respiratory diseases (e.g. asthma) and other lung diseases, especially tuberculosis (Makri and Stilianakis, 2008). Considering national risk factors causing the burden of disease, indoor and urban air pollution are ranked 16th and 17th respectively (MRC, 2008). Associated health effects, to be precise, tuberculosis and lower respiratory tract infections were the third and sixth, respectively, most prevalent diseases. Outdoor urban air pollution was estimated to cause 3.7 per cent of national mortality from cardiopulmonary disease, and 5.1 per cent of mortality attributable to cancers of the trachea, bronchus and lungs in adults older than 30 years (Norman *et al.*, 2007a).

With approximately 20 per cent of South African households exposed to smoke from burning solid fuels, indoor air pollution was estimated to cause 2 489 deaths in 2000 (Norman *et al.*, 2007b). A review of household energy, indoor air pollution and child respiratory health in South Africa found that indoor burning of domestic fuels was associated with acute lower respiratory infections among children living in such households compared with children living in households using electricity (Barnes *et al.*, 2009). Indoor fuel combustion was estimated to lead to the greatest non-carcinogenic health risks across all urban areas considered, accounting for approximately 70 per cent of all respiratory hospital admissions in South Africa (Scorgie *et al.*, 2004). Acute respiratory infections, which may lead to pneumonia, accounted for approximately 14 per cent of deaths amongst children less than five years of age in South Africa (Norman *et al.*, 2007b).

The impacts of air pollution therefore place a significant burden on the healthcare system. A study to investigate and rank a set of policy and technological interventions intended to reduce these healthcare costs, particularly of urban air pollution in dense population areas, found that the most efficient interventions were at household level (Leiman *et al.*, 2007). For example, insulating roofs and making use of the basa njenga magogo technique of lighting a fire (a top down approach where kindling is placed above rather than below the coal). This technique has been promoted through the low-smoke strategy of the former Department of Minerals and Energy (now the Department of Energy).

Epidemiological studies in air pollution 'hot spots' have found similar results to these national statistics, supporting the link between air pollution and adverse impacts on human health. This can be seen in four case studies:

1. Vaal Air Pollution Study - Vaal Triangle

The Vaal Air Pollution Study) was a major epidemiological study conducted in the 1990s in the current priority area to assess whether air pollution was detrimental to human health. Approximately 14, 000 schoolchildren were involved in the study. Results suggested that total suspended particulate (TSP) levels in the air were 2.5 times the acceptable level (annual average 184 μg/m^3 in 1992) (Terblanche, 1998). In some township areas, concentrations were between four and six times higher than the average for the region. The use of coal as the household energy source was found to be the single most significant risk factor for respiratory illnesses in children living in townships. Sixty-five percent of participants suffered from upper respiratory diseases and 29 per cent from lower respiratory diseases. A cross-sectional study compared schoolchildren from the Vaal Triangle with schoolchildren from a less polluted area. This found that schoolchildren in the Vaal Triangle had a 134 per cent higher risk of developing upper respiratory illnesses and a 203 per cent higher risk of developing lower respiratory illnesses than the children in the control area (Terblanche, 1998).

2. 'Birth to Ten / Twenty' Study – Soweto, Johannesburg

A longitudinal study known as the 'Birth to Ten' study and later the 'Birth to Twenty' study was initiated in 1990 to assess environmental, economic, psycho-social and biological determinants of health, development and well-being among 3275 children in Soweto, Johannesburg (Mathee & Von Schirnding, 2003). Housing factors, fuel usage and health status of the children was assessed. Ambient air quality monitoring as well as indoor air monitoring (in some of the houses) were undertaken. Approximately half of the children experienced a high frequency of colds and chest illness since birth. Amongst the most frequently reported respiratory symptoms were: runny noses (53 per cent) sneezing (38 per cent) and a productive cough (28 per cent). The most frequent symptoms diagnosed by a doctor (since birth) were ear infection (eight per cent), bronchitis (five per cent), pneumonia (four per cent) and allergies (four per cent). Factors identified as posing the greatest risk for respiratory symptoms in children were living in low lying area (relatively more polluted than high lying areas), being in the kitchen during cooking, living in homes with water damage, and living in homes with pets or cockroaches.

3. Highveld Study - Highveld

In 1990, the respiratory health of children living in the Highveld Priority Area was compared to that of children living further east in an environment deemed to have less air pollution (Zwi *et al.*, 1991). The 'Highveld' children were found to be more likely to have a morning cough, wheeze, chest colds and asthma compared to the other group. Risk factors identified included attendance of school in the exposed area, cigarette smoking, and not using electricity for cooking in the home.

4. South Durban Health Study - Durban

The relatively recent South Durban Health Study comprised an epidemiological study and human health risk assessment. Results indicated that relatively moderate concentrations of NO_2, NO, PM_{10} and SO2 were strongly and significantly associated with reduced lung function in child asthmatics (Naidoo *et al.*, 2006). Children residing in the southern parts of Durban, where petrochemical, chemical and other heavy industries are clustered, were at greater risk of developing persistent asthma and airway hypersensitivity than children in the north of the city.

Conclusions

These studies provide evidence of the persisting challenges that South Africa faces in addressing air pollution related health impacts. These challenges are compounded by the interaction between industry and traditional lifestyle choices that pervade in South Africa. The AQA holds the promise of delivering ambient air quality that is not harmful to human health. There is some evidence of an improvement in ambient air quality in at least one of the air pollution hot spots (see figure 2) but many challenges remain.

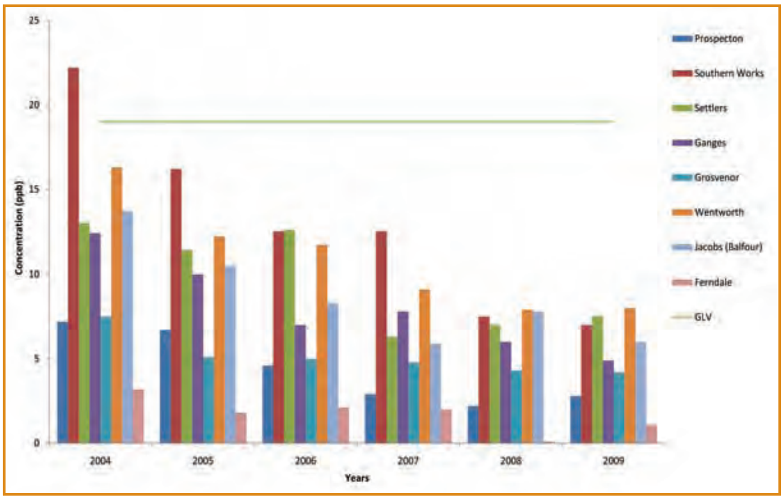

Figure 2: Sulphur dioxide (SO2) annual trends measured at several stations in Durban showing a downward trend between 2004 and 2009. GLV, annual guideline value of 19.0 ppb (Reproduced from the eThekwini Air Quality Monitoring Network Annual Report, 2009).

Caradee Wright, Rebecca Garland and Tirusha Thambiran are Senior Researchers in the Natural Resources and the Environmental Unit of the Council for Scientific and Industrial Research in South Africa. Roseanne Diab is Emeritus Professor in the School of Environmental Sciences at the University of KwaZulu-Natal and Executive Officer of the Academy of Science of South Africa (ASSAf).

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SUPPORTING AIR QUALITY MANAGEMENT IN DELHI

DR TIM CHATTERTON discusses how India can avoid the air pollution difficulties still pervading Europe

Despite being in a position of being accused of having the joint worst air quality in the world (tied with Beijing) (McIntyre, 2010), Delhi has come a long way recently. However, relentless growth and poor management of diffuse sources mean that there are still very significant challenges to be met. Whilst India's Metro cities (those with populations great than four million: Delhi, Mumbai, Kolkata, Chennai, Hyderabad, Ahemdabad and Pune) have deeply entrenched pollution problems that may prove impossible to shift in the short term, there are around 180 rapidly expanding cities across the country where the opportunity lies for good quality planning to help prevent the significant deterioration in air quality that usually accompanies rapid urban development, especially in Asia.

In the last 15 years, India, and Delhi in particular, have made a number of very significant advances in achieving visible reductions in ambient air pollution levels.

Industrial Sources

The main national legislation controlling air pollution in India is contained within the Air (Prevention and Control of Pollution) Act which came into being in 1981 and the Environment (Protection) Act in 1986. These allocated responsibilities for controlling industrial emissions to both Central and State Pollution Control Boards. Despite a Development Master Plan calling for the relocation of heavily polluting industries as early as 1962, it was not until the intervention of the Supreme Court in the mid-1990s that significant steps began to be taken (Narain & Bell, 2005). In December 1996, the Court ordered the Delhi Government to produce an air quality action plan. Following an initial response by the Delhi state government which set out a range of options, the following year the national government produced The White Paper on Pollution in Delhi with an Action Plan (Ministry of Environment and Forestry, 1997) which set out many similar options – but attached a timescale to them (Bell *et al.*, 2004). Some of the main interventions included the following:

- Between November 1996 and June 1997, Delhi Pollution Control Board ordered the closure of 1,328 industrial processes within the city that fell within the 'Category H' e.g. Heavy Industry and processes like brick kilns.
- From 2000 through to 2005, almost 5000 'Category F' processes were relocated away from the city centre to industrial parks (Narain & Krupnick, 2007).
- Also in 2000, the three big power stations close to Delhi were fitted with electro-static precipitators and began to be run on low ash coal.

In 2000, all 'polluting industries' were ordered to move out of residential areas of the city (Kathuria, 2001). Whilst this was

a very major step, and one that proved controversial (leading to days of protests in the city), the action has been criticised from both sides – from one side for forcing the closure of many non-polluting industries (including barbers (Nigam 2001)), from the other for only being able to tackle a fraction of the problem as only around 30,000 out of an estimated 126,000 processes were licensed in any case.

Domestic Sources

There has been little in the way of formal control on domestic emissions in Delhi and improvements have largely been made due to improved standards of living seeing a shift towards the use of liquefied petroleum gas (LPG) – first bottled, and now in many areas through a piped distribution network. However, some traditional cooking methods, such as old style tandoor ovens, and the numerous 'chaat' street food vendors still use wood or coals. The two largest problems result from lack of provision of effective municipal services: the open burning of waste; and the widespread use of diesel generators in response to the very frequent (almost daily) power cuts. There have been suggestions that both problems could be tackled through more effective waste collection linked to energy from waste (EfW) plants. Efforts to build a 'thermal' EfW plant in north Delhi have led to years of controversy, partly due to the unsuitability of Delhi's waste stream which contains a lot of moist waste – prohibiting effective incineration. More effective ways of solving these problems may be to move towards anaerobic digestion and decentralised power generation (primarily solar photo-voltaic).

Transport Sources

Along with most of the world, India is seeing a massive rise in vehicle usage – but possibly on an altogether larger scale, with roughly 12 million new vehicles were sold in India in 2009/10 (SIAM, 2011). In order to get emissions from the transport system under control, a number of very significant measures have been undertaken. India now has its own "Bharat Standards" for motor vehicles (the Indian transposition of Euro Standards – Bharat being the Hindi name for India). Catalytic convertors were introduced in 1995, lead has been removed from petrol, sulphur levels are being stepped down (current levels are 50 ppm in Delhi – compared to 350 ppm still in most other parts of India), and pre-mixed oil and petrol have been made compulsory for two-stroke vehicles. Although India has regular vehicle fitness checks for commercial vehicles, along with a requirement for thrice-yearly attainment of a 'Pollution Under Control' (PUC) certificate by all vehicles, there are serious problems with the ability of the system to cope with both issuing certificates and enforcement.

The most significant changes that have occurred have been the widespread move to powering vehicles by Compressed Natural Gas (CNG), a daytime ban on Heavy Goods Vehicles entering the city limits, a ban on commercial vehicles older than 15 years and the introduction of the Delhi Metro.

Following a ruling from the Indian Supreme Court, the entire public vehicle fleet (buses, taxis and auto-rickshaws) was moved to CNG in 2001/2, leading to a massive reduction in black smoke emissions from vehicles. The introduction of gas as a vehicle fuel is widespread in Asia, but is not something which has been successful in the UK. It is also of note that Delhi has made the choice to move to CNG rather than LPG which has been the fuel of choice (for auto-rickshaws at least)

in most other Indian cities. However, a recent paper by Canadian Researchers (Reynolds *et al.*, 2011), has suggested that for the auto-rickshaw fleet, the move to CNG may not have been beneficial in terms of either $PM_{2.5}$ (particulate matter of 2.5 micrometers or less) or greenhouse gas emissions (mainly methane). Overall the change also appears to be leading to a considerable increase in NOx concentrations.

Delhi's Metro system has now been operating for around eight years, the first lines opening in December 2002. It now carries over one and a half million people a day over 100 miles of lines (compared to up three million people per day over 250 miles of track on London's Underground – an achievement in less than a decade of operation). For the Commonwealth Games in 2010, the city also introduced a number of Bus Rapid Transit (BRT) routes, which although courting criticism from sections of the media when first introduced, appear to be having a beneficial effect on the speed and desirability of bus services along these routes and they look likely to be extended over the next few years.

A key issue is the two-fold problem of discipline and enforcement. The poor lane discipline of Indian drivers is thought to be a leading contributor to high levels of congestion and consequent emissions. Unfortunately this makes it very difficult to implement the widespread traffic counts that will be necessary to model significant sections of the road network. This has also led to difficulties with efforts to segregate road space, such as with the BRT lanes and lanes for bicycles and other non-motorised transport. During the Commonwealth Games improvements were reported – mainly due to the threat of Rs2000 fines (approximately £27) and much increased monitoring and enforcement. With the reduction in enforcement following the games, drivers rapidly appear to be returning to their old ways.

However, it is not just enforcement of good driving behaviour that is a challenge. The allocation of vehicle PUC certificates and of driving licences themselves has also proved difficult. This is one area where encouraging sharing of good practice within India may reap rewards as the representative from Tamil Nadu police shared their experience of taking strong enforcement measures with regard to lax PUC certification and the problem of corrupt driving school 'wallahs'. [Editors note: the effects of vehicular pollution in Delhi are discussed in more detail in the paper by Rakesh Ranjan]

Other sources

For many years traffic pollution was cited as the major source of pollution in Delhi, particularly with regard to particle pollution. It was commonly claimed that 70 per cent of particle pollution in the city was due to road traffic. However, in January this year, the Ministry of Environment and Forestry published major new source apportionment study (CPCB, 2010) on PM_{10} which, like similar studies in the UK in the late 1990s, has rewritten the book in terms of managing particle pollution. The report clearly identifies traffic as a very significant source of particles, but for the first time, manages to quantify the contributions of secondary particles and resuspended dusts to the particle loading in the city.

In terms of sources, the report found that at residential locations, transport was responsible for only 20.5 per cent of PM_{10} for the exhaust component (and another 14.5 per cent from resuspended road dust) (see Figure 1). Secondary particles (sulphates and nitrates) were found to contribute around 10-15 per cent of the PM_{10} load.

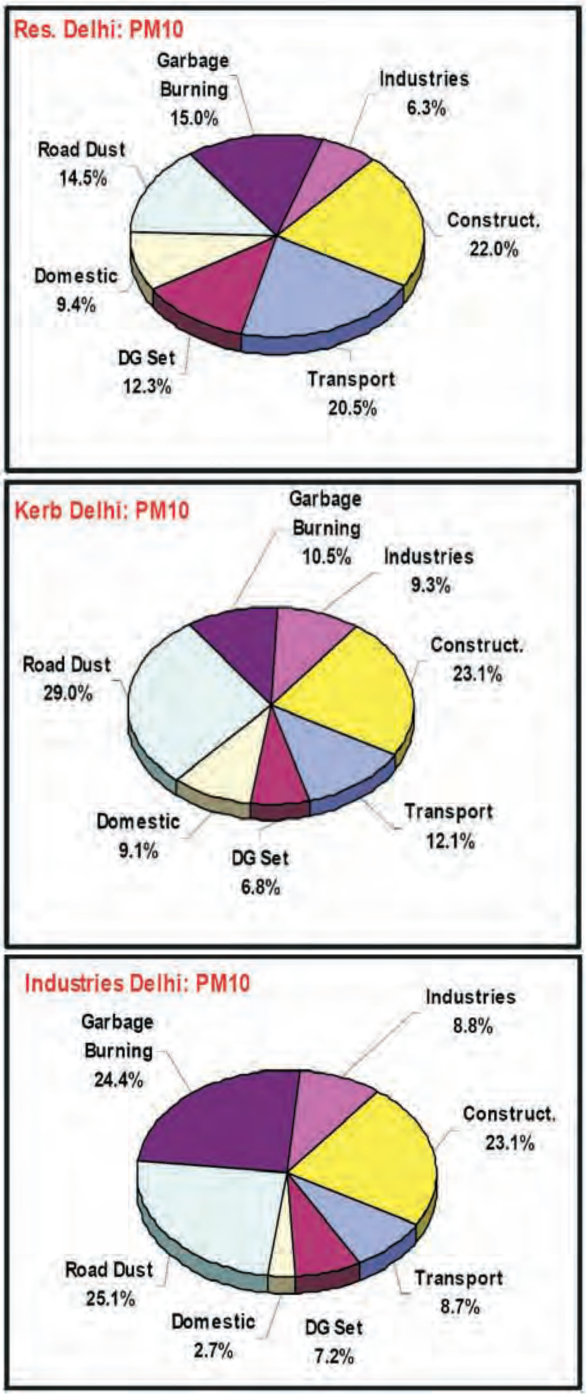

Figure 1: PM_{10} Source Apportionment for Delhi – Residential, Kerbside and Industrial locations. Source: CPCB, 2010.

Technical Capacities

High quality information on air pollution within Indian cities is currently very limited. The Central Pollution Control Board now operates around 50 automatic monitors (across a country 13 times the size of the UK). The data from these is now becoming more readily available, with some measurements from a number of stations being accessible in real-time or archived on the internet (although not necessarily in a user-friendly or intuitive format). There is little in the way of indigenous modelling capacity, with no commercial domestic models having been developed in, or for, India. With limited monitoring data, models have an important role to play in helping determine locations of most concern in order to develop air quality action plans. A team at the Indian Institute for Technology Delhi, led by Prof. Mukesh Khare, has carried out extensive work developing models and testing non-Indian models for suitability in local conditions. However, as with the UK, efforts to accurately model conditions can be severely challenged by the availability of source data (such as traffic counts), reliable emission factors and representative meteorological data.

Comparing the UK and European Experience: successes and failures

Currently, all but two EU member states are exceeding the PM_{10} limit values, and (as of 2009) at least 20 out of 27 member states were likely to exceed the nitrogen dioxide (NO_2) limit values. On the basis of these statistics it is hard to argue that EU air quality has been an out and out success. As exemplified by the UK Local Air Quality Management (AQM) process, the European experience has tended to focus on the assessment of air quality rather than the mitigation. Whilst national policies, led by the EU, have forced the introduction of cleaner vehicle technologies, these have only just managed to keep pace with the relentless growth of traffic on roads. Meanwhile, industry, in the more modern EU states at least, has been relatively well managed under pollution control legislation prior to the introduction of AQM in 1996. In the UK there are records of attempts to control air pollution since the 13th century (Brimblecombe, 1987) and these are reflected in the minor problems that industry now poses. For example, only five per cent of the UK's over 500 Air Quality Management Areas are due to industrial sources. Domestic sources have also been largely removed as a problem. Smoke Control Areas, brought in under the Clean Air Acts following the 1952 London Smog event, have played a role, however the widespread availability of electricity and gas supplies in the second half of the 20th century played a much more significant part.

The key lessons from the UK and EU are in terms of policy. The profusion of diffuse sources means that the key to successfully managing air quality lies in policy, and in particular in land-use and transport planning. Whilst end-of-pipe treatments for pollution are essential, the problem of traffic pollution is mainly due to increasing levels of traffic on roads that simply do not have the carrying capacity. For this reason, solutions operating on a more societal level are required. Current discussions about cultural issues with discipline, through the role of trees in reducing pollution and the need for inclusive street design, to the need to ensure that India's smaller developing cities need to be well planned in order to prevent problems before they happen, provide hope that current development trajectories need not condemn the country to the same entrenched air pollution problems that seem to still plague Europe.

Dr Tim Chatterton is a Senior Research Fellow in the Air Quality Management Resource Centre at the University of the West of England, Bristol. With a background in both social and physical sciences, he has worked for over a decade in the space where these interface with policy. He has recently spent a year on an RCUK Fellowship based in the Department of Energy and Climate Change, and has also carried out work for Defra, DfT, DCLG and a wide range of Local Authorities. He has been involved in a range of international work and is also a trustee of the UK Public Health Association.

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TRENDS IN POLLUTANT CONCENTRATION IN DELHI

RAKESH RANJAN discusses changes in vehicular fuel and the impact on air pollutants in Delhi

India's national capital Delhi has a history of ranking among the most polluted cities of the world. The ambient air quality of Delhi had been loaded with exhaust of numerous diesel-fuelled buses, minibuses, taxies, auto-rickshaws, cars, trucks, and thousands of gasoline-fuelled motorbikes and cars until the deadline of April 2004, when the use of diesel and gasoline in public transport and government owned vehicles was banned in a landmark judgement delivered by Supreme Court of India in 1998. Before the ban almost the entire fleet of public transport vehicles operating in the National Capital Territory of Delhi were diesel powered, and diesel constituted two-thirds of the total fuel consumption in the transport sector.

Studies conducted by the Central Pollution Control Board (CPCB) of India from 1990 to 2000 reveal that suspended particulate matter (SPM) concentration in Delhi exceeded the annual mean guideline of the World Health Organization (WHO) for over 294 days in a calendar year, which was largely due to the exhaust from diesel engines. The hazardous impact of diesel exhaust on human health is well established, which raised concern and resulted in increasing public outrage. Chronic exposure to 1 $\mu g/m^3$ of diesel exhaust leads to 300 additional cases of lung cancer per million people (ARB, 1998). For Delhi this amounts to 4,200 extra cases of lung cancer. The World Bank Group's 'Asia Environment Division' estimated that over 7,500 human lives were lost every year in Delhi because of air pollution, which otherwise could have been avoided by reduction of 142 $\mu g/m^3$ in PM_{10} (Brandon & Hommann, 1995). The particulate matter in the ambient air of Delhi has exacerbated asthma in school age children to the extent that one out of every ten school age child is under routine medical care.

Taking note of the deteriorating public health due to the high concentrations of pollutants in ambient air quality in Delhi, the Supreme Court of India passed an order on July 28, 1998 to reduce vehicular pollution. The judgement banned the use of diesel and gasoline as fuel for all public transport and government vehicles (except the combat vehicles of armed forces) and issued a mandatory verdict for switching over to compressed natural gas (CNG) as the only fossil fuel option for vehicles. The only other available alternative was to adopt battery operated cars and electric vehicles. As a result tens of thousands of vehicles were replaced within a time frame of 20 months before the deadline of 30th of April 2001. By year 2002, Delhi had the highest number of CNG vehicles in the world. Some of the key environmental and health benefits of CNG versus diesel considered by the Supreme Court were:

1. CNG powered vehicles emit 85 per cent less nitrogen oxides (NOX), 70 per cent less reactive hydrocarbons (HCs), and 74 per cent less carbon monoxide (CO) than gasoline powered vehicles of similar engine capacity (NCDENR, 2004).

2. Use of CNG-fuelled vehicles significantly reduces emissions of ozone precursors. Since Gasoline powered vehicles produce NOX, which reacts with volatile organic compounds (VOCs) produced by anthropogenic and biologically derived sources in the presence of sunlight in the lower atmosphere to produce ozone (O_3), which is a primary constituent of smog.

3. Diesel produces 10 to 100 times more particulates than CNG.

Alongside the court order, Delhi has gone through the 'implementation phase of pollution control measures' between 2001 and 2010. Significant changes introduced during this decade include stringent norms for vehicular emissions, substantial improvement in fuel quality, the phase out of vehicles older than eight years, a major expansion of metro-rail network, the introduction of catalytic converters in passenger cars, Bus-Rapid Transit (BRT) corridors and the relatively recent phase out of the entire fleet of over 2000 conventional buses with state of the art high capacity low floor buses.

A decade of active implementation of policy measures targeted to improve ambient air quality of Delhi has started showing distinct benefits despite phenomenal growth in the number of passenger cars and vehicles during this period. The booming Indian economy has pumped millions of passenger cars into the city; as of 2010 year end estimate, the number of daily vehicular operations in Delhi exceeds five million.

A CPCB study showed that 97 per cent of HC, 76 per cent of CO and 50 per cent of NOX emission in the city of Delhi is of vehicular origin. Therefore any noticeable fall in the level of these pollutants could possibly relate to the pollution control measures adopted under the implementation phase of the air quality improvement plan, including implementation of CNG in Public Transport Vehicles. Clearly the contribution of industries and household emissions are low compared to the vehicular air pollution. Implementation of the Master Plan 2001 has forced relocation within the regulated industrial area on outskirts of the State of Delhi or closure, as a result the city has non-polluting service industry, research institutions, financial institutions, engineering design and consulting firms. The Master Plan 2021, which is currently in place has very stringent air pollution prevention norms. Nevertheless the climate and natural sources also play an important role in compounding the concentration of air pollutants in the city.

Meteorological Impacts on Pollutant Concentration

Delhi is situated in a semi-arid climatic zone, which has sporadic pre-monsoon features marked by dust storms and winds blowing from west to east, which deposit large concentrations of suspended particulate matter (Goyal, 2002). Pre-monsoon calms increase the pollution load due to lack of mixing between different atmospheric levels. Concentration of pollutants is higher in winter months due to ground-based temperature inversions, which constrain dispersal of pollutants. During the monsoon the concentration of pollutants decreases due to wet deposition processes associated with monsoon precipitation, high wind velocities and changes in prevailing wind direction.

Monitoring Mechanism and Data Source

The CPCB has installed permanent ambient air quality monitoring stations at seven locations in Delhi. Out of these seven locations, four monitoring stations are located in residential areas; two locations are in industrial areas; and one at the busiest traffic intersection at Bahadurshah Jafar Marg. This observed trends below are based on the ambient air quality data covering CO, SO2, NOX and suspended particulate matter (SPM) data recorded at this busiest intersection for the most representative data of vehicular pollution. CPCB conducts monitoring of air pollutants for 24 hours (four hourly sampling for SO2, NOX and eight hourly for SPM) at a height of between three and five metres with a frequency of twice a week, generating 104 observation days in a year. The data collected by CPCB is available for a long-term study of trends in the concentration of various air pollutants (CPCB, 2011). In this study the data from CPCP monitoring stations have been used with particular focus on permanent monitoring station at Bahadurshah Jafar Marg.

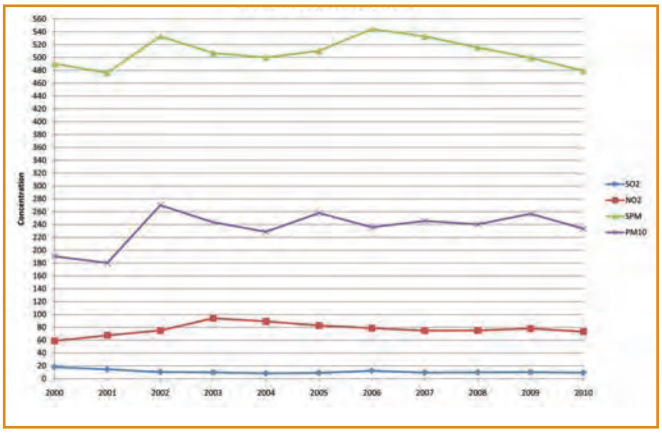

Figure 1: Annual mean concentration of particulates and gases.

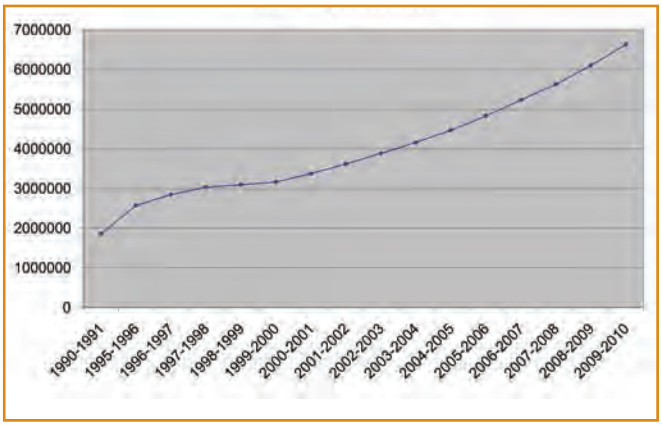

Figure 2: Number of vehicles in Delhi.

Observed Trends

Figure 1 shows annual mean concentrations of a number of pollutants in Dehli over the period 2000 to 2010 while Figure 2 shows the growth in the number of vehicles from 1991. The data provide clear evidence that concentrations have not increased in line with vehicle numbers and illustrate the success of policies to switch public transport from diesel to CNG and reduce the sulphur content of diesel and gasoline. As noted above, pollutant concentrations in the city are heavily influenced by local meteorology which results in distinct seasonal variations. Due to the continental climate, wind patterns in this part of the world, and the geomorphology of the semi-arid region; Delhi faces dust storms and particulate laden winds blowing from west to east. Pre-monsoon calms increase the pollution load. Concentrations of pollutants are also higher in winter (post monsoon season) due to ground based temperature inversions, which constrain pollutant dispersal. PM_{10} concentrations in Delhi are significantly influenced by these natural factors. Relatively dry years show higher concentrations of PM_{10} on an annual average, whereas years with good monsoon precipitation show slight decreases in PM_{10} concentration, resulting in significant inter-annual variability.

Conclusion

Judicial intervention of the Supreme Court and implementation of the government's policy measures have resulted in a broad trend of reducing concentration of various pollutants over the last decade; an impressive achievement given the enormous increase in vehicle numbers. However the changes have not improved the situation for all pollutants equally, and there are still areas of growing concern. The gains made from fuel switching, improvements in fuel quality and vehicle technology are being negated to some extent by the sheer increase in the number of vehicles in Delhi which is now in excess of six million. Nevertheless a decade of active implementation of air pollution control measures has set an example for many other large cities of the world.

Rakesh Ranjan is a chartered environmentalist and an international EIA consultant with over 17 years of consulting experience for a wide range of developmental schemes. Currently he is an international environmental consultant for the Asian Development Bank in Timor Leste for the Road Network Development Sector Project.

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IES: NEW MEMBERS AND RE-GRADES

continued from page 17

Name	Occupation	Grade
Robert Haythornthwaite	Technical Officer (Pollution)	A
Cara Heller	Graduate	A
Kataharine Hill	Graduate	A
Jonathan Hirons	Graduate	A
Ross Hunter	Senior Environmental Scientist	M
Lance Ingrams	Environmental Projects & Landfill Manager	M
Arshid Iqbal	Professor of Physics	M
Okuroghoboye Itugha	Environmental Consultant	M
Andrew Jackson	Stepping Stones Project Manager	M
Chantelle Jarvis	Youth Worker	Af
Siân Jones	Contaminated Land Consultant	M
Martin Kaonga	Director of Science & Conservation	M
Celia Kibblewhite	Self employed designer	Af
Paul Kimber	Technician Team Leader	M
Laura Kirman	Performance & Improvement Manager	M
Charlene Knox	Engineer	A
Wai Lam	Technical Officer	M
Victor Lau	Compliance Manager	M
John Leigh	Project Engineer	A
Carya Maharja	Student	Af
Darren McGrath	Associate	M
Kendrew McIntosh	Graduate	A
Joanna Miller	Air Quality Consultant	M
Craig Morrison	Principal Geo-Environmental Engineer	M
Hayley Moy	Sales & Marketing Graduate	A
Samantha Munn	Analysist Air Quality	A
Matthew O'Brien	Principal Environmental Scientist	M
Kathryn Ogden	Contaminated Land Officer	M
Susanne Page	Environmental Business Advisor	A
Stuart Parr	Nuclear Regulator	M
David Partridge	Independent Consultant	M
Damian Pawson	Air Quality Consultant	A
Robert Pearson	Assistant Environmental Specialist	M
Paul Pippard	Civil Servant	Af
Attilio Poli	Chairman & Project Leader	M
Jonathon Porritt	Founder Director	F
Francis Pyatt	Lecturer	F
Lily Qin	Assistant Engineer	M
Charlotte Reeve	Project Environmental Scientist	M
Craig Roberts	Principal Geo-Environmental Consultant	M
Niamh Roche	Environmental Consultant	M
Jacqueline Rogers	Student	Af
Antonia Scrase	Environmental Consultant	M
Rosalind Spain	Senior Environment Consultant	A
Julia Stalleicken	Environmental Scientist	M
Andrew Stelling	Senior Occupational Hygienist	M
David Sutton	Environmental Protection Officer	M
Alice Sydney	Database Assistant	A
Andrew Talbot	Associate, Air Quality Specialist	M
David Thornton	Senior Geo-environmental Scientist	M
Richard Tindell	Senior Environmental Consultant	M
Charles Wheater	Associate Dean	F
Emma Wheeler	Asbestos Operations Manager	M
Richard Wheeler	Student	Af
Matthew Williams	Higher Research Scientist	M
Mathew Worboys	Associate	M
Roland Woodbridge	Associate	M
Thomas Wright	Graduate Air Quality Consultant	A
Yiu Wah Yip	Senior Environmental & Safety Officer	A
Lee Ypey	Student	Af

KEY: F = Fellow, M = Member, A = Associate, Af = Affiliate