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Characterization of fine particulate matter in Ohio: Indoor, outdoor, and personal exposures

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Abstract

Ambient, indoor, and personal $PM_{2.5}$ concentrations were assessed based on an exhaustive study of $PM_{2.5}$ performed in Ohio from 1999 to 2000. Locations in Columbus, one in an urban corridor and the other in a suburban area were involved. A third rural location in Athens, Ohio, was also established. At all three locations, elementary schools were utilized to determine outdoor, indoor, and personal $PM_{2.5}$ concentrations for fourth and fifth grade students using filter-based measurements. Three groups of 30 students each were used for personal sampling at each school. Continuous ambient $PM_{2.5}$ mass concentrations were also measured with tapered element oscillating microbalances (TEOMs). At all three sites, personal and indoor $PM_{2.5}$ concentrations exceeded outdoor levels. This trend is consistent on all week days and most evident in the spring as compared to fall and winter. The ambient $PM_{2.5}$ concentrations were similar among the three sites, suggesting the existence of a common regional source influence. At all the three sites, larger variations were found in personal and indoor $PM_{2.5}$ than ambient levels. The strongest correlations were found between indoor and personal concentrations, indicating that personal $PM_{2.5}$ exposures were significantly affected by indoor $PM_{2.5}$ than by ambient $PM_{2.5}$. This was further confirmed by the indoor to outdoor (I/O) ratios of $PM_{2.5}$ concentrations, which were greater when school was in session than non-school days when the students were absent.

Keywords: $PM_{2.5}$; Personal exposure; Rural; Urban; CPF

1. Introduction

Fine particulate matter, or $PM_{2.5}$, refers to a mixture of solid and liquid atmospheric particles with an aerodynamic diameter (d_{ae}) less than or equal to 2.5 μm. It arises mainly from anthropogenic sources such as fossil fuel combustion by electric utilities and motor vehicles, wood burning, and the smelting or other processing of metals. $PM_{2.5}$ consists of sulfate, nitrate, ammonium, trace elements, carbon compounds, and water (Chow et al., 1994; Chow and Watson, 1998). The majority of $PM_{2.5}$ components are secondary materials, derived from the chemical reactions of gaseous precursors such as SO_2, NO_x, volatile organic compounds (VOCs), organic and elemental carbon, and a range of trace metals.

Recent environmental epidemiological studies suggest that ambient $PM_{2.5}$, measured at a fixed outdoor site, is more strongly correlated with adverse health effects than particles in other size ranges (Dockery et al., 1993; Schwartz et al., 1996; Pope et al., 1995; Liao et al., 1999; Spengler et al., 1996; Klemm et al., 2000; Pope and Dockery, 2006; Schlesinger et al., 2006; WHO, 2005a, b, 2006). The health effects range from slight respiratory symptoms to increased mortality rates. Certain population groups such as seniors, respiratory and cardiovascular patients, and children are most susceptible to particle pollution. To protect the general public from $PM_{2.5}$ pollution, the United States Environmental Protection Agency (USEPA) established a standard for the ambient $PM_{2.5}$ in 1997 (Federal Register, 1997).

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The associations between ambient $PM_{2.5}$ concentrations and a variety of adverse health outcomes suggest that ambient concentration may be an indicator for personal $PM_{2.5}$ exposure, and ambient $PM_{2.5}$ should correlate well with indoor and personal $PM_{2.5}$ concentrations (Wilson and Suh, 1997). However, studies have shown inconsistent correlations between outdoor, indoor, and personal $PM_{2.5}$ levels, with correlation coefficients (R) ranging from below zero to close to one (Wilson and Burton, 1995; Wallace, 1996, 2000; Watson et al., 1997; Wilson et al., 2000; Goswami et al., 2002; Allen et al., 2003). The large range of R-values, on one hand, reflects that personal $PM_{2.5}$ exposure is impacted by individual lifestyles (e.g. sedentary indoor vs. active outdoor type) and the characteristics of the microenvironment (e.g. poor vs. good ventilation), where the subjects spend time (Wallace, 1996, 2000). On the other hand, it suggests that the interpretation of ambient $PM_{2.5}$ concentrations as a proxy of personal $PM_{2.5}$ exposure is perhaps questionable. Since the total personal $PM_{2.5}$ exposure is a result of $PM_{2.5}$ concentrations in various microenvironments, a more accurate personal $PM_{2.5}$ exposure estimation is measured by a personal exposure monitor worn by the subject or obtained by averaging the time-weighted concentration of different microenvironments (Wilson et al., 2000).

Limited information is available regarding correlations between personal, indoor, and outdoor $PM_{2.5}$ concentrations. Most studies focus on senior subjects and respiratory patients, while only a few studies investigate children's personal $PM_{2.5}$ exposure and its relationships with indoor and outdoor levels (USEPA, 1996, 2001; Patterson and Eatough, 2000). Studies that focus on children are often conducted in homes, an environment quite different from a classroom (e.g. Janssen et al., 1999). This study evaluates the correlations between personal $PM_{2.5}$ exposures, indoor, and outdoor $PM_{2.5}$ concentrations, using data from a 2-year health-based study conducted in three elementary schools in southeastern Ohio. These data are part of the Air Pollution and Pediatric Health Impact Assessment (APPHIA) project. In this paper, temporal trends of $PM_{2.5}$ and the transport of ambient particulate pollutants were also studied to research the possibility of an inherent pattern in the outdoor, indoor, and personal concentrations of $PM_{2.5}$. This research provides valuable information in examining the relationship between personal, indoor, and outdoor $PM_{2.5}$ levels.

2. Methods

2.1. Study sites

This study was conducted in central and southeastern Ohio (Fig. 1) from January 1999 through August 2000. Two schools in Columbus (Koebel Elementary School and New Albany Elementary School) and one school in Athens (East Elementary School) comprised the monitoring sites. Approximately 30 students of fourth and fifth grades at each site were involved. The three elementary schools are in residential neighborhoods. Koebel is located to the south of Columbus in the industrial center of the city. The industrial activities include foundries, plastic facilities, and gravel/quarrying operations. This site is also located within 0.5 km of a major transportation artery. New Albany is approximately 8 km northeast of downtown Columbus in the Franklin County and is approximately 32 km northeast of Koebel. New Albany is a bedroom community of Columbus with few commercial facilities and no significant industrial operations within the municipal boundary. Since the prevailing winds are from the southwest, transport of $PM_{2.5}$ precursors from the Columbus area may influence the particle pollution at this site.

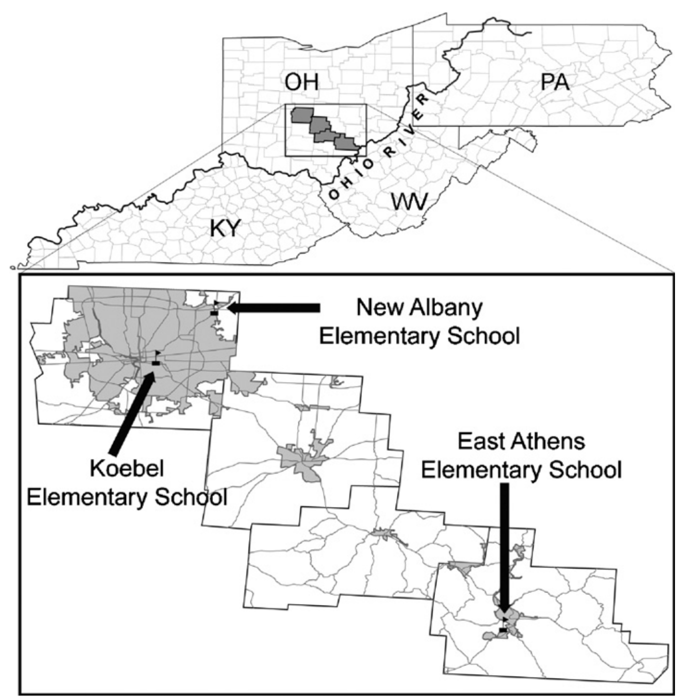

Fig. 1. Locations of the three sites involved in the study.

The third site, Athens, is approximately 120 km southeast of Columbus and is a rural location. Athens is a university town with a population of 20,000. The site is in a residential area and the only significant local stationary pollution source is Ohio University's coal-fired power plant. Athens is about 32 km west of the Ohio River Valley, which has numerous coal-fired power generation facilities, chemical manufacturing facilities, and industrial operations. Athens is an upwind remote site for the Department of Energy's Ohio River Valley $PM_{2.5}$ monitoring projects (Ambient Monitoring, The Upper Ohio River Valley Project (UORVP)).

The Koebel School is a one-story building while the New Albany and Athens schools are both two-storey buildings. Classrooms at each elementary school used for indoor monitoring were selected as far as possible from the kitchen facilities to reduce the impact of cooking-generated $PM_{2.5}$. The classrooms at Athens and New Albany are air conditioned. Koebel elementary school has a central heating system but no central air conditioning system. All three schools use natural ventilation during the warm months, so classroom windows are typically open during the months of April, May, June, September, and part of October. With central air conditioning, Athens and New Albany may close their windows during very warm days. However, windows are open a majority of the school days during the spring and fall.

2.2. Measurement methods

The monitoring scheme is outlined in Table 1. Personal, indoor, and ambient $PM_{2.5}$ concentrations were measured concurrently at all sites using Whatman 37, 37, and 47 mm Teflon filters with 2-μm pores size, respectively. In addition, continuous ambient $PM_{2.5}$ measurements were also conducted.