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CHARACTERISTICS AND HEALTH IMPLICATIONS OF FINE AND COARSE PARTICULATES AT ROADSIDE, URBAN BACKGROUND AND RURAL SITES IN UK

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Abstract

Recent studies have pointed to evidence that fine particles in the air could be significant contributors to respiratory and cardiovascular diseases and mortality. Epidemiologists looking at the health effects of particulate pollution need more information from various receptor locations to improve the understanding of this problem. Detailed information on temporal, spatial and size distributions of particulate pollution in urban areas also is important for air quality modellers as well as being an aid to decision and policy makers of local authorities. This paper presents a detailed analysis of temporal and seasonal variation of PM_{10} and $PM_{2.5}$ levels at one urban roadside, one urban background and one rural monitoring location. Levels of PM_{10}, $PM_{2.5}$ and coarse fraction of particulates are compared. In addition, particulate levels are compared with NO_2 and CO concentrations. The study concludes that PM_{10} and $PM_{2.5}$ are closely related at urban locations. Diurnal variation in $PM_{2.5}/PM_{10}$ ratio shows the influence of vehicular emission and movement on size distribution. This ratio is higher in winter than in summer indicating a build-up or longer residence time of finer particulates or washout due to wet weather in winter. In the second part of this study, a disease burden analysis is carried out based on the dose-response relationships recommended by the UK Committee on the Medical Effects of Air Pollution. The disease burden analysis indicates that if Marylebone Road levels of PM_{10} were prevalent all over London, it will result in around 2.5% increase in death rates due to all causes. Whereas, if Bloomsbury levels were prevalent in London, which is more likely to occur as this is more representative of the urban background environment to which people in London are likely to be exposed, the corresponding increase would be around 1.7%. Considering this, in London, at Bloomsbury levels 973 deaths and 1515 Respiratory Hospital Admissions (RHA) are attributable to PM_{10} while 2140 RHA are attributable to NO_2. After deducting the disease burden due to background levels at

Rochester, PM_{10} emission caused by anthropogenic activities in London equate to 273 additional deaths and 410 additional RHA while NO_2 account for additional 1205 incidences of RHA.

Keywords: Particulates, disease burden, health, temporal, spatial and size variation

1 Introduction

The adverse effects upon health of airborne particulate matter are well recognised. Earlier reports (QUARG 1993; POST, 1994; Schwartz, 1994) looked at the effect of air pollution on health, especially asthma, and pointed to evidence that fine particles in the air could be significant contributors to respiratory and cardiovascular diseases and mortality. Since then, there have been many further studies that have reinforced such concerns, and suggest that fine particles from diesels and other sources may contribute to significant mortality across the world (Dockery and Pope, 1994; HEI, 1995; IP, 1995; Pope et al. 1995; POST, 1996). Elevated concentrations of ambient particulate matter have been associated with increases in all-cause mortality, mortality for respiratory and cardiovascular diseases, hospital admission and exacerbation of respiratory symptoms in chronically ill patients (US-EPA, 1996; NCR, 1998; Dockery and Pope, 1994; Bascom et al., 1996; Pope and Dockery, 1999). It has been estimated, for example, that in UK urban areas, 24 000 premature deaths occur each year due to poor air quality (DoH, 1998).

As health impacts of fine particulates become more widely acknowledged it is apparent that more detailed study of the behaviour and levels of particulate matter is needed (APEG, 1999). Epidemiologists, looking at the health effects of particulate pollution, need more information from various receptor locations and geometric configurations of buildings and roads to improve understanding of this problem. It has been observed by many researchers that pollution levels are higher in less ventilated areas, such as the street canyons formed by buildings on both sides of roads, typical of urban central districts. However, detailed information on temporal, spatial and particularly size distributions of particulate pollution in urban areas are not well understood yet important for air quality modellers and to inform decisions and policies made in local authorities to maintain good air quality in our cities.

2 PM_{10} and $PM_{2.5}$ monitoring in UK

In response to the growing demand of detailed information on temporal, spatial and size distributions of particulate pollution in urban and rural areas, the UK government started a campaign of monitoring particulates at representative locations across the country. Currently PM_{10} is being monitored at 69 locations and $PM_{2.5}$ at four locations. All $PM_{2.5}$ stations are co-located with PM_{10} stations giving an opportunity to compare seasonal and temporal variations and to explore any inter-relationships between PM_{10} and $PM_{2.5}$ levels. The list of stations simultaneously monitoring PM_{10} and $PM_{2.5}$ is given below:

Marylebone Road, London	Urban Kerbside
Bloomsbury, London	Urban Centre
Rochester, Kent	Rural
Harwell, Oxfordshire	Rural

This paper presents the analysis of PM_{10} and $PM_{2.5}$ data for the first three stations for the year 2001 representing an urban kerbside, urban centre and rural site. Kerbside sites are located within 1m of the edge of a busy road with a sampling height of 2-3m. Source influences are mainly from the local traffic. The main objectives of kerbside monitoring is to identify vehicle pollution black spots, assess worst-case scenarios, evaluate impacts of vehicle emission control technologies, and to determine the impacts of traffic planning/calming schemes. Urban Centre sites are non-kerbside sites located in an area representative of typical population exposure in town or city centre areas e.g. pedestrian precincts and shopping areas. Sampling heights are typically within 2-3m. Rural monitoring sites are open country locations distanced from population centres, roads and industrial areas (DEFRA, 2004).

Monitoring Method

The tapered element oscillating microbalance (TEOM) is used to continuously measure particulate concentrations at most sites. It automatically measures the mass collected on an exchangeable filter cartridge by monitoring the corresponding frequency changes of a tapered element. The sample flow passes through the filter, where particulate matter collects, and then continues through the hollow tapered element on its way to an electronic flow control system and vacuum pump. The sampler incorporates an inlet head, which selectively samples only the PM_{10} or $PM_{2.5}$ fraction.

3 Characteristics of fine and coarse particulates

Concentrations of CO, NO_2, and particulate matters (PM_{10} and $PM_{2.5}$) are recorded at one-minute interval at the three selected monitoring sites and averaged to give values at 15 minutes and one hour. After ratification, the hourly data is archived and made available to the general public at http://www.airquality.co.uk/. For the research reported here 15 minute averaged data was provided by NETCEN (National Environmental Technology Centre). Corresponding 15-minute value for the year were then averaged (geometric mean) to obtain the yearly and seasonal profiles at the three locations as shown in Figure 1. Table 1 shows a summary of the concentration data measured at these sites, disaggregated by season. The profiles in Figure 1 show a strong diurnal variation in PM_{10} and $PM_{2.5}$ levels at both urban sites, viz. Marylebone Road (MR) and Bloomsbury (BB) but not at the rural site, Rochester (RC). The levels are highest during morning peak hours reflecting the influence of traffic. PM_{10} and $PM_{2.5}$ levels remain high during the day gradually going back to the lowest around 0400 hrs. Particulates levels remain low and almost unchanged at the rural site reflecting the prevailing background levels.

Scatter plots (Figure 2) show that PM_{10} and $PM_{2.5}$ are strongly correlated at urban sites but not at the rural site. R^2 values for MR, BB and RC are 0.964, 0.835 and –0.074 respectively when the best-fit line is forced through zero. Marylebone Road concentrations are generally higher than Bloomsbury again indicating the strong influence of traffic at the kerbside site compared to the urban background site. When the scatter plots of the three sites are combined, as shown in Figure 3, it depicts an interesting picture. When plotted together the three scatter plots, as shown in Figure 2, are in order of traffic activity, viz. rural, urban background and finally the kerbside site. The kerbside site is showing a wider spread compared to the urban background site reflecting variation in traffic.

$PM_{2.5}/PM_{10}$ ratios show relationships between fine and coarse particulates, higher ratio indicating higher proportion of fine particulates. Yearly $PM_{2.5}/PM_{10}$ ratios at three sites presented in Figure 4, shows that during the increased traffic activity hours, the proportion of fine particulates is higher (as high as 82%) at the kerbside site compared to the urban background and rural sites. Yearly $PM_{2.5}/PM_{10}$ ratio at Bloomsbury is lower than even the rural site indicating greater proportion of coarse particles (PM_{coarse}) attributable to wind-blown dusts, re-suspended dust due to traffic, and commercial and industrial activities. Coarse particles are the fraction between PM_{10} and $PM_{2.5}$ and have sources associated with mechanical disintegration processes which include such activities as quarrying and building construction, as well as natural contributors such as sea spray, wind blown soil and surface dust and fungal spores (APEG, 1999). Seasonal variation in

$PM_{2.5}/PM_{10}$ ratios at three sites is shown in and Table 2. Within individual seasons, $PM_{2.5}$ and PM_{10} are strongly correlated but the percentage of PM_{10} comprised of $PM_{2.5}$ shows a strong seasonal dependence. The gradients of the relationships of $PM_{2.5}$ and PM_{10} are given in Table 3. It is clear that at urban background and rural sites the proportion of fine particles is greatest in winter than in summer (see also Table 2). This could most probably be the result of better dispersion of pollutants in hotter months leading to higher lower concentrations of $PM_{2.5}$ and more effective wind-driven suspension of coarse dusts in the dryer months leading to higher concentrations of PM_{coarse}. This is consistent with the findings in the Third Report of QUARG (QUARG, 1996). However, at the kerbside site, this trend is not visible with the ratio of fine and coarse particulates remaining constant throughout the year, again indicating the dominant influence of consistently heavy traffic on Marylebone Road. Table 3 shows negative correlation between PM_{10} and $PM_{2.5}$ at Rochester (R^2 varying from -1.45 in winter to 0.62 in summer) by forcing the best-fit line through zero. This signifies that PM_{10} concentrations increased while $PM_{2.5}$ concentrations decrease. A closer look at the data in Table 1 reveals that the range of the values is very small (9.37 to 10.22 for $PM_{2.5}$ and 13.97 to 14.54 for PM_{10}) hence correlation is not expected. This corroborates with the facts that the site is rural and that the local influence on particulates levels is insignificant.

Comparing Marylebone Road and Bloomsbury with Rochester, the impact of local sources of both fine ($PM_{2.5}$) and coarse particulates within London is very clearly seen as shown in Table 4. An appreciable elevation of around 15 $\mu g/m^3$ of PM_{10} and 12 $\mu g/m^3$ of $PM_{2.5}$ on yearly averages is observed at Marylebone Road. If a notional background of about 10 $\mu g/m^3$ of secondary $PM_{2.5}$ is subtracted (QUARG, 1996), the local elevation at

Marylebone Road is appreciable, almost 100% of primary pollutant background. The rural background level of 10 μg/m^3 for $PM_{2.5}$ as used in QUARG report is also observed in this study (Table 1). The effect of road traffic is very clearly seen in the substantial elevations of both $PM_{2.5}$ and PM_{10} at Marylebone Road, relative to the nearby Bloomsbury urban background site. Compared to Bloomsbury the increase of PM_{10} and $PM_{2.5}$ concentrations at Marylebone Road equate to 9.56 and 10.52 μg/m^3 respectively, strongly indicating that all the changes are mainly due to $PM_{2.5}$. Insignificant changes in PM_{coarse} levels at Marylebone Road and Bloomsbury (–0.97 μg/m^3) strengthen this argument and also indicate that re-suspension of coarse particles due to traffic is trivial. Increases in PM_{10} and $PM_{2.5}$ levels at Bloomsbury compared to the rural site are not high (5.62 and 1.79 μg/m^3) confirming that Bloomsbury is an appropriate choice for urban background site for this analysis. Table 4 also shows that there is no seasonal influence in differences of particulate levels between the urban and rural sites.

Table 5 shows the best-fit line equations and R^2 values between PM_{10}, NO_2 and CO. It shows that there is a very good correlation between PM_{10} and NO_2 and CO and NO_2 at Marylebone Road and Bloomsbury but not at Rochester reflecting a common source (exhaust emissions). Diurnal variations in CO and NO_2 concentrations, as shown in Figures 5 and 6 also link this to traffic variation.

4 Health implications of observed PM_{10} and NO_2 levels

Most epidemiological studies use observational methods with cohort, longitudinal and cross sectional experimental designs (as opposed to controlled laboratory studies). Vedal (1997) reviews eighty such studies which vary in respect of particle size analysed, confounding factors addressed (e.g. meteorology, particle solubility and acidity, co-pollutants and other time variant factors), geographical location, and health effects recorded ranging from minor increases in respiratory irritation and decreases in lung function, to mortality.

The UK Department of Health Committee on the Medical Effects of Air Pollution COMEAP (Department of Health, 1998) reviewed all the available epidemiological evidence on particulates with the objective of defining, if possible, a definitive exposure-response relationship. They concluded that ambient particulates (as PM_{10}) were causally related to both acute and chronic health effects, and that effects were quantifiable. Following a meta-analysis of the literature, with expert judgement to address differences in studies, exposure-response coefficients were presented. These were: + 0.75% per 10 $\mu g/m^3$ (24 hours mean) for deaths (all causes) and + 0.80% per 10 $\mu g/m^3$ (24 hours mean) for acute respiratory symptom hospital admissions (RHA). COMEAP also suggested a dose-response relationship of 2.5% per 50 $\mu g/m^3$ for NO_2. The data did not permit the calculation of confidence limits, and it is stressed that the response measures were all acute, hence the relationships cannot be used to determine the chronic effects of exposure to long term low levels of pollution (Namdeo *et. al*, 2000). However, Vedal (*op.cit*) notes that evidence for chronic effects is weak and that it is the acute effects from repeated short-term PM_{10} increases, which are significant.

Having identified an exposure-response function it is possible to estimate a disease burden. For each monitoring station, the observed concentrations are multiplied by the health response for the corresponding PM_{10} and NO_2 concentration, to give a disease burden at that concentration. COMEAP exposure-response curve considers % change in mortality or hospital admissions per pollutant concentration; hence the disease burden attributable to PM_{10} and NO_2 is expressed as a percentage of the observed death rate in the general population. However, for this application, it has been converted also to absolute terms (e.g. cases of illness or death) for comparison with the figures published earlier.

For disease burden calculations arithmetic means are required not the geometric means, which were used in the analysis in section three. Arithmetic means of PM_{10} and NO_2 levels at the three sites are presented in Table 6. Also presented in this table is the difference in levels between rural and urban sites. Disease burden attributable to PM_{10} and NO_2 concentrations is given in Table 7. It shows that if Marylebone Road levels of PM_{10} were prevalent all over London, it will result in around 2.5% increase in death rates due to all causes. Whereas, if Bloomsbury levels were prevalent in London, which is more likely to occur as this is more representative of the urban background environment to which people in London are likely to be exposed, the corresponding increase would be around 1.66%. Disease burden in terms of respiratory hospital admissions attributable to PM_{10} at Marylebone Road and Bloomsbury levels are 2.68% and 1.77% respectively. RHA attributable to NO_2 levels at Marylebone Road and Bloomsbury account for 4.18% and 2.5% increase in base rates. However, if Rochester levels were considered to be true regional background levels, then changes in disease burden at Bloomsbury levels would equate to 0.45% increase in deaths (all causes) and 0.48% RHA attributable to PM_{10} and 1.41% increase in RHA attributable to NO_2.

The disease burden estimates in absolute terms are presented in Table 8. Base death rates were available for the year 2001 for London whereas base RHA rates were available for England, which have been applied to London as an example. As the table suggests, in London, at Bloomsbury levels 973 deaths and 1515 RHA are attributable to PM_{10} while 2140 RHA are attributable to NO_2. After deducting the disease burden due to background levels at Rochester, PM_{10} emission caused by anthropogenic activities in London equate to 273 additional deaths and 410 additional RHA while NO_2 account for additional 1205 incidences of RHA.

5 Conclusions

Detailed analysis of 15-minute data for a year for three monitoring stations located at kerbside, urban background and rural sites shows marked variation in diurnal, seasonal and spatial profiles of $PM_{2.5}$, PM_{10}, NO_2 an CO levels. Though the rural site does not, both urban sites do, show a strong diurnal variation in concentrations. The levels are the highest during morning peak hours and although the afternoon peak is not pronounced the influence of consistently high traffic flow throughout the day is clear. Scatter plots show that PM_{10} and $PM_{2.5}$ are strongly correlated at urban sites but not at the rural site. Marylebone Road concentrations are generally higher than Bloomsbury, again indicating strong influence of traffic at the kerbside site. The proportion of fine particles changes from 58% at Bloomsbury to 75% at Marylebone Road strongly indicating that the changes are mainly due to $PM_{2.5}$. Insignificant changes in PM_{coarse} levels at Marylebone Road and Bloomsbury strengthens this argument and also indicate that re-suspension of coarse particles due to traffic is trivial. The proportion of fine particulates at Bloomsbury is lower than even the rural site indicating greater proportion of coarse particles, which could be attributed to wind-blown dusts, and commercial and industrial activities.

The disease burden analysis indicates that if Marylebone Road levels of PM_{10} were prevalent all over London, it will result in around 2.5% increase in death rates due to all causes. Whereas, if Bloomsbury levels were prevalent in London, which is more likely to occur as this is more representative of the urban background environment to which people in London are likely to be exposed, the corresponding increase would be around

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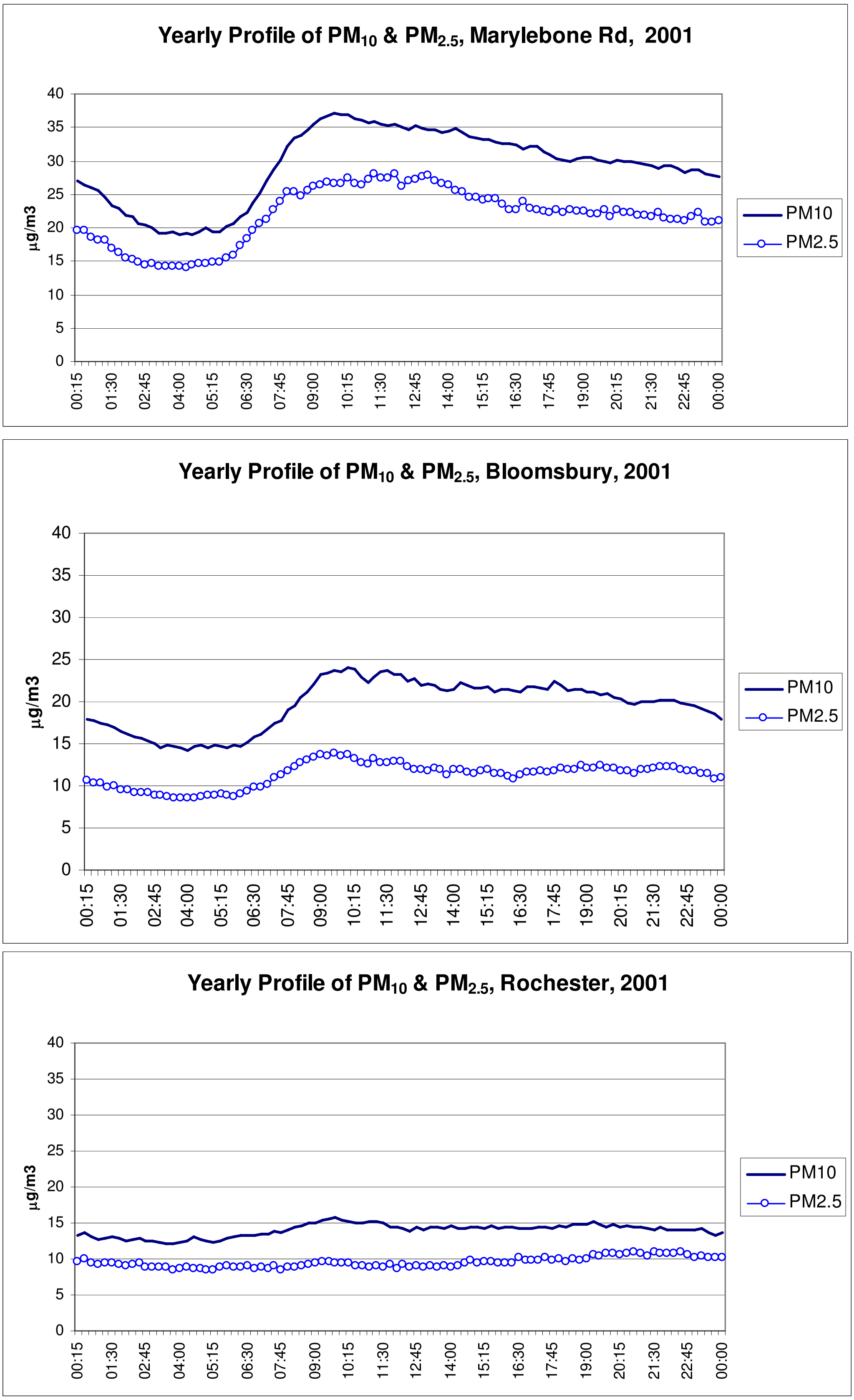

Figure 1: Yearly profile of PM_{10} and $PM_{2.5}$

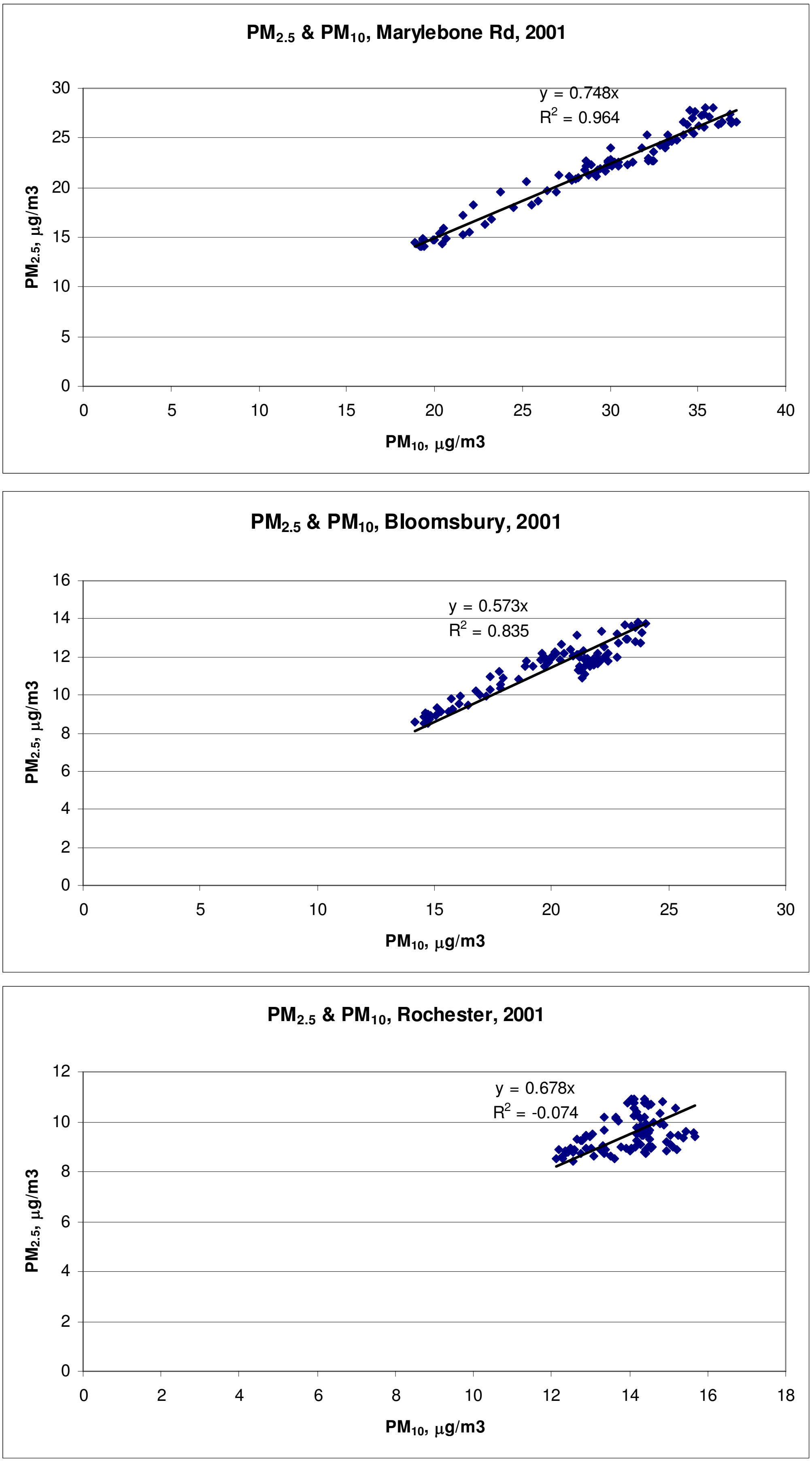

Figure 2: Scatter plots of $PM_{2.5}$ and PM_{10}

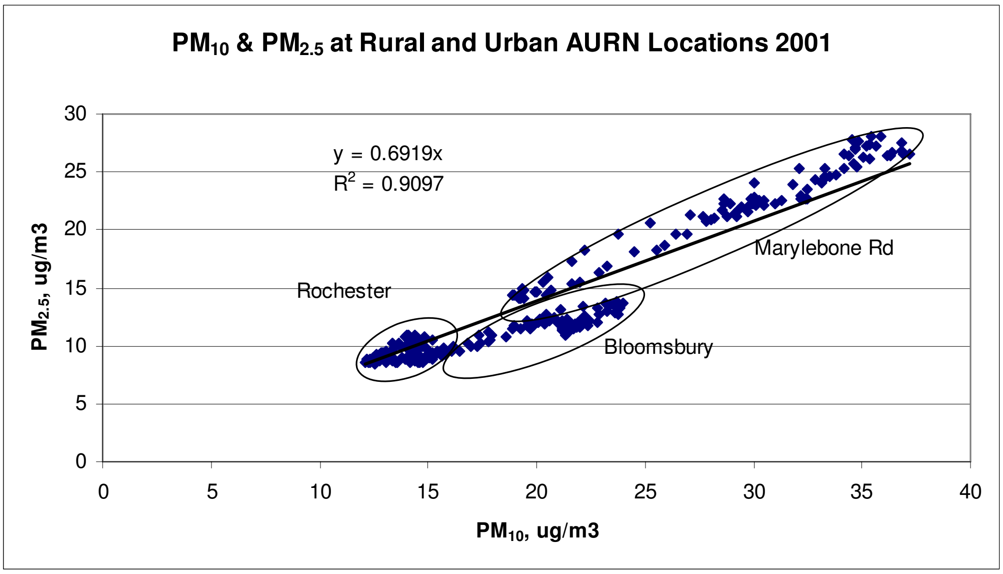

Figure 3: Combined scatter plot of $PM_{2.5}$ and PM_{10} at rural and urban stations

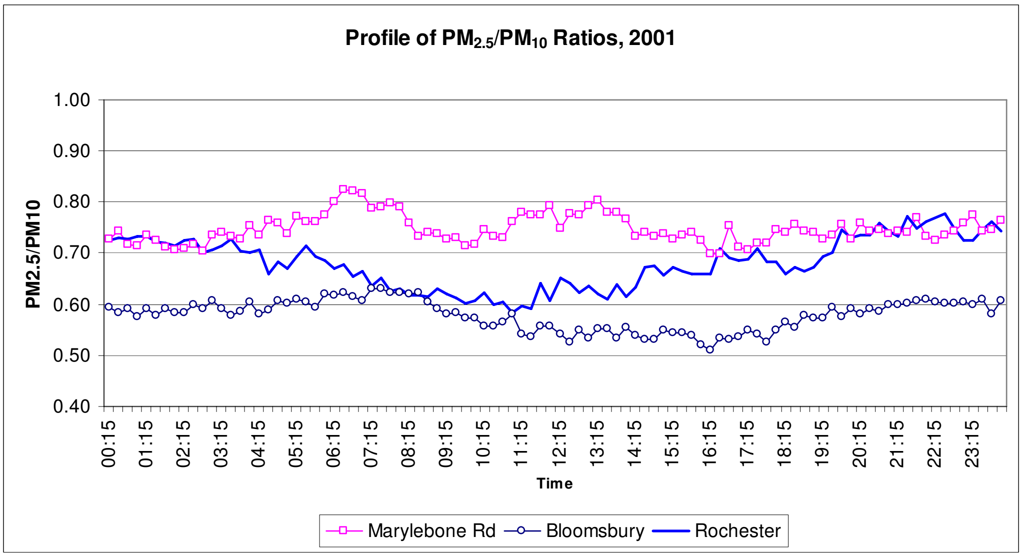

Figure 4: $PM_{2.5}/PM_{10}$ ratios at monitoring sites

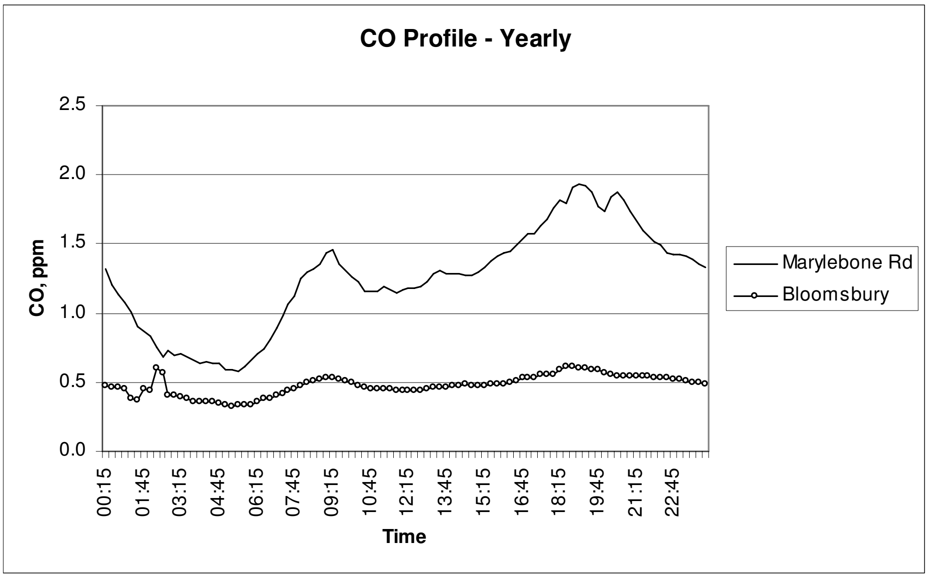

Figure 5: Yearly CO profile at urban monitoring stations

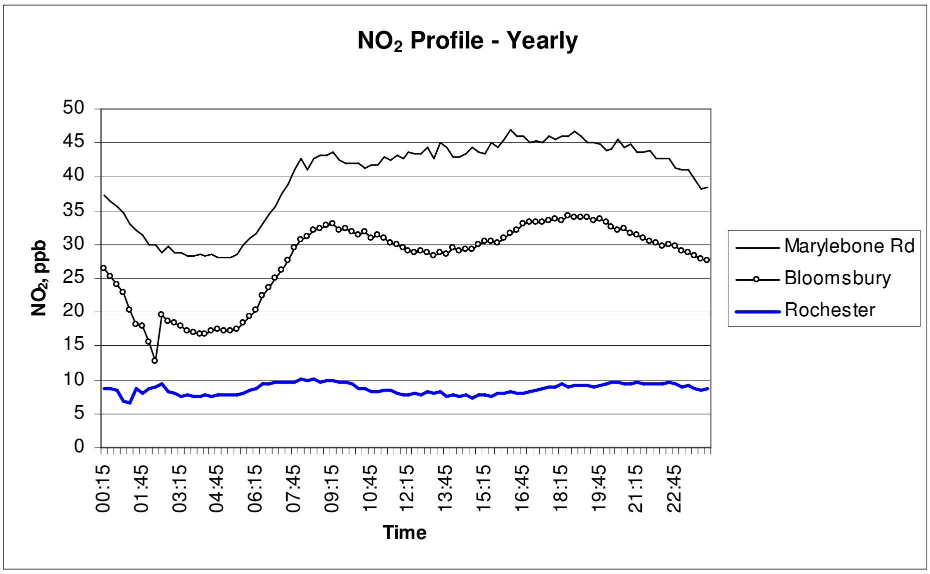

Figure 6: Yearly NO_2 profile at monitoring stations

	Site	PM_{10}	$PM_{2.5}$	Coarse PM	Coarse / PM_{10}	$PM_{2.5}$ / PM_{10}	NO_2	CO
Yearly	Marylebone Rd	29.15	21.80	7.35	0.25	0.75	39.73	1.24
	Bloomsbury	19.59	11.28	8.32	0.42	0.58	24.11	0.48
	Rochester	13.97	9.49	4.48	0.32	0.68	8.64	
Summer	Marylebone Rd	27.63	20.95	6.68	0.24	0.76	38.12	1.12
	Bloomsbury	19.54	11.22	8.33	0.43	0.57	20.74	0.39
	Rochester	14.37	9.37	5.00	0.35	0.65	6.73	
Winter	Marylebone Rd	30.83	22.66	8.17	0.26	0.74	41.31	1.37
	Bloomsbury	19.66	11.35	8.31	0.42	0.58	27.55	0.59
	Rochester	14.54	10.22	4.32	0.30	0.70	9.51	

Note: All concentrations are geometric mean. CO in ppm, NO_2 in ppb and PM in $\mu g/m^3$

Table 1: Profiles of CO, NO_2 and different fractions of PM

Site		Minimum	Maximum	Average
Marylebone Rd	Yearly	0.699	0.824	0.748
	Summer	0.690	0.884	0.760
	Winter	0.676	0.806	0.734
Bloomsbury	Yearly	0.510	0.631	0.578
	Summer	0.497	0.639	0.576
	Winter	0.508	0.634	0.579
Rochester	Yearly	0.584	0.777	0.680
	Summer	0.497	0.825	0.658
	Winter	0.642	0.787	0.703

Table 2: $PM_{2.5}/PM_{10}$ ratios

	Best-fit equation*	R^2
$PM_{2.5}$ v/s PM_{10} – Whole Year		
Marylebone Rd	y = 0.7479x	0.96
Bloomsbury	y = 0.5732x	0.83
Rochester	y = 0.6779x	-0.07
$PM_{2.5}$ v/s PM_{10} – Summer		
Marylebone Rd	y = 0.7567x	0.92
Bloomsbury	y = 0.5708x	0.78
Rochester	y = 0.6457x	-1.45
$PM_{2.5}$ v/s PM_{10} – Winter		
Marylebone Rd	y = 0.7362x	0.97
Bloomsbury	y = 0.5754x	0.82
Rochester	y = 0.7029x	0.62

*Best-fit line through zero

Table 3: Seasonal variation in correlation between PM_{10} and $PM_{2.5}$

		PM_{10}	$PM_{2.5}$	Coarse PM	NO_2
Yearly	Marylebone Rd - Rochester	15.18	12.31	2.87	31.09
	Bloomsbury - Rochester	5.62	1.79	3.84	15.47
Summer	Marylebone Rd - Rochester	13.26	11.58	1.68	31.39
	Bloomsbury - Rochester	5.17	1.85	3.32	14.01
Winter	Marylebone Rd - Rochester	16.29	12.44	3.84	31.80
	Bloomsbury - Rochester	5.12	1.13	3.99	18.04

Note: All values are geometric mean. NO_2 in ppb and PM in $\mu g/m^3$

Table 4: Difference in levels between urban and rural locations

	Best-fit equation*	R^2
PM_{10} v/s NO_2		
Marylebone Rd	y = 0.7987x - 2.5765	0.77
Bloomsbury	y = 0.4536x + 7.0975	0.79
Rochester	y = 0.4405x + 10.167	0.16
PM_{10} v/s CO		
Marylebone Rd	y = 9.4796x + 17.351	0.41
Bloomsbury	y = 24.088x + 8.128	0.35
Rochester	#	
CO v/s NO_2		
Marylebone Rd	y = 0.0546x - 0.9252	0.80
Bloomsbury	y = 0.0093x + 0.2194	0.55
Rochester	#	

* Based on yearly average data. # CO not monitored at Rochester.

Table 5: Inter-relationship between PM_{10}, CO and NO_2 at three sites

		Average Concentrations ($\mu g/m^3$)			Levels above Rochester ($\mu g/m^3$)		
	Site	*NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$
Yearly	Marylebone Rd	83.61	33.54	24.77	61.74	17.38	13.55
	Bloomsbury	50.04	22.15	13.05	28.17	5.99	1.82
	Rochester	21.87	16.16	11.22			
Summer	Marylebone Rd	81.60	31.15	23.06	65.28	14.90	12.17
	Bloomsbury	44.02	22.01	12.79	27.70	5.77	1.90
	Rochester	16.32	16.24	10.89			
Winter	Marylebone Rd	85.44	36.03	26.40	60.56	19.06	14.03
	Bloomsbury	55.23	22.29	13.31	30.36	5.33	0.94
	Rochester	24.87	16.97	12.37			

*NO_2 levels converted to $\mu g/m^3$ from ppb.

Table 6: NO_2, PM_{10} and $PM_{2.5}$ levels (arithmetic means) for disease burden analysis

		Deaths* (% change)	Respiratory hospital admissions (RHA) (% change)	
	Site	PM_{10}	PM_{10}	NO_2
Yearly	Marylebone Rd	2.52	2.68	4.18
	Bloomsbury	1.66	1.77	2.50
	Rochester	1.21	1.29	1.09
Summer	Marylebone Rd	2.34	2.49	4.08
	Bloomsbury	1.65	1.76	2.20
	Rochester	1.22	1.30	0.82
Winter	Marylebone Rd	2.70	2.88	4.27
	Bloomsbury	1.67	1.78	2.76
	Rochester	1.27	1.36	1.24
Dose response function		0.75% per 10 $\mu g/m^3$	0.8% per 10 $\mu g/m^3$	2.5% per 50 $\mu g/m^3$

* Deaths due to all causes. #Respiratory hospital admissions

Table 7: Disease burden attributable to PM_{10} and NO_2 concentrations - seasonal variation

	Marylebone Rd	Bloomsbury	Rochester
Deaths (all causes) brought forward			
*Base death rate (%)	0.815	0.815	
PM_{10} as measured ($\mu g/m^3$)	33.54	22.15	16.16
PM_{10} above Rochester levels	17.38	5.99	-
PM_{10} attributable deaths	1474	973	710
PM_{10} attributable deaths over Rochester	764	263	-
Respiratory hospital admissions (RHA) brought forward			
$# Base RHA rate (%)	1.190	1.190	
PM_{10} attributable RHA	2295	1515	1106
PM_{10} attributable RHA over Rochester	1189	410	-
NO_2 attributable RHA	3576	2140	935
NO_2 attributable RHA over Rochester	2640	1205	
Base population (year 2001)	7188006	London	
Base deaths (year 2001)	58583		
*Base death rate per 100	0.815		
Base population (year 2001)	49181339	England	
Base RHA (year 2001)	585199		
#Base RHA rate per 100	1.190		

$ RHA rates for England assumed for London in absence of data
Source: Department of Health (2001), Hospital Episode Statistics 2000-2001.

Table 8: Disease burden in London for year 2001 attributable to PM_{10} and NO_2 levels