Section 1, Introduction

The relationship between air pollution and human health has attracted the attention of the public, scientists, and policy makers worldwide. Despite the mounting evidence identifying a relationship between air pollution and negative health effects, few data are available to make informed decisions in Ohio. Epidemiological data from one region are not necessarily applicable to another; therefore, it is necessary to evaluate air pollution levels and their influence on public health as it relates to specific geographic regions.

Although the adverse health effects of some air pollutants have been extensively studied, data on the relationship between fine particulate matter, PM$_{2.5}$, and public health are still somewhat limited. This gap in the data is important considering that fine particulate matter may impose a considerably greater health threat than other air pollutants. This imposing threat is due to the origin and size of PM$_{2.5}$, which allows it to be inhaled more deeply into the lungs than the components of larger particulate matter.$^{1}$

Recognizing the gap in the data about the health effects of fine particles, the need for geographically-based research, and the emphasis on children’s health issues, the Ohio Environmental Protection Agency (EPA) issued a requests for proposals (RFP). Responding to the RFP researchers at Ohio University and Texas A&M University initiated the Air Pollution and Pediatric Health Impact project. This project was designed to study the health status of affected populations through a series of non-invasive health assessment methods. The project has two components: prospective and retrospective.

LITERATURE REVIEW

Past research about air pollution and human health effects include studies that have examined the relationship between air pollution and mortality rates, pulmonary and cardiovascular effects of particulate matter, including short and
long term influences of various air pollutant components on human health. Additional research examines the effect of air pollution on human health in susceptible populations, such as children, the elderly, and patients with various pulmonary and cardiovascular diseases.

**Air pollution and mortality**

Associations between air quality and mortality rates have been widely studied with respect to ambient levels of particulate matter. The results of these studies have been surprisingly consistent considering that this research has occurred in various parts of the world.

Studies of daily mortality and PM$_{10}$ levels in Utah Valley found that mortality averaged 4-5 percent higher than normal for each 50 µg/m$^3$ incremental increase of PM$_{10}$ on the same day. Furthermore, mortality rates averaged approximately 6-8 percent higher than normal for each 50 µg/m$^3$ incremental increase of five-day lagged moving average of PM$_{10}$.

The Harvard Six-Cities Study is one of the most prominent to compare the health effects of coarse (PM$_{10}$) and fine (PM$_{2.5}$) particles. The results of the six-city study point to a significant correlation between cause-specific mortality and size of particulate matter. Specifically, a slight increase of PM$_{2.5}$ was associated an increase in pneumonia, COPD, and ischemic mortality rates. The study also stressed the importance of the PM and ischemic heart disease mortality association by suggesting that PM-related mortality is a major component of death due to ischemic disease. The Six City Study was replicated by other researchers with similar results.

The population in the Harvard Six Cities Study was the basis for a comparative study of the health effects of air pollution from several communities. This study revealed an association between mortality due to respiratory diseases and air pollution levels and no association between air pollution and deaths from other all causes considered together. Furthermore, mortality was most strongly associated with exposure to fine particulate matter.

Other countries with different climate and pollution patterns than those in the U.S have also demonstrated associations between air pollution and increased mortality risk. In the Netherlands, researchers have demonstrated an association between total daily mortality and levels of PM$_{10}$, black smoke, O$_3$, SO$_2$, and NO$_2$. Research in South Korea also identified a relationship between respiratory-related mortality and ambient levels of PM$_{10}$, SO$_2$, and CO. One study in the Toronto area demonstrated statistically significant associations between PM, O$_3$, and various categories of daily mortality.

Additional research suggesting that PM$_{2.5}$ has greater impact on daily mortality than PM$_{10}$ was completed in Chile and Philadelphia,
Pennsylvania. The researchers in the Philadelphia study argue that, in the northeastern United States, PM\textsubscript{2.5} exacerbates adverse health effects associated with PM\textsubscript{10}.

Not all research has shown a statistically significant relationship between PM and specific health outcomes. For example, a study conducted in California did identify a relationship between various sizes of particle matter and cardiovascular mortality; however, there was no observed relationship between fine particles and respiratory mortality. Similarly, research conducted in Melbourne from 1991-1996 did not identify an association between PM\textsubscript{10} and PM\textsubscript{2.5} and mortality levels. The Melbourne study attributed respiratory mortality in the summer period to photochemical smog.

The inconsistency in the findings of the California and Melbourne studies with earlier research may be attributed to different statistical models, inclusion of different co-pollutants, weather covariates, and confounding problems. To address some of these factors Schwartz analyzed confounding factors, effect modification, and thresholds in the association between ambient particles and daily mortality. He found an association of daily deaths with airborne particulate pollution that cannot be attributed to any other air pollutants.

Schwartz also identified a higher association between air pollution and outpatient mortality than with hospital mortality. This finding suggests that increased cardiopulmonary mortality risk of non-terminally ill patients may be attributed to airborne air pollutants. Schwartz concluded that interventions that decrease average levels of particulate matter benefit public health better than those that address peak pollution days.

Exposure to particulate matter in the ambient environment is not the only exposure of concern. There is evidence to suggest that people are exposed to higher levels of PM in indoor air than outdoor air. Possible mechanisms for increased indoor exposure include smoking, dusting, vacuuming, and cooking and there is recent research suggesting that indoor air pollution may contribute to infant mortality. Hence, there is the need to further study both outdoor and indoor personal exposure to particulates.

**Air pollution and morbidity**

Short and long term effects of air pollution on human health have been of special interest to many researchers. Adverse health effects associated with air pollution include the exacerbation of chronic pulmonary diseases, an increase in pulmonary symptoms, and increase in respiratory and cardiovascular distress. The indicators for morbidity are largely tied to hospital admissions, emergency room visits, school absenteeism, and peak flow measurements.
Air pollution and respiratory health

Numerous studies have used hospital admissions to demonstrate the negative respiratory health effects of air pollution. For example, a time-series study in Southern Ontario analyzed the relationship between air pollution and respiratory hospital admissions. Data on \( \text{SO}_2, \text{SO}_4, \) and \( \text{NO}_2 \) were correlated with the number of hospital admissions in winter and summer. A significant relationship was noted between air pollution and hospital admissions for both children and the elderly.

Another Ontario study focused on the effects of acid aerosols on respiratory admissions during the summer, finding a significant correlation between \( \text{O}_3, \text{SO}_4, \) and \( \text{H}^+ \) and hospital admissions due to acute respiratory symptoms and asthma. The relevance and importance of this study was that it demonstrated a correlation between hospital admissions and fine, rather than coarse, particulate matter.

Schwartz is one of the most active researchers involved in studying the health effects of air pollution. He has reported an association between \( \text{PM}_{10} \) and increased hospital admissions for elderly patients with respiratory diseases, including pneumonia. In examining asthma, he noted that emergency room visits due to asthma is correlated with increased concentrations of \( \text{PM}_{10}. \)

Air pollution and cardiovascular health

Some studies have analyzed hospital admissions for the relationship between air pollution and cardiovascular conditions. Associations have been noted between hospital admissions for cardiac conditions and air pollution regardless of age, gender, or time period. Specifically, both respiratory and cardiac admission rates increased with increasing concentrations of sulfates (\( \text{SO}_4 \)).

Other studies support the relationship between cardio-respiratory hospital admissions and \( \text{PM}_{10} \) among elderly patients and between particulate air pollution and hospital admissions for all respiratory and cerebrovascular conditions on the same day. Levels of all ambient air pollutants have been associated with cardio-respiratory hospital admissions. However, there appears to be a relationship between hospital admissions and mean particulate matter concentrations as well.

Fine Particles and Chemical Components

Since there is little data on ambient levels of \( \text{PM}_{2.5} \), \( \text{PM}_{10} \) is considered an indicator for finer particles. Respiratory symptoms such as coughing, wheezing, phlegm production are related to both pollutants. While research
suggests that adverse health effects of PM$_{10}$ and PM$_{2.5}$ are similar; effects of PM$_{2.5}$ are more cumulative than PM$_{10}$. Hence, PM$_{2.5}$ may more realistically relate to potential adverse effects of particulate exposure.\textsuperscript{30} Also, due to a longer lifetime and indoor penetration of PM$_{2.5}$ it may be a better indicator of overall (indoor plus outdoor) personal exposure to ambient pollution.

There is a correlation among chemicals coming from the same emission source, so, it is difficult to separate the health effects of particulate matter and other chemical substances. Nevertheless, previous research has analyzed adverse health effects specifically from aerosols including O$_3$, NO$_2$, SO$_2$, and SO$_4$. Upper respiratory infections in children have been associated with high levels of SO$_2$, NO$_2$, particulates, and hydrogen sulfide in Finland.\textsuperscript{31} Another European study showed that children from more polluted areas had a higher frequency of respiratory symptoms and diseases than their peers in less polluted areas.\textsuperscript{32} Severe asthma attacks have been found to be associated with air pollutants, especially NO$_2$.\textsuperscript{33}

\textbf{Air Pollution and Health of Susceptible Populations}

It is generally accepted by the medical community that children are highly susceptible to adverse health effects from air pollution exposure.\textsuperscript{34} However, research regarding the relationship of fine particles and morbidity are somewhat controversial, and the available data is still limited. Limited experimental studies on different deposition patterns of PM, based on age, have attempted to explain increased susceptibility to the adverse effects of PM in children and the elderly. Results range from showing no age-dependent deposition patterns to a slightly higher deposition in children than adults.

There is evidence of an association between COPD admissions of children and elderly patients and NO$_2$ and particulates.\textsuperscript{35} In particular, childhood asthma has shown significant correlations with levels of NO$_2$. In addition, the increase of 1-hour maximum PM concentration was associated with a 5.29 percent increase in hospital admissions of asthmatic children and a 4.6 percent increase in COPD admissions. Increased levels of NO$_2$ concentrations, increase 1-hour max ozone concentrations, and daily mean particulate concentrations were respectively associated with a 6.71, 2.45, and 2.82 percent increase in hospital admissions of elderly people with cardiac diseases.

According to the Behavior Risk Factor Surveillance System (BRFSS), asthma in the United States is one of the “most common chronic diseases.”\textsuperscript{36} Asthma is more prevalent among blacks and lower income people than other groups. Examining asthma prevalence in children underscores the fact that this illness is a major public health problem. According to the Centers for Disease Control and Prevention, since 1980, the prevalence of childhood asthma has increased “dramatically.”\textsuperscript{37} Excluding accidents, asthma is the leading cause of
children’s emergency room visits. These facts emphasize the need to investigate environmental factors endangering children’s health.

The negative impact of air pollution on pediatric health starts early and may even begin before the child is born. One study identified an influence of PM$_{10}$, PM$_{2.5}$, and other associated air pollutants on fetal growth in the early gestation period. Both PM$_{10}$ and PM$_{2.5}$ exhibited significant correlations with retarded intra-uterine growth that negatively affects the structure and function of a range of organs and tissues including the pulmonary system.

The correlation between air pollution and health status of asthmatic children was extensively studied in a sample of asthmatic children living in Mexico City, which has a reputation as one of the most polluted cities. Emergency room (ER) visits of asthmatic children are associated with ozone and SO$_2$ levels. Specifically, an increase of 50 ppb in the 1-hour ozone level lead to a 43 percent increase in the number of ER visits on the following day. Ozone level increases of more than 110 ppb for two consecutive days led to a 68 percent increase in ER visits. Sulfur dioxide (SO$_2$) concentrations were also related to respiratory ER visits, including asthma. Additional studies with active children in Mexico City showed significant decreases in lung function during exposure to high levels of ozone. The study also stated that despite chronic exposure to high levels of ozone, exercising children responded acutely to a 1-hour exposure of ozone above 150ppb.

Additional studies with youth have been completed in Seattle, Hong Kong, southern California, South Karelia, and with college students. These studies report associations between respiratory responsiveness in children and air pollution. In the Hong Kong study, respiratory function improved after a regulation restricting the concentration of SO$_2$ in fuel to 0.5 percent was imposed. In one German study, the researchers concluded that SO$_2$ is related to bronchitis in children; however, although SO$_2$ and PM are correlated, there was no relationship between particulates and bronchitis. The German researchers explain that additional research is needed to examine relationships between particulate matter and health effects in children.

Norris and colleagues (1999) studied the association between fine particles and asthma emergency department visits for children in Seattle. Significant associations were found between fine particulate matters, CO, SO$_2$ and emergency department visits of children from the inner city. The associations between emergency room visits and air pollution have also been noted in Santiago, Chile. The Chilean study reported a stronger association between fine particles and children respiratory illness than with coarse components.

Although there are numerous studies regarding the health effects of ozone, the majority deal with acute health effects. Due to the complexity of personal exposure measurement there still is ambiguity regarding the chronic effects of
ozone and its mechanism of action. Geyh and colleagues studied chronic ozone exposure of children in two California communities.\textsuperscript{49} The study measured outdoor, indoor, and personal exposure of 224 children from mountain and upland areas in southern California for the period from 1995 to 1996. In addition to wearing personal ozone samplers, children kept personal activities dictionaries; parents completed questionnaires characterizing each participant’s house. The study revealed considerable differences between outdoor, indoor, and personal ozone exposure. Children from mountain areas experienced higher outdoor, indoor, and personal exposure during ozone periods. Boys experienced higher exposure than girls.

There is evidence that socioeconomic factors are related to increased asthma morbidity in children, especially in relation to home allergens. Studies have shown that family income, maternal education, and race-ethnicity factors are associated with levels and types of indoor air allergens.\textsuperscript{50} These factors should be considered when analyzing asthma morbidity data for urban communities.

Schwartz analyzed possible reasons for elevated asthma and wheezing rates among black children as compared to white children.\textsuperscript{51} The study showed that higher exposure to environmental pollution is one of the reasons for higher asthma morbidity rates among black children. Low-income areas experience higher per capita exposure to ozone above National Ambient Air Quality Standards and consequently, higher respiratory disease rates than high-income areas.

In one survey of 5,072 students using an adapted WHO Childhood Respiratory Questionnaire, students of urban areas had consistently higher rates of respiratory symptoms and diseases than students living in rural communities.\textsuperscript{52} Although the study suggested a relationship with ambient air pollution, it could not confirm a causal relationship due to many confounding factors and recommended further research. Additional research demonstrates that mean lung function growth rate is lower among children living in more polluted urban areas.\textsuperscript{53}

A study by Weaver and colleagues supports that exposure of children to various environmental factors requires further extensive study.\textsuperscript{54} Potentially increased absorption of air pollutants by children can be attributed to high hand-to-mouth activity, different levels of metabolism and dermal exposure. The study also stressed the importance of further research of the health of urban children and their exposure to specific pollutants such as benzene and volatile organic components.

Reliability of results is of great concern when a study investigates cause and dose-response relationships between air pollution components and human health. However, the aforementioned studies showed consistency in findings
regarding the positive relationships between air pollution and adverse health effects, despite the variety of geographic areas, climates, air pollution components, groups, and health effects that were studied.

**Biological Mechanisms of Adverse Pollution Effects**

Neas summarized several toxicological studies related to short and long term cardiopulmonary PM effects. Physical characteristics such as gravimetric mass, particle number, size, and surface area are important properties of particulate matters responsible for persistent pulmonary inflammation. Chemical characteristics of PM have direct effects on organs in which they are deposited. Acidity has been shown to have a direct negative impact on airways and alveoli. Biological characteristics such as the presence of endotoxins may trigger immune mediated inflammation that decreases pulmonary function. Further reduction of pulmonary capacity among individuals with previously reduced pulmonary function (e.g. asthmatics, patients with pulmonary diseases, the elderly) can result in ER visits, hospitalizations, or even death.

Brief intense airborne exposure deposits tremendous amounts of particles in alveolar cells. Inhibited particle clearance results in prolonged internal pulmonary exposures. Persons with damaged clearance mechanisms such as asthmatics may clear fine particles less efficiently than normal individuals, thereby, increasing their internal exposure to pollutants. Finally, prolonged exposure to fine particles may lead to irritation and potential reduction in alveolar surface area responsible for gas exchange. Consequently, these changes may cause cardiopulmonary stress, cardiac arrhythmias, and apneas.

**ORGANIZATION OF REPORT**

The remainder of this report is organized into three sections. Section 2 focuses on the prospective health study and includes three chapters: 1) particulate matter measurements; 2) chemical characterization of particulate matter; and 3) health evaluation of study participants. Section 3 contains two chapters: 1) retrospective evaluation of air quality data; and 2) evaluation of hospital admissions and air quality data. Section 4 focuses on air toxics monitoring at the study sites.
NOTES


6. See note 5 above.

7. See note 1 above.


18. See Dab et al. in Note 2 above.


23. See Schwartz et al., 1993 in Note 2 above.


27. See Wordley et al., 1997 in Note 2 above.


35. See Note 25 above.


37. MMWR, Measuring Childhood Asthma Prevalence Before and After the 1997 Redesign of the National Health Interview Survey --- United States, *MMWR* 49 (2000); 40, 908-911.


42. C. Wong, T. Lam, J. Peters, A. Hedley, & S. Ong, Comparison between two districts of the effects of an air pollution intervention on bronchial responsiveness in primary school children in Hong Kong, *Epidemiological and Community Health* 52 (1998); 571-578.


