EVIDENCE BASED PUBLIC HEALTH POLICY AND PRACTICE

Apheis: public health impact of PM_{10} in 19 European cities

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Study objective: Apheis is a public health surveillance system that aims to provide European, national, regional, and local decision makers, environmental health professionals, and the general public with up to date and easy to use information on air pollution and public health. This study presents the health impact assessment done in 19 cities of Western and Eastern European countries.
Design: Apheis developed guidelines for gathering and analysing data on air pollution and the impact on public health. Apheis has analysed the acute and chronic effects of fine particles on premature mortality using the estimates developed by Aphea2 study and two American cohort studies. This health impact assessment was performed for different scenarios on the health benefits of reducing levels of particles less than 10 μm in size (PM_{10}).
Main results: PM_{10} concentrations were measured in 19 cities (range: 14–73 μg/m^3). The population covered in this health impact assessment includes nearly 32 million inhabitants. The age standardised mortality rates (per 100 000 people) range from 456 in Toulouse to 1127 in Bucharest. Reducing long term exposure to PM_{10} concentrations by 5 μg/m^3 would have ''prevented'' between 3300 and 7700 early deaths annually, 500 to 1000 of which are associated with short term exposure.
Conclusions: Apheis shows that current levels of air pollution in urban Europe have a non-negligible impact on public health, and that preventive measures could reduce this impact, even in cities with low levels of air pollution.

The international literature shows that air pollution continues to threaten public health despite tighter emission standards, closer monitoring of air pollution, and decreasing levels of certain types of air pollutants. In Europe, multicentre studies[1–4] have shown the adverse health effects of short term exposure to air pollution, and in Switzerland and the Netherlands other studies[5 6] have shown the long term association between air pollution, mortality, and morbidity.

Epidemiological studies provide very valuable estimates of the associations between environmental factors and health outcomes. However, these estimates are often difficult to interpret for public health decision makers or the general public.[7 8]

A health impact assessment in three European countries[9] showed that public health impact and related costs of short and long term exposure to outdoor air pollution and traffic related pollution was considerable. Other studies have shown similarly large impacts from other air pollution sources.[10–15]

The Apheis programme was created in 1999 in 26 European cities to provide European, national, regional, and city decision and policymakers, environmental and health professionals, and the general public with an up to date and easy to use information resource on air pollution and its impact on public health (http://www.apheis.net). The objective is to bridge the gap between epidemiological research findings and public health actions.

This paper presents the health impact assessment (HIA) mortality findings for particles less than 10 μm in size (PM_{10}) in the 19 Apheis cities measuring PM_{10}.

METHODS

To develop this information resource, Apheis assembled a network that brings together environmental and public health professionals on the city, regional, and national levels across Europe. This network performs epidemiological surveillance on an ongoing basis following a standardised protocol for HIAs of air pollution in Europe[16 17] allowing for comparability across all participating cities.

We went through the five main steps in HIA[16] city by city and then comparatively. *Exposure*: PM_{10} was measured in the 19 cities at 104 monitoring stations. PM_{10} was studied using urban background stations as defined in the Apheis guidelines.[17] Decisions regarding the application of a conversion factor were made by the local air quality networks. (table 1). *Health outcomes*: we studied premature mortality excluding accidents and violent deaths (ICD9 001-799). *Choice of exposure response (E-R) functions*: for short term exposure we used the E-R functions developed by APHEA2.[1] For long term exposure we used the E-R functions developed in the HIA performed in Austria, France, and Switzerland based on two American cohort studies (table 2).[9] *The last two steps* were: derive population baseline frequency measures for the health outcomes studied and calculate the number of cases in the target population.

We chose different HIA scenarios to provide decision makers at the local, national, and European levels with a range of possible benefits from reducing PM_{10} levels. Although studies examining the concentration response relation between air pollution and deaths have shown a lack of a threshold down to very low concentrations,[1–3] these scenarios took into account Council Directive 1999/30/EC of 22 April 1999 relating to limit values for particulate matter that should not be exceeded in 2005 and 2010.[18] To provide an estimation of the potential benefits of sustained reductions in air pollution levels, we also proposed a scenario for smaller reductions such as 5 μg/m^3.

FINDINGS

Descriptive findings

Nearly 32 million inhabitants in Western and Eastern Europe were covered by this HIA (table 3). Levels of PM_{10} vary widely across Europe. The annual average levels in Apheis cities range from 14 to 73 μg/m^3 (fig 1).

Table 1 PM_{10} measurements methods in the 19 Apheis-2 cities measuring PM_{10}

City	Year	Area* (km^2)	Area† (km^2)	PM 10‡	TSP§	PM 10 HIA¶	TSP HIA¶	Interval	QA/QC**	Method	Factor††
Bordeaux	2000	560	283	7		4		24 h	yes	TEOM‡‡	
Bucharest	1999	238	180		5		4	24 h§§	yes	gravimetric	$PM_{10}=TSP\times0.6$
Budapest	1999	524	524		8		8	cont.	yes	ß-ray-absorption	$PM_{10}=TSP\times0.58$
Celje	1999	230	100	2		1		cont.		TEOM (50°C)	
Cracow	1999	320	320	6		1		24 h	yes	ß-ray-absorption	
Gothenburg	2000	282	282	4		1		cont.	yes	TEOM (50°C)	$1.03\times PM_{10}+3$ µg/m^3
Lille	2000	612	612	7		5		cont.	don't	TEOM	
Ljubljana	1999	902	400	2		2		cont.	yes	TEOM (50°C)	
London	1999	1600	1600	13		1		cont.	yes	TEOM	
Lyon	2000	500	132	4	1	2				TEOM	
Madrid	1998	606	606	25		14		cont.	yes	TEOM	1.3
Marseille	2000	355	355	4		3		cont.	yes	TEOM (50°C)	
Paris	1998	762	762	3		3		hourly	yes	TEOM	
Rome	1999	1495	320	4		4		cont.	yes	ß-ray-absorption	
Seville	1999	141	90	10		6		cont.	yes	ß-ray-absorption	
Stockholm	2000	500	500	3		1		cont.	yes	TEOM (50°C)	$1.03\times PM_{10}+3$ µg/m^3
Strasbourg	1999	304	304	1		1		cont.	yes	TEOM (50°C)	
Tel Aviv	1996	171	52	2		2		cont.	yes	TEOM	
Toulouse	2000	713	635	3		2		cont.	yes	TEOM	

*Total area; †area covered by air network; ‡particulate matter with a size lower than 10 µm; §total suspended particulate; ¶selected sites for health impact assessment (HIA); **quality assessment/quality control; ††use of correction or conversion factor; ‡‡tapered oscillating microbalance method; §§four weekdays (Monday–Thursday).

Table 2 Exposure-response functions used in Apheis-2 health impact assessment

Health indicator	Relative risk for a 10 µg/m^3 increase in PM_{10}*	95%CI
Total mortality excluding external causes ICD9† <800 All ages	1.006‡	1.003 to 1.008
Total mortality excluding external causes ICD9 <800 30 years+	1.043§	1.026 to 1.061

*Particulate matter with a size lower than 10 µm; †International Classification of diseases-9th revision; ‡relative risk for short term exposure[1]; §relative risk for long term exposure.[9]

Health impact assessment findings

In this paper we present one scenario for acute effects of PM_{10} and two scenarios for long term effects. In figures 2 to 4, 95% CI are based on 95% CI of the exposure-response functions.

Short term effects scenarios

- Reduction by 5 µg/m^3 of daily values of PM_{10} to allow for sustained reductions in the levels of PM_{10}.

Figure 2 shows the potential benefits of reducing daily PM_{10} levels by 5 µg/m^3. All the cities would have benefit from a 5 µg/m^3 reduction in daily PM_{10} levels.

Long term effects scenarios

- Reduction of the annual mean value of PM_{10} to a level of 20 µg/m^3 (2010 limit values for PM_{10})

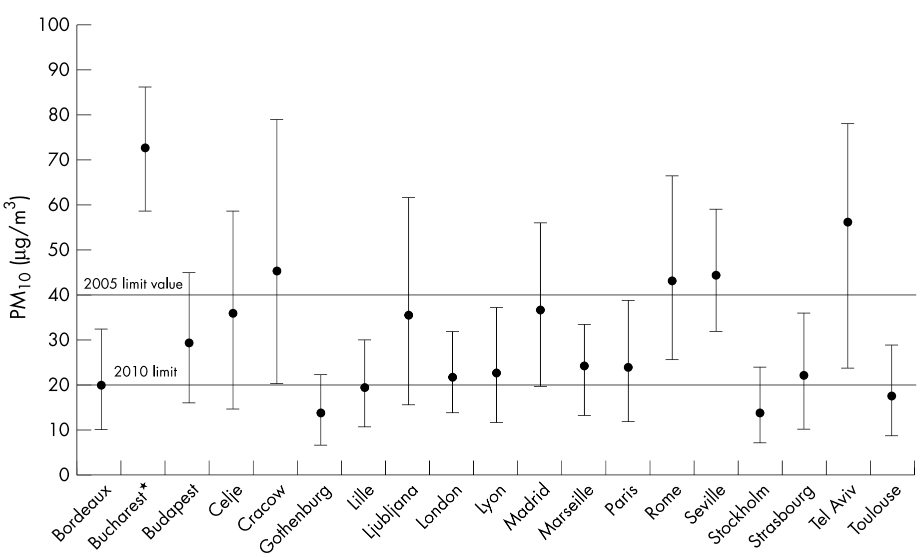

Figure 1 Annual mean concentrations and 10th and 90th centiles of the distribution of PM_{10} in 19 Apheis-2 cities. *Bucharest shows the highest PM_{10} levels, but in this city measurements were only available for four weekdays (Monday to Thursday); this may explain the high levels observed.

Table 3 Demographic characteristics of the 19 Apheis-2 cities measuring PM_{10}*

City	Year	Population Number	Population over 65 years %	Age standardised mortality rate†
Bordeaux	1999	584164	15.8	497
Bucharest	1999	2028000	13.0	1127
Budapest	1999	1775587	17.5	1021
Celje	1999	50121	14.0	913
Cracow	1999	738150	13.4	766
Gothenburg	2000	462470	16.4	600
Lille	1999	1091156	12.8	648
Ljubljana	1999	267763	14.8	803
London	1999	7285100	12.6	596
Lyon	1999	782828	15.7	477
Madrid	1998	2881506	17.8	517
Marseille	1999	856165	18.7	525
Paris	1999	6164418	13.8	470
Rome	1995	2685890	17.2	525
Seville	1996	697485	13.5	719
Stockholm	1999	1163015	15.6	578
Strasbourg	1999	451133	13.3	531
Tel Aviv	1996	1139700	14.2	672
Toulouse	1999	690162	13.5	456

*Particulate matter with a size lower than 10 µm; †age standardised mortality rate per 100000 using the European population (IARC 1982).

- Reduction by 5 µg/m^3 of the annual mean value of PM_{10} to allow for sustained reductions in the levels of PM_{10}.

Potential benefits of reducing annual mean values of PM_{10} for each of these scenarios are presented in figures 3 and 4. All other things being equal, if we consider a reduction in annual mean values of PM_{10} to 20 µg/m^3, all cities would have benefit from this reduction in air pollution levels except Bordeaux, Gothenburg, Lille, Stockholm, and Toulouse, which already comply with this level of air pollution. If annual mean values of PM_{10} were reduced by 5 µg/m^3 in all the cities, the consequent reduction in the number of deaths per 100 000 residents would range between 32 in Budapest and 13 in Toulouse.

Overall, in the 19 cities, reducing long term exposure to outdoor concentrations of PM_{10} by 5 µg/m^3 would have "prevented" between 3300 and 7700 early deaths annually, 500 to 1000 of which are associated with short term exposure.

Key points

- The Apheis programme aims to provide European, national, regional, and local decision makers, environmental health professionals, and the general public with up to date and easy to use information on air pollution and public health.
- This study presents the health impact assessments in 19 European cities, including nearly 32 million inhabitants.
- Reducing long term exposure to PM_{10} levels by 5 µg/m^3 would have "prevented" between 3300 and 7700 early deaths annually, 500 to 1000 of which are associated with short term exposure.
- Apheis has created an active public health and environmental information network on air pollution related diseases in Europe using a standardised methodology.

DISCUSSION

This study shows that achievable reductions in air pollution levels have an impact on public health, and that this impact justifies taking preventive measures, even in cities with low levels of air pollution. Our HIA findings are consistent with those of other organisations conducted in Europe and America.[10–12 14]

From a public health point of view, it is very important to consider the estimates for a reduction by 5 µg/m^3 in the background mean levels. Many studies on particulate pollution and mortality show that a linear shape can be assumed[1–3 19–21] and maintained reductions all over the year should be much more effective in terms of health benefits than a strategy focusing on air pollution peaks above limit values.

Factors that influence the reliability of our HIA findings

The reliability of our HIA findings depends mainly on the quality of the studies selected for our exposure-response functions and on the quality of the exposure and health data used in each city.

Regarding the exposure-response functions, we used the effect estimates recently developed by the APHEA2 study[1 2 21] for short term exposure to air pollution, as the cities in the Apheis programme are almost the same as those in APHEA2. Recent problems with GAM raised by NMMAPS[22] lead the APHEA investigators to conduct sensitivity analysis of the findings in APHEA2. Different convergence parameters were applied to the S-PLUS GAM function and results do not show a relevant change in the estimates when more stringent criteria for GAM were used (4% decrease).[23] Further investigation of the sensitivity of the model to how season and weather are controlled is underway as part of the APHENA project, and will be incorporated in future Apheis HIAs.

For long term exposure to air pollution, in the absence of European studies on chronic mortality and air pollution at the time we did the study, we selected the exposure-response function used in the HIA done in Austria, France, and Switzerland[9] based on two American cohort studies,[24 25] re-analysed by the Health Effects Institute.[26] The choice of Künzli *et al* estimate in Apheis 2 was done before the

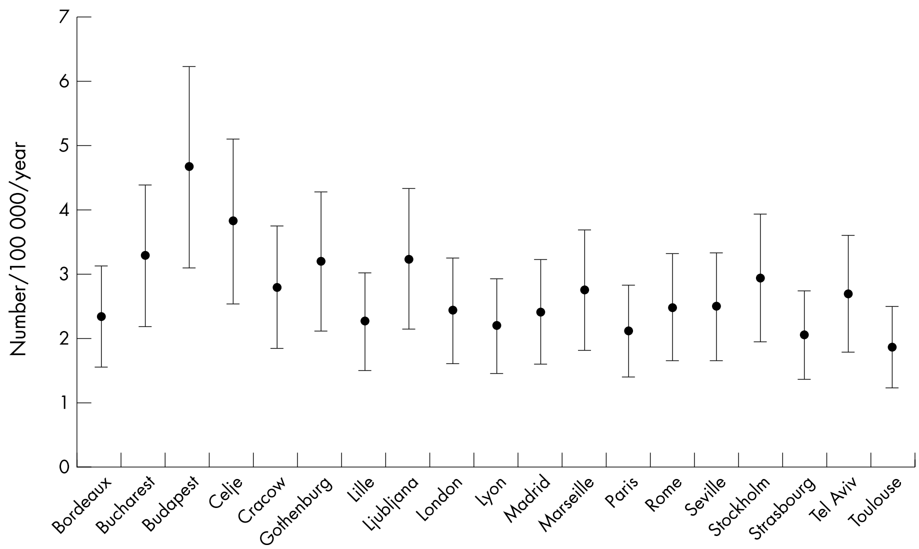

Figure 2 Number of "preventable" early deaths per 100000 residents (95% confidence limits) associated with a 5 μg/m^3 reduction in daily PM_{10} levels in 19 Apheis-2 cities.

publication of Pope *et al*'s 16 year follow up of the ACS study.[27] If we would have used Pope *et al*'s 16 year follow up, the estimated number of premature deaths delayed would have been almost 40% higher. In Apheis 3, ongoing HIA will use Pope's estimates.

The question of transferability of estimates between the US and Europe could be raised, because the particulate composition and populations can differ substantially between the two continents. European cohort studies on chronic mortality and air pollution have begun, and preliminary results of the Netherlands cancer study confirm significant associations between long term exposure to ambient air pollution and longevity,[6] with even larger effect estimates for traffic pollution than used in our HIA. These studies should provide European long term estimates that will be used in future phases of Apheis.

The estimated short term effects used in this HIA were derived from the APHEA study, which used the mean of PM_{10} on the day of death and the day before death as exposure. It is possible that the adverse effects of PM exposure, mediated by systemic inflammation, increased infectivity, or other mechanisms, may persist for longer than two days. A second APHEA analysis,[28] restricted to 10 large European cities, examined the effect of PM_{10} exposure up to 40 days before the date of death. The estimated effect was two and a half time higher than when just using the two day mean. This study also enabled to evaluate the potential for harvesting: the harvesting effect has been observed for COPD mortality,[29] but for cardiovascular deaths, the increased probability of dying from a heart attack is not followed by a decrease in the probability of dying in the following days or months.[30] This suggests the acute analyses in our HIA may underestimate risk, and that the differences between acute and chronic studies are less than previously thought. Apheis 3 HIAs will incorporate these new distributed lag effect estimates.

Regarding exposure data, our HIA findings depend directly on the levels of particulate pollution measured. These levels vary widely as a function of the number and location of the monitoring sites, the analytical methods used, and the sites selected for our HIA. This explains the importance of using the Apheis guidelines to ensure comparability of the data. A detailed analysis of the type of data and methods used concluded that, although they could be improved, results for the exposure to be used in the HIA were reliable.[31] In Apheis, the automatic PM_{10} measurement methods was applied, but

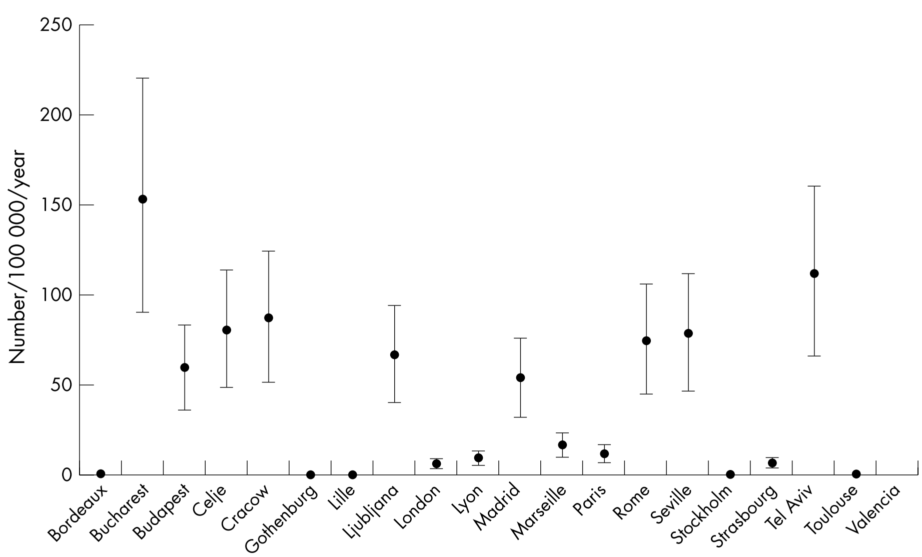

Figure 3 Number of "preventable" early deaths per 100000 residents (95% confidence limits) associated with a reduction of annual mean values of PM_{10} to a level of 20 μg/m^3 (2010 limit values for PM_{10}) in 19 Apheis-2 cities.

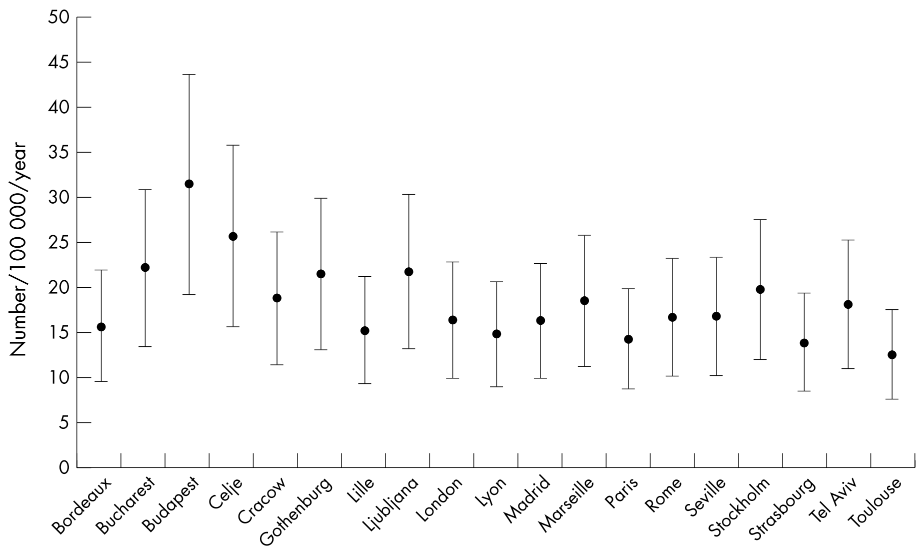

Figure 4 Number of ''preventable'' early deaths per 100000 residents (95% confidence limits) associated with a 5 $\mu g/m^3$ reduction in annual mean values of PM_{10} in 19 Apheis-2 cities.

after decisions from the local air quality networks, a conversion factor was used only for three cities. The short term HIA was performed using the APHEA2 findings, which used the same measurement methods as used in Apheis. However, the long term HIA used North American effect estimates of PM_{10} measured by gravimetric sampling. Then, long term HIA may underestimate by 30% the PM_{10} impact in Apheis 2. In Apheis 3, ongoing HIA local analyses are being conducted to decide on the local applicability of the recommended European conversion factor of 1.3 to be applied in long term HIA.

Different sources of air pollution can be distinguished in the participating cities—that is, Mediterranean cities have more wind blown dust, Eastern Europe more coal, and Western Europe more traffic and these different sources of particles may have different toxicities. So identifying such links is important for HIA, and, of course, for decision making purposes, and requires attention in future Apheis work. For example, if dust derived (larger) PM_{10} are less harmful than traffic derived (smaller) PM_{10}, the effects of PM_{10} and of reductions in PM_{10} in Tel Aviv might be less than the one estimated, based on results from studies conducted in cities where most PM_{10} is traffic derived.

Regarding health indicators, a detailed analysis of the data provided concluded that the selected data was reliable and fully comparable for the selected categories of mortality.[31] For frequencies we calculated standardised mortality rates using the European population as the reference population, allowing us to compare mortality rates between cities.

Although outside of the purposes of this paper, it is interesting to mention that biological plausibility of the association between particulate air pollution and health has been assessed for respiratory and, more recently, for systemic and cardiovascular diseases, with an increasing amount of evidence for a causal link.[32–38]

Finally, attributable cases are often interpreted as cases that would be removed if the exposure were removed. But caution must be used when interpreting the findings in this way. For multicausal diseases the sum of percentages of attributable cases across several risk factors does not total 100%, but may be larger.[39] Impact measurements that take competing risks into account need to be developed.

This paper reports a broad based European HIA of air pollution, embracing data from 19 cities. By harmonising the information relevant to exposure assessment, Apheis is contributing to more uniform air pollution measurements in Europe. As black smoke has been measured for many years in most European cities, we would like to emphasise the importance of continuing to measure this air pollution indicator, which represents small black particles (less than 4 µm) that have measurable health effects. We also encourage the implementation of PM_{10} and $PM_{2.5}$ measurements in every Apheis city, if they have not already done so.

Other noteworthy points include the fact that, as part of Apheis' objective to bridge the gap between research findings and decision making, this report comprises an HIA conducted simultaneously on both local and European levels, and thereby provides officials in each city with local data for local decision making, and European officials with Europe-wide data for making decisions on a European level.

Our HIA provides a conservative but accurate and detailed picture of the impact of air pollution on health in 19 European cities, and shows that air pollution continues to threaten public health in Europe.

Policy implications

- Even small reductions in air pollution levels could prevent a large number of deaths in the European population.
- With its monitoring system, Apheis will continue to keep the information we provide as up to date and accurate as possible on both the city and European levels simultaneously.

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