Inappropriate use of daily mortality analyses to estimate longer-term mortality effects of air pollution

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Background To avoid the usual problems of multi-population correlation studies of air pollution and mortality, and for reasons of convenience, daily time-series mortality studies within single populations have recently become popular in air pollution epidemiology. Such studies describe how the short-term distribution of deaths relates to short-term fluctuations in air pollution levels. The regression-based risk coefficients from these acute-effects studies have been widely used to estimate the excess annual mortality within a population with a specified average level of air pollution. Such calculations are inappropriate. Since daily time-series data provide no simple direct information about the degree of life-shortening associated with the excess daily deaths (many of which are thought to be due to exacerbation of well-advanced disease, especially cardiovascular disease), such data cannot contribute to the estimation of the effects of air pollution upon chronic disease incidence and long-term death rates. Yet it is that category of effect that is of most public health importance.

Conclusion Such effects are best estimated from long-term cohort studies that incorporate good knowledge of local (or personal) exposure to air pollutants and of potential confounders. Time-series studies, properly evaluated, can identify the existence of acute toxic effects of transient peak levels of air pollution; they are thus useful for monitoring acute toxicity and for identifying the most noxious pollutants. However, to quantify the long-term health impacts of air pollution we cannot use acute-effects data.

Keywords Air pollution, mortality, study design, time-series data, acute effects, chronic effects

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Urban air pollution is a major focus of public health concern and regulatory activity. Yet there is an unresolved, indeed poorly recognized, tension between the prevailing type of epidemiological data and the information most needed to make policy. The setting of appropriate air quality guidelines requires knowledge of the population burden of illness and premature death avoidable by control of specified air pollutants. However, most epidemiological studies of the mortality impacts of specific air pollutants have been based on daily time-series data. These do not allow estimation of the usual population indices of premature mortality, based on changes in annual age-specific death rates.

Time-series analyses, conducted in many Western cities, have consistently shown that upwards excursions in daily pollutant levels are accompanied by extra daily deaths. This provides clear evidence of a measurable ‘acute’ effect of air pollution episodes upon daily mortality. At the least, it indicates that air pollution causes alterations in the day-to-day distribution of deaths within that population, presumably by precipitating death in susceptible persons (usually with advanced disease). However, the more important public health question is whether sustained exposure to elevated levels of air pollution affects annual death rates, by inducing or contributing to the development of life-shortening chronic disease. That latter question cannot be addressed by daily time-series mortality data since, by their nature (including the lack of an external comparison population), they provide no direct information on the loss of person-time associated with the ‘extra’ deaths. Nor can they tell
us about the contributions of transient peaks in exposure to longer-term disease processes.

Much recent public discussion and economic impact assessment has confused this issue. A recent briefing report prepared internally for the British Parliament illustrates the general problem. The report explicitly recognizes that there are ‘acute’ and ‘chronic’ effects of air pollution on mortality. But it nevertheless states, on the basis of time-series findings, that ‘if measures were taken to reduce average annual levels of PM$_{10}$ (i.e. fine respirable particulates), each 1 µg/m$^3$ reduction might reduce the number of deaths each year by 400 or so.’ This statement, like various others published recently, inappropriately scales up the transient excess daily mortality from time-series studies in order to estimate the impact of sustained pollutant exposure on annual death rates.

What, then, do daily time-series studies actually measure? By regressing the daily death counts on daily air pollutant levels, we can estimate the relative risk of immediate death associated with a given short-term increase in air pollution. For example, it has been estimated that there is an approximately 1% increase in daily deaths for a day with a level of particulates (PM$_{10}$) 10 µg/m$^3$ higher than another day. (Capital cities in Europe typically have mean PM$_{10}$ levels around 20-40 µg/m$^3$.) Indeed, since no ‘threshold’ (no-effect) level of exposure is evident, a general linear relationship is presumed such that even the many days with relatively low PM$_{10}$ levels are presumed to entail an increment in daily deaths.

Summing these small daily increments over a whole year yields a large number of ‘extra’ deaths associated with daily upward fluctuations in levels of PM$_{10}$ (or other air pollutants). The annual sum can run into several thousands, even for small countries such as the Netherlands. But how should such summation be interpreted? We simply do not know whether, for a population with a given long-term mean exposure, one sequence of daily PM$_{10}$ fluctuations causes more or less total deaths during a whole year than does some other sequence of PM$_{10}$ exposures—or, indeed, than does a non-fluctuating exposure level. Presumably, many of these extra daily deaths (which must come from some unidentified, constantly refilling, pool of susceptibles) would have occurred during that particular year anyway, even without fluctuations in air pollution. However, since we cannot identify those actual individuals who die because of a transient air pollution episode (nor, therefore, can we estimate their pre-episode life expectancy), it is not possible to estimate directly the loss of person-time associated with the estimated number of extra deaths. Hence, summing the series of acute mortality excesses, without knowledge of the loss of person-time, cannot yield an estimate of the change in annual death rate.

Examples of inappropriate use of time-series data

This confusion has not been confined to government documents. Various scientific papers and working documents have blurred the distinction between study types or have inappropriately used the published results of daily time-series studies to estimate impacts on annual death rates. For example, inappropriate estimates were made for Paris, in 1995, of the annual number of lives that could be saved by eliminating particle and sulphur dioxide pollution. Using risk coefficients from local daily mortality time-series studies, the authors estimated the proportional change in daily deaths achievable by reducing current annual mean pollution levels to zero, and then multiplying the estimated daily mortality saving by 365. This calculation assumes that none of those deaths would otherwise have occurred during that year, whereas the underlying time-series data neither allow nor suggest that assumption.

Relatedly, a recent estimate was made of the annual health costs attributable to air pollution from road transport in the UK (£19.7 billion in 1993). Pollutant-specific risk coefficients from daily time-series studies were, again, used to estimate the annual extra number of lives lost. For each death a standard economic cost was assumed. Yet the real costs to society vary as a function of the amount of life actually lost. A similar confusion was evident in a World Bank working paper, published in 1994, that used a time-series-based approach to estimate the mortality impact of air pollution in order ‘to (help) analyse the economics of pollution control in developing countries.

This confusion has been compounded by a recent technical report from WHO entitled ‘A Methodology for Estimating Air Pollution Health Effects’. The report acknowledges that, since ‘cumulative long-term exposure to particles may also contribute to premature mortality, it is likely that the acute effect (time-series) exposure studies ... underestimate the effects’ (p.10). Surprisingly, and without satisfactory explanation, the report proposes averaging the dose-response coefficients from daily time-series and long-term follow-up studies to estimate mortality impacts from particulates.

Short-term mortality displacement or ‘harvesting’

There is no doubt that brief elevations of various air pollutants cause extra deaths, and that some reduction in life-span (i.e. loss of person-time) thus occurs. There is, however, need for a clearer understanding of the ‘losses’ involved. Deaths in serious air pollution episodes and during heat-waves are known to occur disproportionately among the very old and very sick. Hence, it is likely that many, perhaps most, of the excess daily deaths evident in time-series data result from short-term displacement of the time of death (e.g. from well-advanced cardiovascular disease), sometimes called ‘harvesting’. Every such extra death involves some degree of prematurity, from as little as a day to many years. For the important public health task of estimating the impact of air pollution on population mortality, measured as changes in the annual death rate, we need to be able to estimate the person-years of life lost. This issue is well-understood by epidemiologists in other contexts. For example, avoidable deaths at young age (e.g. traffic accidents killing young adults) entail a greater loss of person-time than do avoidable deaths in late adulthood.

There has been some recent recognition of the existence of short-term displacement of mortality by transient elevations of air pollution. The UK Government’s Expert Panel on Air Quality Standards, reviewing time-series studies, recently questioned ‘whether such excess death rates (sic) represented either more people dying overall, i.e. an increase in absolute mortality, or rather the deaths of already ill people being brought forward, perhaps by only a few days, and therefore fewer dying over the
Research: past developments, current needs

It is instructive for epidemiologists to consider how this confusion over acute and chronic mortality impacts of air pollution has arisen.

Several well-recognized difficulties in quantifying the mortality effects of air pollution explain much of the evolution of epidemiological research methods. The earliest studies were based on the dramatically obvious acute effects on mortality, within a single population, of major air pollution episodes (e.g. the London smog of 1952). Early studies of the long-term mortality impacts of air pollution compared populations in different locations that had different pollutant exposures. However, since those latter studies were prone to inter-population confounding (e.g. by differences in prevalence of cigarette smoking), a preference has emerged over the past decade for analysing time-trends within a single population. This has arisen.

Despite the new enthusiasm for daily mortality time-series studies, the basic conceptual problem persists. By design, daily mortality time-series studies show only how the short-term distribution of deaths relates to short-term fluctuations in air pollution levels. Nevertheless, time-series studies have drawn attention to the existence of acute toxic effects of low levels of air pollution; they are useful for monitoring acute airborne toxicity and for identifying the most noxious components or mixtures; and they can be used to explore the phenomenon of mortality displacement.

In order, now, to differentiate between the acute and longer-term mortality impacts of air pollution two types of research are needed:

1. Assessment of the extent to which the observed increases in daily mortality represent short-term mortality displacement. This will require either the development of statistical approaches to the estimation, from daily time-series data, of the amount of person-time lost, or studies that provide more detailed descriptions of the clinical characteristics of people who die on days with increased air pollution—including studies that analyse jointly morbidity and mortality rates in the same locales over the same time interval. Such studies are now undereway.

2. Additional studies of the impact of long-term exposure to air pollution on mortality from chronic diseases. Cohort (or, sometimes, case-control studies) can provide the best such information, provided that there is satisfactory control of confounding effects.

Finally, it should be noted that the abovementioned limitation upon the type of health impact assessment derivable from daily time-series data applies particularly to mortality studies. Whereas death is a once-only event, many non-fatal health events can occur repeatedly in an individual. Time-series analyses may therefore be especially informative for non-fatal outcomes.

Conclusions

The many recent time-series analyses of daily air pollutant level in relation to daily deaths indicate that several categories of air pollution pose an acute health hazard. However, we must be cautious in interpreting these findings. Daily time-series analyses, well able to describe variations in the daily distribution of deaths (particularly in the vulnerable subgroups who are the 'canaries' of our modern cities), do not provide a satisfactory basis for estimating the longer-term change in mortality attributable to sustained exposure to air pollution.

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Disclaimer

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References

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