Health impact assessment of PM_{10} and EC in 1985–2008 in the city of Rotterdam, The Netherlands

M. P. Keuken[1], P. Zandveld[1], S. van den Elshout[2], N. Janssen[3] & G. Hoek[4]
[1]*TNO, Netherlands Applied Research Organisation, The Netherlands*
[2]*DCMR, Rijnmond Environmental Agency, The Netherlands*
[3]*RIVM, Netherlands Environmental Agency, The Netherlands*
[4]*IRAS, Utrecht University, The Netherlands*

Abstract

The health impact assessment (HIA) PM_{10} and elemental carbon (EC) was investigated in the period 1985–2008 in the city of Rotterdam. The spatial distribution of the concentrations was modelled by the URBIS model. The modelling results for 2008 were validated by PM_{10} and EC measurements at various locations in Rotterdam. This paper describes the HIA related to improved air quality in the period 1985-2008: at urban background locations 18 $\mu g.m^{-3}$ PM_{10} and 2 $\mu g.m^{-3}$ EC. The gain in life years saved due to long-term exposure to PM_{10} and EC in this period was, respectively, 13 and 12 months per person. The similar health impacts for PM_{10} and EC suggests that a reduction of combustion aerosol was important for the reduction in health impact of PM_{10}. It is concluded that EC is a more adequate indicator for HIA of traffic measures than PM_{10}.
Keywords: health impact assessment, PM_{10}, EC, historical trend.

1 Introduction

Exposure to elevated levels of particulate matter (PM) has been associated with health effects in epidemiological surveys [1]. However, in urban areas the population is exposed in particular to emissions by road traffic related to exhaust emissions, tire/engine wear and re-suspension of road dust. Over the years, a

WIT Transactions on Ecology and the Environment, Vol 147, © 2011 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/AIR110241

variety of (inter)national and local measures have been implemented to reduce exhaust emissions by road traffic. Examples are more stringent emission standards and environmental zoning to prevent high emitters near residential areas. Consequently, there is a need to assess the impact of these measures on air quality and health. The mass of PM is less adequate for this purpose. Because even near heavy traffic locations, PM mass is dominated by regional background concentrations. Elemental carbon (EC) is considered a more appropriate indicator for dispersion and exposure of the population to PM exhaust emissions [2].

This paper describes a study is to assess the health impact of PM_{10} and EC in the city of Rotterdam in the period 1985-2008. Rotterdam has the largest harbour of Europe and consequently, road traffic is intensive with a relatively large contribution of heavy duty vehicles. In sections 2 and 3, the approach of the study is detailed and in section 4, the results are presented and discussed. The conclusions and recommendations are elaborated in section 4.

The study was financed by the Ministry of Infrastructure and Environment in the framework of The Netherlands Policy Support Program on Particulate Matter (“BOP”).

2 Study approach

The URBIS model has been applied to estimate the spatial distribution of annual average PM_{10} and EC in the city of Rotterdam for the years 1985, 1995 and 2008. The URBIS model combines a street-canyon and line-source model to compute the contribution of emissions by urban traffic and motorways to air quality [3]. The spatial resolution of the URBIS model is a 10*10 m^2 grid up to the housing façade along inner-urban roads and up to 500 m near motorways.

The next step in the health impact assessment is to combine the spatial distribution of annual average PM_{10} and EC with GIS based population distribution data. This provides information on the population exposure to long-term air pollution at house address. Subsequently, concentration-response-function for long-term health effects of PM_{10} and EC are applied to the population exposure maps [4]. Finally, the trend in health effects in the period 1985 - 2008 is evaluated in relation to exposure to PM_{10} and EC.

3 The modelling and experimental setup

3.1 Modelling

The required model input for spatial concentrations of PM_{10} and EC concerns:

- *meteorological conditions;* The ten-year average meteorological conditions for the period 1995-2004 have been used for all three years 1985, 1995 and 2008 to eliminate the effect of meteorological variation on the health impact assessment;
- *traffic data;* Actual traffic data on the motorways and main urban roads for the years 1985, 1995 and 2008 were available in Rotterdam. The data for 1985 and 1995 concerned aggregated traffic volume on

motorways and main inner urban roads. For 2008 more detailed information was available which was used to further detail the 1985 and 1995 traffic data;

- *emission factors;* Emission factors for road traffic (e.g. friction and exhaust emissions) for the period 1990-2008 are available for the car fleet in The Netherlands [5]. These emission factors were used to extrapolate emission factors for 1985. For EC, emission factors were derived from an EU database with EC emission factors as a fraction of PM *exhaust* emissions [6]. These data combined with the information on PM exhaust emission factors in The Netherlands, were used to estimate EC emission factors for 1985, 1995 and 2008;
- *regional and urban background;* The regional and urban backgrounds of PM_{10} in 1985 and 1995 for Rotterdam were extrapolated from the monitoring data in 2008 with an increasing trend of 0.7 μg.m^{-3} PM_{10} per year for previous years [7]. The regional and urban backgrounds of EC were based on time series of Black Smoke measurements in and near Rotterdam in the period 1985–2008. A factor 10 was applied to convert Black Smoke to EC concentrations. This conversion factor was based on parallel measurements in 2006-2007 of Black Smoke and EC in the city of Rotterdam.

3.2 Measurements

In 2006-2007, two-weekly PM samples were collected at traffic, urban and regional locations in and near Rotterdam and analyzed by the Black Smoke method and thermal EC analysis. The results are presented in Figure 1.

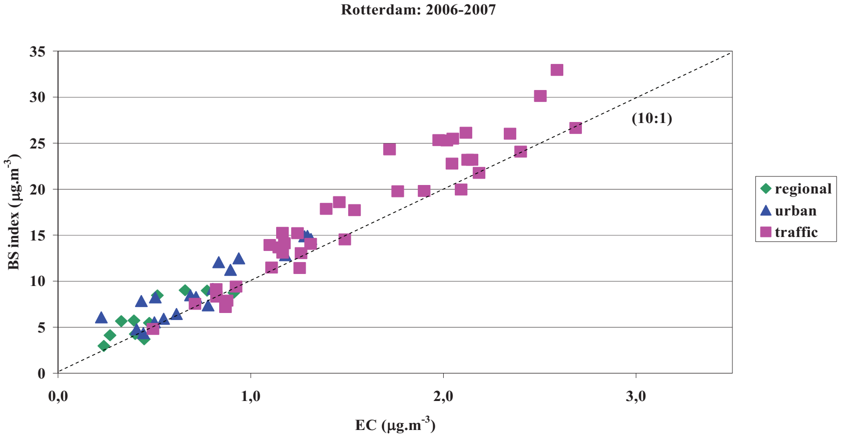


Figure 1: Two-weekly average black smoke index (μg.m^{-3}) and thermal EC (μg.m^{-3}) at traffic, urban and regional locations in and near Rotterdam in 2006-2007.

Figure 1 illustrates that the Black Smoke index is linear correlated with EC at various locations in and near Rotterdam. The linear regression has a slope 11, an intercept near zero and the regression coefficient (R^2) 0.9. Taking into considering also results from other studies, a factor 10 has been derived to estimate EC concentrations from Black Smoke index measurements.

At two urban traffic stations and a regional station 15 km south of Rotterdam, annual average Black Smoke data were available for the period 1985-2008 [source: RIVM/DCMR]. The relation presented in Figure 1, has been used to derive from the trend in EC from the Black Smoke measurements in this period. The trend for EC is shown in Figure 2.

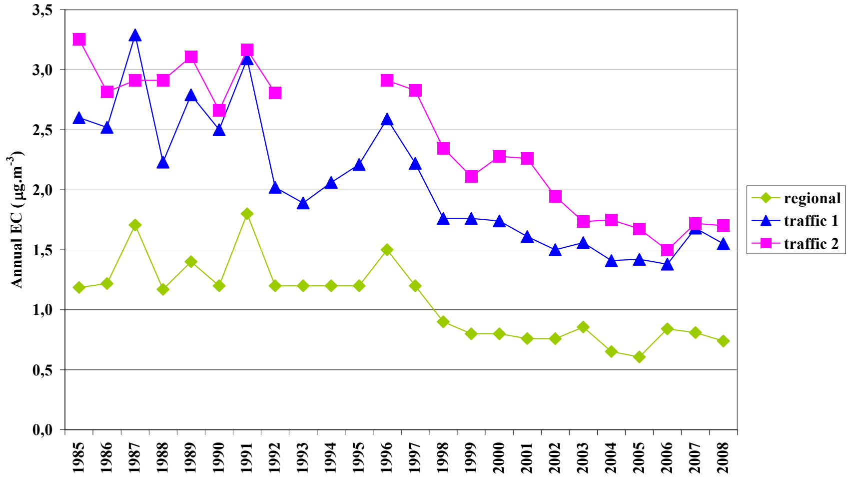


Figure 2: Annual EC (µg.m^{-3}) at two traffic locations in Rotterdam and one regional location near Rotterdam in 1985-2008.

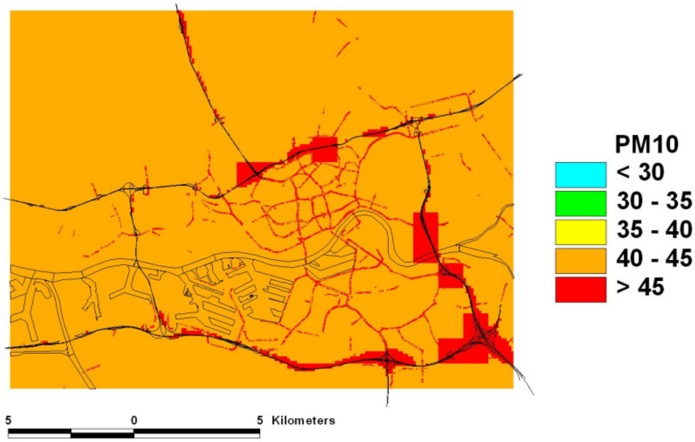
Figure 2 shows a decreasing trend in EC concentrations both at the traffic stations and at the regional location. The *delta* between the traffic and the regional stations especially decreased in the period 1995 – 2003. This reflects the introduction of catalytic convertors in the nineties and emission reduction of combustion aerosol by road traffic. This measure had a relatively larger impact on EC concentrations at the traffic locations than the regional background. Since 2003, no further decreasing trend is detected neither at the regional nor at the traffic locations. This indicates that further reduction of (diesel) emissions by "cleaner" vehicles do not longer balance the growth in traffic volume.

4 Results and discussion

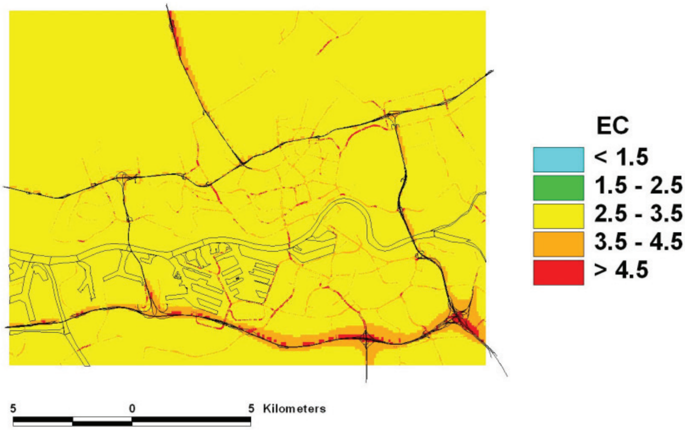
4.1 Air quality of PM_{10} and EC in 1985, 1995 and 2008

Based on the input presented in section 3.1, the spatial distribution for PM_{10} and EC has been modelled with the URBIS model for the years 1985, 1995 and 2008 in Rotterdam. In Figures 3A and 3B the results are presented for PM_{10} and EC in

1985. In these figures, the motorways are presented around the city centre with extensions to the north, south, east and west. Also, the river "Oude Maas" is presented with harbour areas in the west. As it is difficult to show this data in "black/white" only the data for 1985 are presented.



A



B

Figure 3: A. Annual average concentrations of PM_{10} ($\mu g.m^{-3}$) in Rotterdam (1985). B. Annual average concentrations of EC ($\mu g.m^{-3}$) in Rotterdam (1985).

Figures 3A and B illustrate that the air quality for PM_{10} and EC in the city of Rotterdam was elevated near motorways and inner-urban roads with heavy traffic. EC concentrations were a factor two elevated near traffic locations compared to the urban background, while PM_{10} was “only” 20% elevated as PM_{10} is dominated by regional background concentrations. The results for all years 1985, 1995 and 2008 are presented in Table 1.

Table 1: Annual average PM_{10} and EC concentrations ($\mu g.m^{-3}$) at regional, urban and traffic locations in Rotterdam in 1985, 1995 and 2008.

	PM_{10} ($\mu g.m^{-3}$)			EC ($\mu g.m^{-3}$)		
	regional	Urban	traffic	regional	Urban	Traffic
1985	40-45	40-45	45-55	2.5-3.5	2.5-3.5	3.5-6
1995	30-35	35-40	35-45	2.5-3.5	2.5-3.5	3.5-5
2008	20-23	23-27	27-35	0.5-0.8	0.8-1.2	1.2-3

The results in Table 1 show that the air quality for both PM_{10} and EC improved significantly in the period 1985-2008 in Rotterdam. The urban background for PM_{10} decreased from average 43 $\mu g.m^{-3}$ in 1985 to average 25 $\mu g.m^{-3}$ in 2008. This is caused for 70% by large-scale emission reduction by industry, energy production and road traffic of *precursors* (sulfur dioxide, ammonia and nitrogen oxides) for secondary particles [7]. Only 10% reduction of PM_{10} is related to primary combustion emissions and the remaining 20% by secondary organic aerosols and less water adsorbed to PM_{10} particles.

Table 1 demonstrates that similar to PM_{10} the air quality for EC also improved significantly in the period 1985-2008. This is attributed to lower regional background concentrations as a result of reduced emissions of soot particles by combustion processes in general (e.g. industry, energy production, shipping and road traffic) and at the urban scale of (diesel) emissions by road traffic in particular. Consequently, the urban background of EC decreased from average 3 $\mu g.m^{-3}$ in 1985 to average 1 $\mu g.m^{-3}$ in 2008.

4.2 Validation of modelled air quality in Rotterdam in 2008

Based on meteorological data for the year 2008, the spatial distribution of PM_{10} and EC in the city of Rotterdam was modelled by the URBIS model. The modelling results were validated by measurements in 2008 at an urban background and traffic locations in the monitoring network of the environmental protection agency (DCMR) in Rotterdam. The results are presented in Table 2.

The uncertainty in monitoring annual concentrations is in the order of 15%, while for modelling, the uncertainty is in the range of 25 to 40% for an urban background and road side location, respectively [8]. Considering these uncertainties, the results in Table 2 show good agreement between modelled and monitoring annual averages for PM_{10} . For EC, the modelling and monitoring results at the urban background location differ by a factor 2. This may be explained by a.) *under*estimation of the urban background by a too large conversion factor 11 of Black Smoke to EC concentrations and b.) *over*estimation of the measured background by the MAAP instrument of EC concentrations due to calibration of MAAP by VDI thermal EC analysis. The

VDI protocol overestimates EC concentrations due to inadequate correction of *artefact* EC formation during thermal analysis. Our study underlines that more experimental data on EC is required to further improve modelling of dispersion EC in urban areas.

Table 2: Measurements and modelling results of the annual average PM_{10} and EC at locations in Rotterdam (2008).

	PM_{10} ($\mu g \cdot m^{-3}$)		EC ($\mu g \cdot m^{-3}$)	
	model	monitoring	model	Monitoring
Urban background - "Schiedam"	27.9	25.7^{A}	1.0	2.0^{C}
Traffic location - "Floreslaan" - "Vasteland"	25.6 28.9	27.2^{A} n.a.	1.2 1.4	1.6^{D} 1.7^{D}
Motorway station - "Ridderkerk"	30.7	28.3^{B}	2.2	n.a.

^{A}: gravimetric analysis;
^{B}: Tapered element oscillating monitor – TEOM corrected with 1.3;
^{C}: Multi angle absorption photometer – MAAP;
^{D}: Conversion from Black Smoke index;
n.a.: not available

Table 3: The number of inhabitants in Rotterdam exposed to various levels of annual average PM_{10} and EC in the period 1985 – 2008.

	Number of inhabitants (#)		
	1985	1995	2008
PM_{10} ($\mu g.m^{-3}$)			
20-30	-	-	565.000
30-35	-	15.000	5.000
35-40	-	550.000	-
40-45	515.000	5.000	-
45-55	55.000		
EC ($\mu g.m^{-3}$)			
0.5-1.5	-	-	565.000
1.5-2.5	-	-	5.000
2.5-3.5	535.000	560.000	-
3.5-4.5	30.000	10.000	-
4.5-6.0	5.000	-	

4.3 Health impact assessment of PM_{10} and EC in 1985, 1995 and 2008

4.3.1 Population density in Rotterdam in 1985-2008

To investigate the health impact assessment in 1985-2008, we have maintained a constant figure for the population of Rotterdam at 570.000. This number of inhabitants per X,Y-coordinate in the URBIS modelling domain has been combined with the air quality for PM_{10} and EC in the period 1985-2008. The exposure of the population in Rotterdam has been classified to various levels of PM_{10} and EC and presented in Table 3.

4.3.2 Health effects of PM_{10} and EC in Rotterdam in 1985-2008

In general, a health impact assessment (HIA) of outdoor air pollution by PM_{10} and EC is based on four components [9]:

1. an assessment of the ambient air concentrations of PM_{10} and EC by monitoring or model-based estimation;
2. a determination of the size of the population exposed to specific concentrations of PM_{10} and EC;
3. a determination of the health effect of prime interest, including the baseline rate of the health effect being estimated (e.g. the underlying mortality rate in the population in deaths per thousand people);
4. a derivation and application of concentration-response functions from the epidemiological literature that relate ambient concentrations of PM_{10} and EC to selected health effects.

Population exposure distributions (steps 1 and 2) were taken from Table 3. Health impact calculations were performed for the midpoints of the exposure categories and a rounded value just below the lowest category and above the highest category. Though air pollution has been associated with both mortality and morbidity effects, quantitatively the effects of mortality have been shown to be most important in previous health impact assessments [10]. We therefore focus on quantification of mortality effects. Mortality effects of long-term exposure are substantially larger than mortality effects related to short-term daily exposures [10]. We therefore derived an exposure response function based upon long-term exposure studies.

Exposure response functions were selected from a recent review of the evidence for $PM_{2.5}$ and EC [4]. For $PM_{2.5}$, we used a relative risk (RR) 1.007 (95% confidence interval 1.002 – 1.011) expressed per 1 $\mu g.m^{-3}$. For EC we used RR 1.06 (95% confidence interval 1.02 – 1.10) expressed per 1 $\mu g.m^{-3}$. Note that the RR for EC is a factor 10 higher per mass unit as compared to $PM_{2.5}$. We assumed that we could apply the $PM_{2.5}$ exposure response function to the Rotterdam case, even though exposure was characterized as PM_{10}. This may be problematic for the calculation of the health impact for a particular year, but much less so for the calculation of differences between years as most decrease in PM_{10} is due to a decrease of the fine fraction of PM_{10} [7].

We have expressed mortality impacts in life years gained or lost estimated with life table calculations [11]. For the calculation we used a population of 500,000 people aged 18 to 64, distributed in age categories comparable to the 2008 Dutch population. We have estimated *the effects on this population for a lifetime,* as follows: For 1985, 1995 and 2008 we first calculated the life years lost related to the exposure distribution in that year. We then subtracted the life years lost in 1995 and 2008 from the life years lost in 1985 to calculate the gain in life years related to a decrease in concentration. The outcome of the health impact assessment is that the decrease in PM_{10} concentration from *1985 to 2008* results in a gain in life of on average 13 months per person with a range of 7 to 20 months. For EC, a gain of 12 months per person is calculated with a range of 4 to 20 months.

The health impact is similar for PM_{10} and EC. This is explained as follows. The population weighted PM_{10} concentration dropped from 43 $\mu g.m^{-3}$ in 1985 to 25 $\mu g.m^{-3}$ in 2008 which is equivalent to 18 $\mu g.m^{-3}$ PM_{10}. EC "only" decreased from 3 to 1 $\mu g/m^3$ over the same time period. As aforementioned in section 4.1, the decrease in PM_{10} in the last twenty years in The Netherlands is for 70% due to secondary inorganic aerosol and only for 10% due to primary PM emissions, including combustion aerosol [7]. The similarity in health impact for PM_{10} and EC suggests that the health impact of PM_{10} is mainly related to the contribution of combustion aerosol in PM_{10} and less to the contribution of secondary inorganic aerosol. This demonstrates that measures directed to reduce combustion aerosol (e.g. exhaust emissions of road traffic and (inland) shipping) are more effective to reduce health effects of air quality than reducing PM_{10} in general.

5 Conclusions and recommendations

Our study shows that in Rotterdam in the period 1985-2008 the air quality of PM_{10} and EC improved significantly both at urban background and near heavy traffic locations. This results in a gain in life on average of 13 months (PM_{10}) or 12 months (EC) per person in Rotterdam. The ten times larger drop in PM_{10} concentrations as compared to EC results in similar health impact. This is explained by the ten times higher relative risk per $\mu g.m^{-3}$ for EC as compared to PM_{10}. This demonstrates that EC is a more sensitive indicator (compared to PM_{10}) to monitor the health effects of traffic measures. It is noted, that EC is likely *not* causing the health effects but acts as a proxy for the mass of combustion aerosol.

Further experimental research is recommended to improve modelling of EC in urban areas (e.g. establish emission factors of EC for free-flowing and congested road traffic) and to validate effects of traffic measures on air quality of EC (e.g. low emission zones and speed limitation).

References

[1] Brunekreef B. and Holgate S.T. *Air pollution and health.* Lancet 360: 1233-1242, 2002.

[2] Schauer J. *Evaluation of elemental carbon as a marker for diesel particulate matter.* Journal of Exposure Analysis and Environmental Epidemiology 13: 443-453, 2003.

[3] Beelen R., Voogt M., Duyzer J., Zandveld P. and Hoek G. *Comparison of the performance of land use regression modelling and dispersion modelling in estimating small-scale variations in long-term air pollution*

concentrations in a Dutch urban area. Atmospheric Environment 44: 4614-4621, 2010.

[4] Janssen N.A.H., Hoek G., Lawson-Simic M., Fischer P., Bree van L., Brink van H., Keuken M.P., Atkinson R., Brunekreef B. and Cassee F. *Black carbon as an additional indicator of the adverse health effects of combustion particles compared to PM_{10} and $PM_{2.5}$.* Submitted to Environmental Health Perspectives, 2011

[5] PBL *Netherlands Emission Factor Database and Annual background concentrations*. (http://www.mnp.nl/bibliotheek/rapporten/500088002.pdf (Table H.1, pp. 109)

[6] Ntziachristos L and Samaras Z. *EMEP/EEA emission inventory guidebook - COPERT4*. www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-road-transport.pdf

[7] Hoogerbrugge R., Denier van der Gon H.A.C., van Zanten M.C. and Matthijsen J. *Trends in particulate matter.* BOP-report 500099014/2010 www.pbl.nl/en

[8] Denby B., Larssen S., Builtjes P., Keuken M.P., Sokhi R., Moussiopoulos N., Douros J., Borrego C., Costa A.M. and Pregger T. *Recommendations on spatial assessment of air quality resulting from the FP6 EU project Air4EU.* International Journal of Environmental Pollution Vol. 44 Nos 1-4: 128-138, 2010

[9] Ostro B. *Outdoor air pollution: Assessing the environmental burden of disease at national and local levels*. Geneva, World Health Organization, 2004 (WHO Environmental Burden of Disease Series No. 5)

[10] Künzli N., Kaiser R., Medina S., Studnicka M., Chanel O. and Filliger P. *Public-health impact of outdoor and traffic-related air pollution: a European assessment*. Lancet 356: 795-801, 2000

[11] Miller B.G. and Hurley J.F. *Life table methods for quantitative impact assessments in chronic mortality.* Journal Epidemiology Community Health 57: 200-206, 2003