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Health risks of NO_2, SPM and SO_2 in Delhi (India)

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Abstract

There is increasingly growing evidence linking urban air pollution to acute and chronic illnesses amongst all age groups. Therefore, monitoring of ambient concentrations of various air pollutants as well as quantification of the dose inhaled becomes quite important, specially in view of the fact that in many countries, policy decisions for reducing pollutant concentrations are mainly taken on the basis of their health impacts. The dose when gets combined with the likely responses, indicates the ultimate health risk (HR). Thus, as an extension of our earlier studies, HR has been estimated for three pollutants, namely, suspended particulate matter (SPM), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) for Delhi City in India. For estimation and analyses, three zones have been considered, namely, residential, industrial and commercial. The total population has been divided into three age classes (infants, children and adults) with different body weights and breathing rates. The exercise takes into account age-specific breathing rates, body weights for different age categories and occupancy factors for different zones. Results indicate that health risks due to air pollution in Delhi are highest for children. For all age categories, health risks due to SO_2 (HR_SO_2) are the lowest. Hence, HR_SO_2 has been taken as the reference with respect to which HR values due to SPM and NO_2 have been compared. Taking into account all the age categories and their occupancy in different zones, average HR values for NO_2 and SPM turn out to be respectively 22.11 and 16.13 times more than that for SO_2. The present study can be useful in generating public awareness as well as in averting and mitigating the health risks.

Keywords: Air pollution; Exposure; Health risks; Dose–response; Population classes

1. Introduction

The effects of air pollution on health are very complex, as there are many different sources and their individual effects vary from one to the other. Air pollutants that are inhaled affect human health severely by way of damaging the lungs and respiratory system. They are also taken up by the blood and pumped all around the body. However, the risk varies from one pollutant to another. Oxides of sulfur can oxidize and form sulfuric acid, thereby leading to the damage of lungs and various lung disorders such as wheezing and shortness of breath. Oxides of nitrogen, on the other hand, can in particular make children susceptible to respiratory diseases specially in winters. When exposure to these oxides gets combined with the exposure to suspended particulate matter (SPM), the long-term effects are quite difficult to ascertain. The main chemical component of SPM that is of major concern is lead, others being nickel, arsenic and those present in diesel exhaust. When we breathe, these particles damage our lung tissues and cause various respiratory problems (http://edugreen.teri.res.in/explore/air/health.htm).

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In short, air pollution affects not only human health but also ecological health of a region (Okita et al., 1996; Pandey et al., 2002, 2004; Srivastava, 2004; Srivastava et al., 2005). For instance, sulfate aerosols, through the processes of scavenging and acid rain, lead to serious degradation of terrestrial and aquatic ecosystems.

Particulate matter (PM) in urban areas is mainly made up of metals, organic compounds, materials of biological origin, secondary particulate matter (sometimes even in ionic form) and pure or elemental carbon. The particle core, which often forms bulk of the urban particulate matter, mainly comprises elemental carbon. Many organic compounds can lead to mutations and can be cancerous. A major fraction of diesel particles are smaller than 1 μm in diameter. They consist of a carbonaceous core with large surface area on which many organic compounds like carcinogenic polycyclic and nitro-polycyclic hydrocarbons are adsorbed. A recent study by the United States Environmental Protection Agency has linked diesel emissions with high cancer risks (US-EPA, 2002).

Airborne particulate matter is a mixture of many chemical species (pollutants) in solid and liquid forms. Depending on whether they are emitted directly by emission sources or are formed because of atmospheric reaction of various gases, PM_s are, respectively, classified as primary or secondary particulate matters. For instance, reaction between ammonia and oxides of nitrogen or sulfur may lead to the formation of secondary particulate matter. The particle size for PM can vary from 0.005 (0.005×10^{-6} m) to 100 μm in diameter. All ambient PM irrespective of size is referred to as SPM. Particulate matter less than 10 μm in diameter is referred to as PM_{10}, and PM less than 2.5 μm is referred to as $PM_{2.5}$.

While trying to understand the role of particle size and composition in terms of its health risks, there are strong evidences supporting the fact that smaller particles are more harmful. Studies have also shown that particles of different sizes vary in their respiratory tract deposition, movement, clearance and consequent retention time in the human body. Ultra-fine sub-micron size particles behave almost like gases and travel to the lower regions of the lungs. The smaller the particle, the greater is the fraction of particles deposited in airways and lungs, and greater is the surface area available for interaction with biological systems. In contrast, larger particles (larger than 10 μm) get deposited in the upper or middle region of the respiratory tract. The intermediate size range gets deposited in between these two extremes. Moreover, SPM may contain fungal spores and pollen, which induce several allergic responses. Because of their acidic nature, sulfate and nitrate ions can even damage respiratory tract (http://www.worldbank.org/sarurbanair).

For quantifying impact of air pollution on human health, normally three types of approaches are used: meteorological approach, risk-based (exposure, dose rates) approach and epidemiological approach. The first (meteorological) approach confines to the emissions of various air pollutants, their transport, transformation and removal from the environment. The second (risk-based) approach examines the pathways through which air pollution enters the body and estimates the amount of exposure and related risk. The third (epidemiological) approach studies the health outcomes like hospital admissions, disease rates, mortality and potential mechanisms of biological effects. Although research results have been amply reported for all these three approaches, there has been very little effort to integrate the information (Middlebrook et al., 2004).

So, by now there is a general consensus that air pollution leads to several adverse health effects such as acute respiratory infection (of both the upper and the lower respiratory tracts), bronchitis, asthma, cardiovascular disease and lung cancer. Long-term exposure to them may even lead to nervous system disorders (HEI (Health Effects Institute), 2002). The most important issue, therefore, is how severely it affects the human health through the dose inhaled. Dose along with its likely responses, indicates the ultimate health risk (HR). Quantification of HR at a given location, thus, requires following information (Hall, 1996):

- ambient air quality data for all pollutants of interest,
- exposure response and/or dose–response functions specific to the local population and pollutant mix,
- demographic data including population, its spatial distribution and age-specificity, and
- time–activity profiles (occupancy factors) for different age groups of population in different regions (residential, industrial, commercial, etc.).

There is a strong need now for carrying out health risk assessment studies for the cities, which are suffering from serious pollution-related health problems. This involves generation of site-specific data connected with environmental pollution and associated socio-economic profiles. There is also a need for characterizing exposure profiles within every age group. This means generation of more detailed information through intensive monitoring and household surveys. Any macro-environment can thus be divided into smaller and more homogeneous components (micro-environments) in which concentrations of specific air pollutants can be more easily estimated from known characteristics of these micro-environments. Also, the occupancy factors have to be more precisely estimated for the micro-environments (Pandey et al., 1993).

As far as India is concerned, it accounts for nearly one third of the total 150 million asthma afflicted people worldwide. It ranks highest in terms of premature deaths due to outdoor and indoor air pollution. Recent findings also suggest that 30% of Delhi's population suffers from respiratory disorders due to air pollution, and the incidence of respiratory diseases in the city is as high as 12 times the national average. Common disease symptoms are eye irritation, throat infection, respiratory discomfort, skin ailments, impaired hearing, chest disease, excessive carboxy haemoglobin and annoyance with noise (http://www.delhitrafficpolice.nic.in/art8.htm). In terms of SPM, Delhi is the fourth most polluted city in the world (http://www.gisdevelopment.net/application/natural_hazards/overview/nho0019.htm).

Constantly rising population levels, their haphazard distribution and growth and the consequent rise in the levels of infrastructure needed to support them are the main reasons behind this pollution rise. Haphazard industrial development along with transportation activities are equally responsible (Srivastava, 2004). Vehicular emissions, in particular, are estimated to account for 60–70% of total air pollution (CPCB, 2004). Diesel generating sets and vehicles, particularly autorickshaws, are major sources which not only generate significant amount of air pollution, but also lead to highly uncomfortable levels of noise pollution.

These and several other associated facts make it almost imperative to carry out site-specific and age-specific quantitative health risk assessment with respect to air pollution so as to provide relatively accurate and representative estimates of HR for all study zones, viz. residential, commercial and industrial. In the present work, age-specific and zone-specific human exposures to air pollutants viz. SPM, NO_2 and SO_2 have been estimated and analyzed for Delhi city in India. Delhi has been chosen as it is an area of serious concern. Three age groups viz. infants, children and adults, as well as three specific zones viz. residential, commercial and industrial zones have been considered in this exercise. The methodology has taken into account various age-specific parameters like body weights and breathing rates as well as site-specific parameters like occupancy factors for all the zones (ICRP, 1975; McKone, 1987; Wallace, 1987; Pandey et al., 2004).

2. Methodology

Central pollution control board (CPCB), India, has established a national network of ambient air quality monitoring stations (CPCB, 2004). This programme known as the National Ambient Air Quality Monitoring (NAAQM), was launched in 1984 with a network of 28 monitoring stations covering seven cities. Over the years, the number of stations has increased and presently the network comprises 290 stations spread over 92 cities/towns. Under this programme, National Environmental Engineering Research Institute (NEERI) monitors ambient air quality in 30 stations covering 10 major Indian cities including Delhi (NEERI, 2003–2004) and evaluates long-term air quality trends with respect to health-related criteria pollutants such as inhalable dust, sulfur dioxide, nitrogen dioxide, hydrogen sulfide, ammonia and toxic polycyclic aromatic hydrocarbons and trace metals. Air samples are collected from residential, industrial and commercial zones by sampling for 8 days in a month at each site. Suspended Particulate Matter (SPM) are monitored on an 8-hourly basis for 24 h by collecting the particulates on $8'' \times 10''$ glass fibre filter (Whatman GF/A) using ENVIROTECH-APM 460 NL sampler. The flow rate is maintained at $1.2\,l\,min^{-1}$. Glass fibre filters are equilibrated in desiccators containing silica gel for 24 h before and after sample collection and weighed on a pre-calibrated AFCOSET balance (ER182A). NO_2 and SO_2 are monitored on a 4-hourly basis for 24 h as per the National Ambient Air Quality Standards (NAAQS, 1998) using Improved West and Gaeke method for SO_2 and Modified Jacob and Hochheiser method for NO_2. The samples are collected at the rate of $5\,l\,min^{-1}$ during the entire 24 h of sampling period.

Exposure has been considered as the event during which a person comes in contact with a pollutant (Ott, 1985). It is an interaction of two events, viz. occurrence of a pollutant at a specific location and presence of a person at the same location. An individual's exposure to a contaminant is defined as the contact at one or more boundaries (e.g. mouth and skin) between a human being and contaminant(s) at specific concentration(s) over a period of time. There is a subtle difference between 'dose' and 'exposure'. Dose occurs only when the pollutant crosses the physical envelope representing the person. Exposure occurs even if the pollutant merely comes into contact with the envelope.

The present analysis is age-specific as it divides the total population under three age-specific categories: infants, children and adults, with different body weights and breathing rates. The temporal exposure envelope is location-specific as it has been divided into three zones: residential, commercial and industrial. Representing the physical boundary of the person as an envelope, the record of a person's exposure as a function of time throughout the day is represented in terms of occupancy factors (Fig. 1). Subsequently, the dose rate for a given zone (residential, industrial or commercial) has been estimated through the following expression over a day:

$$D_{(a,c,i)} = [BR_{(a,c,i)}/BW_{(a,c,i)}] \int_0^{24} C(t)\,Of_{zone}(t)\,dt, \qquad (1)$$

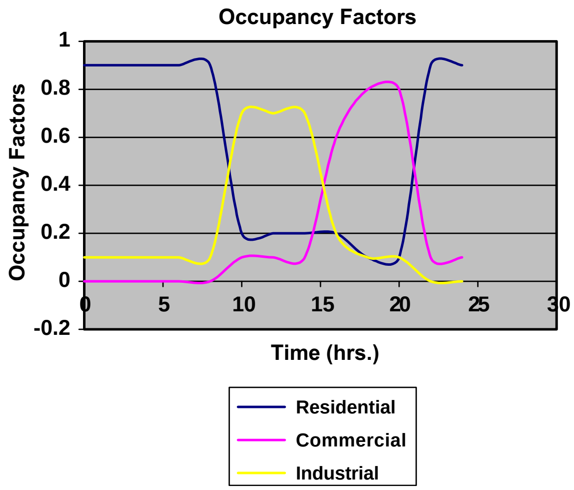

Fig. 1. Occupancy factors for different zones (Residential, industrial and commercial).

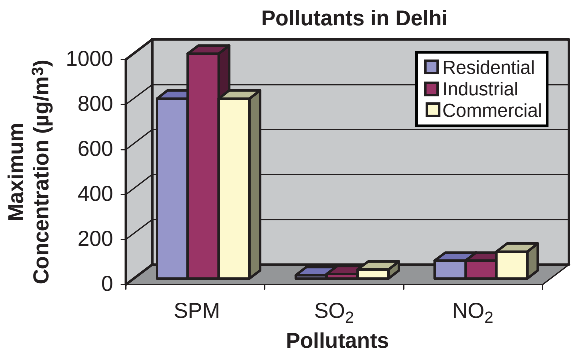

Fig. 2. Zone-wise maximum concentrations observed for SPM, SO_2 and NO_2.

where $D_{(a,c,i)}$ is the age-specific dose rate ($\mu g\,kg^{-1}$); (a,c and i represent adults, children and infants, respectively), $BR_{(a,c,i)}$ is age-specific breathing rate ($L\,min^{-1}$); $BW_{(a,c,i)}$ is age-specific body weight (kg); $C(t)$ is diurnal concentration of the pollutant ($\mu g\,m^{-3}$); and $Of_{zone}(t)$ is occupancy factor (Fig. 1) for the zone (percentage of population likely to be in the zone at a given interval of time).

Dose rates for all the population categories have been estimated on the basis of pollutant-specific concentration under different activity zones (residential, industrial and commercial). Since the primary objective of the present exercise was to estimate the maximum (possible) dose rates for a pollutant in different zones for different age groups, we have used the maximum concentration of every pollutant during the day (Fig. 2).

For estimating the ultimate health risks (Lall et al., 2004; Hall, 1996; Alexeeff et al., 2002; Molhave et al., 2000) these dose rates have been integrated with the lowest observed adverse effect levels (LOAEL) values for SPM ($19.7\,\mu g\,kg^{-1}$), NO_2 ($1.5\,\mu g\,kg^{-1}$) and SO_2 ($7.1\,\mu g\,kg^{-1}$). LOAEL values for SPM and SO_2 were taken from Cerna et al. (1998) as average of morbidity values. While for estimating the LOAEL value for NO_2, first the following dose–response model was constructed on the basis of data available in Neuberger et al. (2002):

$$Y = 103.6\,X^{-0.1003}, \quad (2)$$

where Y is the response (in terms of % endexpiratory flow rates), X is dose rates ($\mu g\,kg^{-1}$) for children estimated from the corresponding values given for NO_2 in Neuberger et al. (2002).

The dose value at which endexspiratory flow rate becomes lower than 100% was taken as the LOAEL value for NO_2. HR has, subsequently, been defined and expressed as

$$HR = [(\text{dose rates})/(\text{pollutant-specific LOAEL})]. \quad (3)$$

HR is dimensionless and quite useful for relative comparisons.

3. Results and discussion

Dose rates, obtained for three age groups, and for different pollutants at different locations (residential, commercial and industrial) have been plotted in Figs. 3–5. Fig. 6 presents pollutant-specific highest and lowest health risks calculated on the basis of pollutant-specific LOAEL values. A closer analysis of Figs. 3–5 indicates that health risks due to SO_2 (HR_SO_2) are the lowest for all age categories. Hence, HR_SO_2 has been taken as the reference with respect to which HR values due to SPM and NO_2 have been compared. Fig. 7 presents the relative HR values for SPM and NO_2 with respect to SO_2.

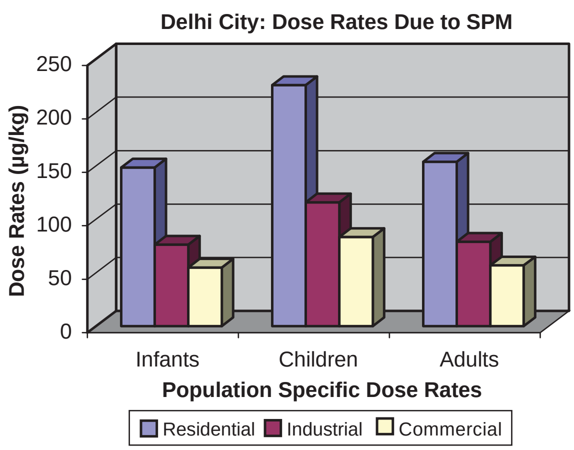

Fig. 3. Dose rates ($\mu g\,kg^{-1}$) for different population age groups in Delhi City due to SPM.

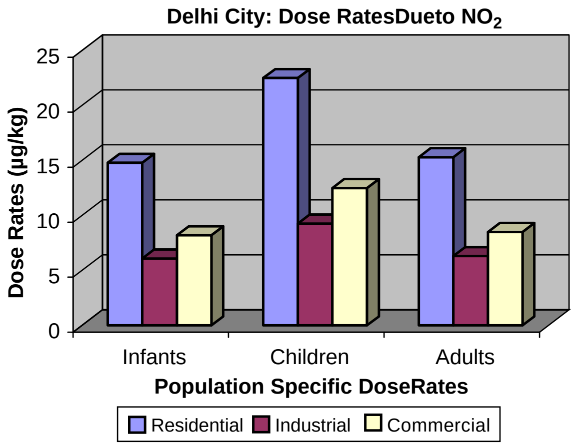

Fig. 4. Dose rates ($\mu g\, kg^{-1}$) for different population age groups in Delhi City due to NO_2.

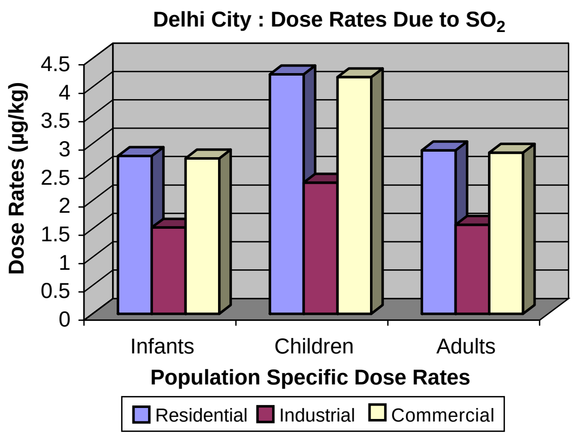

Fig. 5. Dose rates ($\mu g\, kg^{-1}$) for different population age groups in Delhi City due to SO_2.

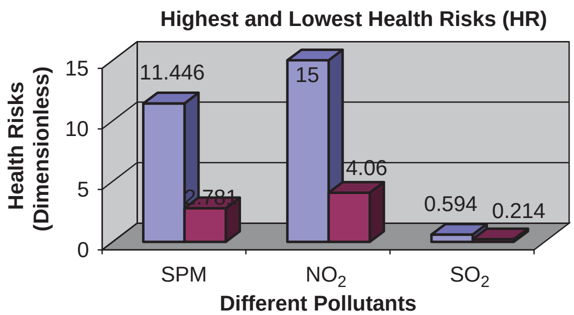

Fig. 6. Highest and lowest health risks (HR) with respect to different pollutants.

It is observed that dose rates for children are always higher than those for the other age groups. This trend indicates that the absolute value of the dose rate depends

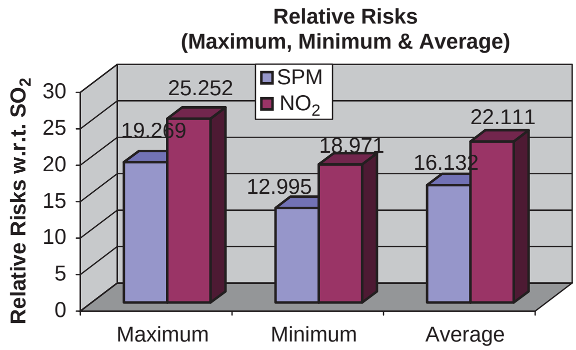

Fig. 7. Relative health risks (maximum, minimum and average) with respect to SO_2.

on the concentration of the pollutants, while its' being higher or lower for any age class depends on the occupancy factors (exposure profiles) for different zones, viz. residential, industrial and commercial. The lower the value of pollutant-specific LOAEL, the higher is the health risk. Similarly, the higher is the dose rate, higher is the health risk. Taken together, HR for a given pollutant is estimated as a function which is directly proportional to the dose rates and inversely to the LOAEL values. Comparison of HR values indicates that children in the residential zone suffer from the highest health risk (15.0) due to NO_2. The lowest health risk is due to SO_2 for infants in the industrial zone (0.214), while the highest health risk due to SO_2 is 0.594, once again for children in the residential zone. For NO_2, the lowest health risk (4.06) is for infants in the industrial zone. A pollutant-wise relative ranking exercise was also done subsequently (Figs. 6 and 7). Comparison of pollutant-wise highest HR values shows that NO_2 is about 25.25 times more risky than SO_2., while HR due to SPM is about 19.27 times more than that due to SO_2. Similarly, when we do the relative ranking with respect to lowest health risks, we find that NO_2 is 18.97 times more risky than SO_2, while HR due to SPM is 12.99 times more than that due to SO_2. Taking these highest and lowest HR values together, the average health risk (HR) due to NO_2 in Delhi is about 22.11 times more than that due to SO_2, and HR due to SPM is about 16.13 times more than that due to SO_2.

NO_2, which turns out to be the most risky pollutant in Delhi, is an indicator of traffic-related air pollutants. Earlier studies (Agarwal et al., 1996; Pandey et al., 2001) have also indicated that vehicular pollution is the main cause behind the rising levels of air pollutants in Delhi and is responsible for approximately 64% of the total air pollution load. NO_2 has long-term effects on respiratory systems and it results in decreasing lung function specially in children (Neuberger et al., 2002, 2004).

4. Conclusion

Health risk (HR) assessment involves the following steps:

- identification and characterization of sources and pollutants;
- transport, distribution and assimilation of pollutants through various pathways of entry;
- quantification of population exposure to different pollutants;
- estimation of doses received by those who are exposed;
- estimation of ultimate HR based on dose–response relationships.

Distribution and transport of pollutants through air, water and soil, human exposure to pollutants, and toxicology and pharmaco-kinetics of pollutants are the main elements involved in any HR assessment exercise (Hamilton, 1984). However, strategies for exposure assessment change depending on the kind of data (information) available (Spengler and Soczek, 1984; Wallace, 1987). HR varies from area to area. It would be different in residential, commercial and industrial zones, and depends on the type of pollutants and the population characteristics and socio-economic profile of the region.

The present exercise estimates and assesses HRs due to different pollutants (SPM, NO_2 and SO_2) for three different age classes, viz. infants, children and adults under three different activity zones, namely, residential, industrial and commercial. The values turn out to be quite different for different zones, different pollutants and different age groups of population. Similar conclusions have also been drawn by several epidemiological studies carried out in other parts of the world (Neuberger et al., 2002; Cerna et al., 1998). Although these studies have not specifically quantified the age-specific HRs, their general conclusions are in consonance with our findings.

The present case study of Delhi City helps in ranking (relatively) different pollutants in terms of HRs which they are likely to pose. Results point out that HRs due to air pollution in Delhi are highest for children. HR for NO_2 and SPM are, respectively, 22.11 and 16.13 times more than that due to SO_2.

There is a strong need, therefore, for carrying out similar assessment studies for other cities too. This will entail generation of more precise site-specific information regarding environmental pollution and associated socio-economic features. Arising out of limitations related to monitoring and quality of data inputs, some uncertainties would always remain (Simpson, 1990). However, in general, controlling air pollution should be based on the responses of the most sensitive groups of persons (Goldsmith, 1968; Pandey et al., 1993). Under the circumstances, exposure studies should be designed to identify a specific population at risk, define norms for the people in general, and examine long-term effects of the reduction or increase of exposure to a contaminant (Ott, 1985; Wallace, 1987). Our present analysis, in particular, points out that children happen to be the most sensitive group. Therefore, our health research strategies should focus on their more systematic monitoring.

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