Environmental Risk Factors for Asthma Emergency Care:
A Multilevel Approach for Ecological Study

By

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Abstract

ENVIRONMENTAL RISK FACTORS FOR ASTHMA EMERGENCY CARE: A MULTILEVEL APPROACH FOR ECOLOGICAL STUDY

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This cross-sectional, retrospective ecological study describes a model for evaluating environmental risk factors to explain neighborhood differences in adult use of New York City's Harlem Hospital Asthma Emergency Department (Asthma ED) services. A multilevel or "nested" design incorporates methods for hypothesis testing using geographic information systems (GIS) to help map existing data from Harlem Hospital Center, city agencies, and other sources; as a tool to screen for clusterings of residences associated with increased visits to the Asthma ED; to facilitate the definition of environmental variables, and for creating new spatial districts to be used as units of analysis.

Spatial data analysis accomplished with the aid of GIS and point pattern analysis revealed clusterings of addresses for Asthma Emergency Department visitors. Multilevel modeling offered the means whereby variables measured on the building and / or neighborhood levels of analysis could be analyzed for their direct effects on the health outcome (asthma visits) while accounting for the influence of other variables and partitioning the variance between variables to manage multicollinearity, or correlations between explanatory variables.

Buildings and segments were classified according to whether they ran in a north-south or east-west direction to facilitate analysis.

Results of modeling show both building and neighborhood level effects of environmental variables on increased Asthma Emergency Department (ED) visits. Variables found to have a direct effect on Asthma ED visits included building violations, pollution sources, segment density, and corner location of a building with models differing by geographic direction of streets and level of analysis. The study points to the importance of examining the influence of environmental factors at different spatial scales for a deeper understanding of ecological conditions which may lead to asthma exacerbation and increased Emergency Department use. Specific policy implications are proposed to improve the health outcomes of inner-city residents with asthma.

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CHAPTER I: INTRODUCTION

The Harlem communities of New York City have had among the highest asthma mortality rates in the US (Corn, Hamrung, Ellis, Kalb, & Sperber, 1995). While a number of risk factors have been associated with overall trends of increased asthma morbidity and mortality over the past 25 years, particularly striking are reports documenting how low-income people from African-American and Latino ethnic backgrounds living in large cities and inner-city neighborhoods are disproportionately affected by the condition (Call, Smith, Morris, Chapman, & Platts-Mills, 1992; Corn et al., 1995; Lang & Polanski, 1994; Malveaux, Houlihan, & Diamond, 1993; Marder, Targonski, Orris, Persky, & Addington, 1992). Research is providing increasing evidence that neighborhood properties play an important role in residents' risk for disease.

Various aspects of the urban environment have been associated with triggers that exacerbate asthma. For example, residents of urban low-income neighborhoods can be disproportionately exposed to higher levels of outdoor pollution as well as indoor air pollution, in part a result of poor housing conditions and outdoor pollution becoming trapped inside (EPA, 1995a). An impressive body of research has documented the effects of exposures to allergens and irritants from single sources; there has, however, been limited research and less understanding of community ecological conditions that foster these exposures.

Given the substantial role that environmental variables can play in asthma symptomatology it is important to develop methodologies to include contextual information towards a better understanding of asthma symptom exacerbation. This retrospective study examines housing and neighborhood environmental conditions as a way to explain patterns of Asthma Emergency Department (ED) use in Central Harlem, part of an “asthma belt” that runs from the South Bronx and is characterized by a high concentration of pollution sources and diesel buses (Fraser, 1999). Working on the assumption that Asthma ED patients spend substantial residential time at addresses they report to the Emergency Department, the research methods rely on a combination of geographic information system (GIS) applications, spatial data analysis, and multilevel modeling to define and analyze measures of environmental exposure aggregated at different geographic scales. By considering the effects of building and neighborhood characteristics interventions may be designed that address the role of community factors as well as the individual in asthma management.

The following literature review provides background on the many environmental links that have been associated with asthma exacerbation and focuses on those that have the most relevance to the urban locale of the study area. Ecological factors important for understanding health outcomes are discussed followed by a comparison of methods that have been applied by different disciplines to investigate health and illness patterns that can vary over geographic area and units of time. Finally, study objectives are outlined, hypotheses presented, and research questions are posed to guide the research.

Environmental Correlates of Asthma

It is well established that allergic reactions are often the basis for asthma symptoms arising from exposure to biological agent allergens and to some non-biological chemical irritants as well. Illness may come as a result of sudden and intense exposure, a lag or delay in response to exposure, sensitization over time, concomitant exposure to other irritants or allergens, or in combination with temperature and climatic conditions (Brooks, 1995; Cullinan & Newman Taylor, 1994). Exposures can originate from indoor or outdoor sources.

Biological Agents

Biological allergens commonly found outdoors such as pollens and mold spores have long been associated with asthma symptoms (NHLBI Guidelines, 1991). Moisture is critical for the growth of microorganisms and mold from either outdoor or indoor sources and is associated with humidifiers, air conditioning systems, and water damage (Samet, Marbury, & Spengler, 1988). In addition, all warm-blooded animals can potentially cause allergic reactions as well. Small rodents, birds, dogs, and cats produce allergens from different bodily excretions including urine, feathers, fur dander, and saliva. Rodents and in particular male rats characteristically excrete protein through their urine, an agent thought to contribute to asthma (EPA, 1992). While some allergic people have shown positive skin test reactions to rodent urinary proteins, there is a dearth of research to establish the significance of such a relationship. Findings from the Harlem Center for Health Promotion and Disease *Harlem Household Survey,* however, have revealed a strong relationship between complaints about rats and mice and residents' reports of asthma (i.e., the chances of having an association over not having an association, or the Odds Ratio, was 1.7. D. McClean, personal communication, January 16, 1997). Dust mite allergens, found in both suburban and urban areas, have also been associated with asthma symptoms with mite growth varying with the season and indoor humidity (Platts-Mills, Hayden, Chapman, & Wilkins, 1987).

The connection between cockroach allergens and asthma has received increasing attention in the research literature. High concentrations of cockroach allergens are present in the feces, skins, and nest debris of the insects; exposure can trigger positive asthma responses in individuals who have been sensitized (Gelber, Seltzer, Bouzoukis, Pollart, Chapman, & Platts-Mills, 1993; Kang, 1976; Kang, Wu, & Johnson, 1992; Rosenstreich, Eggleston, Kattan, Baker, Slavin, Gergen, Mitchell, McNiff-Mortimer, Lynn, Ownby, & Malveaux, 1997).

Non-Biological Asthma Triggers

Irritants and pollutants found both inside and outside of the home have also been associated with triggering asthma symptoms. Oxidants such as sulfur dioxide, ozone, and nitrogen dioxide from outdoor sources and chemicals from cleaning products, fresh paint, colognes & perfumes, and other indoor sources can irritate airways and exacerbate asthma symptoms (Koenig, Covert, Hanley, Van Belle, & Pierson, 1990; NHBLI, 1991; Utell & Looney, 1995). Many carbon-based chemicals known as volatile organic compounds (VOC) that release gases into the air have also been directly associated with airway irritation (Norback, Bjornsson, Widstrom, Bowman, 1995). Formaldehyde is present in materials such as particleboard, paneling, sub flooring, paints, cigarette smoke, and in unvented combustion appliances such as gas stoves and kerosene space heaters (EPA, 1995b). Particulate matter, especially the smaller respirable components (PM 10 & PM 2.5 micrometers in diameter) associated with combustibles, smoke, and diesel exhaust can remain in the air for days to weeks and can carry toxins deeply into the lungs.

Seasonal Influences on Ecological Patterns

Characteristics of the different seasons can also be linked to changes in patterns of social and behavioral activity and asthma exacerbation. For example, summer months are characterized not only by greater amounts of ozone due to sun interactions with by-products of outdoor combustion sources but also by residents' increased time spent out-of-doors and exposed to outdoor pollution, molds, and foliage. Fall may be characterized not only by certain pollens, ragweeds, and molds but also by increased precipitation, incidence of viral infections, and fluctuations between warm and cold days influencing residents' exposure to outdoor and indoor air. Similarly, springtime brings exposure to certain grasses and pollens as well as shifts in temperatures (American Academy of Allergy Asthma and Immunology, 2005). During winter months residents may spend more time indoors and be more exposed to indoor air. Carbon monoxide levels (which can easily penetrate the indoor environment) are higher outside due to less-efficient auto emissions (Ostro, Lipsett, Wiener, & Selner, 1991) and heating systems release by-products of operation or do not function at all.

Potentiation And Synergism

While chemical irritants can act alone as triggers they can also enhance sensitization to other triggers; chronic and/or acute exposures may serve to potentiate the lungs and maintain a state of bronchial hyperactivity (Utell & Looney, 1995; Seltzer, 1994). Exposures to many contaminants can occur either simultaneously or sequentially and can vary with humidity, wind direction, season, type of the building, materials, building condition, ventilation, occupant activities, etc. Thus, the effects of allergens and irritants on the lung are mediated by a number of variables and interactions including the extent to which the allergens become airborne and the extent of mixing and distribution with other air (Ministry of Environment, Lands and Parks, 1995). Lindfors, Wickman, et al., (1995), found a significantly increased risk for asthma among children aged 12-48 months who were sensitized to dog or cat allergen and were exposed to high doses of allergen, second hand tobacco smoke, and damp housing (typically defined by level of humidity or signs of mold or condensation, Odds Ratio 8.0, with Confidence Interval 1.9-34.1, $p<0.01$). Tobacco smoke alone or in conjunction with other triggers has also been linked to asthma exacerbation in adults.

Ecological Risk Factors

Identifying environmental sensitivities for people with asthma is an important step for management of the condition. Asthma management in everyday living settings becomes a challenge to not only identify the triggers present but to address the complexity of multiple potential triggers and the conditions under which asthma becomes an emergency condition. Many environmental agents associated with asthma symptoms have been identified in housing and neighborhood settings and their significance can vary with characteristics such as geography, climate, and built environments (Call, et al., 1992; Sarpong, Wood, & Eggleston, 1996; Yocum, 1982). As an illustration, high concentrations of cockroach allergen have been found in lower income residences and in apartments more than in individual homes (Roberts, 1996; Wickman, Nordvall, Pershagen, Sundell, & Schwartz, 1991). Roaches will migrate from focal points of infestation in storerooms, basements, laundry areas, and specific apartments or from reservoir populations in nearby refuse accumulation, sewer systems, warehouses, and other harborages to areas that have better sanitation (Frantz, 1981). Exposure to higher levels of cockroach allergen may be more of a risk factor for residents of urban areas while for residents of suburban areas exposure to high levels of cat dander poses a greater risk than roach allergen (Gelber et al., 1993). Lower income residents with asthma living in urban areas were found to demonstrate high rates of sensitivity to cockroach allergen (Kang, et al., 1992; Sperber, Kendler, Yu, Nayak, & Pizzimenti, 1993) although there is some evidence that the relationship may be influenced more by socioeconomic status than by geographic residential area (Sarpong, Hamilton, Eggleston, & Adkinson, 1996). Generally, neighborhood physical conditions such as vacant or boarded up buildings have been related to poor health outcomes Independent of the effects of socioeconomic status (Cohen, Mason, Bedimo, Scribner, Basolo, & Farley, 2003). The authors offer potential explanations for this phenomenon. First, resources available in the area may influence conditions of health and illness. Businesses and services distant from neighborhoods in decline with multiple vacant properties can result in some degree of social isolation for residents of affected neighborhoods. The effects of this isolation may be that local infection rates, in this case of colds and flu, rather than individual behavior expose individuals to conditions that can trigger asthma. In addition, sicker people with minimal resources may occupy these areas while healthier people or those with greater resources may have been able to move away or otherwise gain access to necessary services.

Neighborhood context and segregation. Polednak (1997) has also suggested the effects of greater segregation on increased Black mortality rates as operating through neighborhood and housing variables. The variables include quality of air; water; housing stock; neighborhood sanitation, safety, and other services; noise control; community political and economic power structures; discrimination; and crime rates. Geographic distribution of poverty may be related to neighborhood and housing variables in such a way as to reflect the stratification of poverty rates and concentration of lower income groups in poor quality neighborhoods. Acevedo-Garcia and Lochner (2003) remind researchers that population groups can be segregated by race, ethnicity, social class, sex, and/or age and that residential segregation may be defined by different spatial dimensions including concentration, clustering, isolation, unevenness, and centralization. Through a variety of channels, a region's lack of economic resources can affect the maintenance of healthy community conditions that facilitate people's abilities to avert illness.

The US Environmental Protection Agency recognizes that residents of urban low-income neighborhoods can be disproportionately exposed to higher levels of indoor air pollution, in part a result of outdoor pollution and poor housing conditions and that low-income, predominantly Black and Latino minority communities typically "bear disproportionately high and adverse human health and environmental effects from pollution" (EPA, 1995a; p. 1, EPA, 1996). Environmental racism describes the inequities of site decisions, zoning of polluting industries, and clean-up of contamination (The Public Health Institute and Labor Institutes, 1998). The concentration of inordinate numbers of pollution sources in low-income ethnic minority neighborhoods has been condemned by environmental justice organizations as a form of discrimination. The Harlem communities are home to a concentration of parking facilities, hazardous waste sites, and diesel bus depots, sewage treatment plants, coal-burning industrial incinerators, and a deteriorating stock of old buildings (Fraser, 1999) creating the context for greater exposures to health contaminants. Most recently, the Office of the Public Advocate for the City of New York (2003) reports that there are higher instances of asthma, among other illnesses, for all 21-community neighborhoods of the city's five boroughs (as defined by the United Hospital Fund, a widely used zip code based administrative unit) that contain Superfund sites. Superfund sites contain the most hazardous accumulations of toxic waste in the United States. Such environmental degradation has fueled the resurgence of public health researchers' argument that community characteristics be included in multilevel research designs which can help manage data on different levels of analysis toward a greater understanding of health outcomes (Acevedo-Garcia, Lochner, Osypuk, & Subramanian, 2003; Susser, 1996).

Geographic Scale and Ecological Studies

The study of disease as it relates to geographic features is based upon the assumption that knowledge about spatial patterns of disease can help identify possible factors that may predispose an area to greater prevalence of the condition (Mayer, 1983). Mayer (1983) has suggested that mapping strategies can contribute to greater understanding of diseases through the identification of possible factors related to causation and in the development of indicators of relationships between places and disease. This later function serves to help eliminate hypotheses generated through other methodologies when relationships between potential factors and disease do not consistently appear.

An earlier study using census tract data to show relationships between the distribution of community characteristics in Central Harlem and morbidity patterns (Gesler, Todd, Evans, Casella, Pittman, and Andrews, 1980) and Goldstein & Arthur's 1978 identification of an "asthma alley" in Brooklyn, New York are local examples of research that identifies spatial patterns of illness. Other, more recent applications of spatial analysis in the study of asthma and environmental factors reported relationships between adult asthma, proximity to point sources of pollution and commercial roadways as well as distance decay effects of decreased risk of asthma with further distance from the sources of pollution in Buffalo, NY (Oyana, Rogerson, & Lwebuga-Mukasa, 2004).

Methodological Distinctions

A number of disciplines have developed distinctive approaches toward ecological and spatial health research. Medical geography uses geographic methods and information about spatial structures in the analysis of health and disease. While the broader field of spatial analysis is concerned generally with the quantitative study of disease distributions and patterns of health care service delivery, spatial data analysis is a more narrowly defined statistical approach. Spatial data analysis uses observational data based on the outcome of a disease process across an area to help identify potential underlying spatial organization or structures that may be related to the disease. (Gatrell & Bailey, 1996). Most approaches in medical geography view disease from an ecological perspective as a product of environmental, social, cultural, and biological interrelations. The geographic study of health and disease builds upon those influences by integrating social interests with information about distance, time, and separation and is thus capable of incorporating a perspective of the day-to-day activities of the place. Kearns (1993) describes the topic of the geography of health as focusing on the relationships between health and people's emotional, psychological, and physical experience of a place, an orientation more recently evolving in medical geography. This emphasis considers the impacts of population health and health services on the vitality of social places.

Epidemiologists traditionally focus on disease occurrence in populations and have used geography to assist in the detection of disease causation and to examine the distribution of disease in space and time among population groups (Mayer, 1982). Environmental epidemiology in particular has focused on associations between human exposures to contaminants in community or occupational settings, which are outside of the individual's control, and the potential biologic effects of these exposures (Marsh, 1995). Studies are generally classified into one of 3 distinct categories or scopes of analysis: the first is based on existing routine and easily accessible exposure and health outcome records; a second requires the collection of more precise data inclusive of information on potential confounding factors. Category three involves more long-term studies (Marsh, 1995). Studies can incorporate aspects of one or all three levels and can involve exploratory or confirmatory methods. Mapping used for these purposes has typically involved only basic descriptive statistics such as the plotting of data with little attention to issues of scale or spatial analysis.

There has been some indication that other medical and social sciences are beginning to replace established mechanistic cause-effect constructions with recognition of the existence of multiple antecedent conditions operating individually and synergistically (Mayer, 1983). Conventional causal analysis concepts can present a number of different theoretical conditions but the basic "same cause, same effect" principle advances the idea that the effect is generalizable over time and place, is always the same, won't be produced without the identified cause, and the very presence of disease implies the presence of the cause (Franck, 2003). Work with more contemporary chronic diseases such as coronary heart conditions, cancers, ulcers, and asthma, however, has revealed the multicausal nature of these illnesses and has called for new models to account for social and environmental influences on the incidence of many diseases (Diez Roux, 2003).

The field of Environmental Psychology and its emphasis on human and environment relationships is well suited to help advance the understanding of ecological characteristics and their role in explaining patterns of disease occurring in communities. In studying both the processes and results in which physical environments influence and are influenced by political, social and individual activities the approach helps make salient underlying 'textures' of human - environment relationships. Patterns of environment-behavior activities (e.g., hospital emergency department utilization, local seasonal influences on indoor vs. outdoor use of space, reports of and responses to housing and health violations) as well as departures from those patterns may reveal important features of community life that can help explain a health phenomenon. Environmental Psychology not only recognizes the implications of transactional relationships for human well being in physical and social networks but also has access to a wide array of research strategies that facilitates a creative approach to exploring complex relationships. Methods can evolve through an iterative process in which information generated along the way helps guide prospective steps in the research design. Using more diverse and flexible approaches, health research objectives may be advanced through a better understanding of underlying relationships between the physical community, social and civic activities, and individual health.

As noted earlier, environmental epidemiology and medical geography are among the disciplines that have incorporated information on time and space into health research. Ecological studies represent one area of research design that works not with individual disease and exposure relationships but with aggregated data and data organized at a specific scale or geographically defined area at a particular time. The availability of aggregated data essential to ecological research for small area or comparable studies, however, is usually limited to geopolitical scales such as zip codes, census tracts, and, to a lesser extent, census block levels. Data on smaller scales (e.g., building or address level) may be available but the information may be disaggregated by apartment, involve searching multiple sources, or exist in various forms or levels of organization resulting in more unwieldy data collection and management efforts.

Relevant Studies Incorporating Strategies of Spatial Data Analysis

A number of studies have reported important relationships between asthma and geographic locations. Investigations into clusterings of asthma symptom exacerbation produced a series of studies cited by Antó and Sunyer (1992) including Antó and colleagues (1989a, 1989b, 1990), Goldstein and Rausch (1978), Mendes & Ulhoa Cintra (1954), Ussetti, Roca, Agusti, Montserrat, Rodriguez-Roisin, & Agusti-Vidal, (1983). These projects offered empirical support for time clusters of asthma symptoms that occur across sites within the same time period and/or geographic clusters where symptom outbreaks were found to occur primarily in specific areas relevant to environmental incidents. Simultaneous time and space clusters were highly suggestive of a point-source epidemic. Antó and Sunyer (1992) plotted a spatial distribution based upon addresses of the patients. The authors found, however, that maps plotted from place of residence alone were less accurate than when cases were plotted according to places and times when symptoms began. Their studies led to additional studies to formally investigate, for instance, the suspected causal relationship between soybean unloading in a harbor and nearby asthma outbreaks.

More recent studies into the spatial relationships between asthma and pollution sources have also incorporated combinations of GIS mapping, ecologic, or multilevel research designs (Buckeridge, Glazier, Harvey, Escobar, Amrheim, & Frank, 2002; Oyana, Lwebuga-Mukasa, & Jamson, 2004; Oyana TJ; Rogerson P; Lwebuga-Mukasa, 2004), to test for covariation of environmental factors and asthma hospitalization over a region. Results have shown that exposures to environmental factors can be effectively modeled over small areas to show greater hospitalization rates and prevalence of asthma associated with motor vehicle emissions and other pollutants independent of socioeconomic influences.

A Swedish study compared environmental risk factors and socioeconomic standing for children living in two postal code areas (Andrae, Axelson, Björkstén, Fredriksson, & Kjellman, 1988). Findings suggested that children living in homes damaged by dampness had a significantly greater reported occurrence of bronchial hyperreactivity and allergic asthma independent of family smoking habits. The effects were most noticeable where family history included asthma. Further, children living in the area with a pulp and paper mill also had more reported symptoms than those from the area with little industrial pollution.

Methodological Issues in Defining Units of Analysis

Determinations about unit or scale of analysis are particularly important for mapping strategies for neighborhood research as well as statistical modeling given the multiple and complex influences on disease distribution. For example, variations in time at a location and specifically time-space interactions in local events suggest changes in geographic continuity as well as in human activity which create a "synthesis of social forces that roll across the landscape" (Kearns & Joseph, 1993, p. 714). Issues of scale also address the conditions for potentially striking differences which may not be apparent at other scales of analysis (Gestler, 1986). Selection of the scale and unit of analysis has critical implications for the identification of disease patterns because the use of one scale may mask or ignore spatial variations of another scale (Mayer, 1983). For example, a high incidence of a disease might be evident when a particular street block is measured but the significance of this measure may be lost when the data are grouped or averaged on a block-group or census tract level. The unit of analysis at which the data are collected by institutional or government sources, however, typically influences which scale is selected for analysis.

The application of findings at one level to another level of analysis or even ignoring relevant variables on a different level of analysis can result in one of a number of inferential errors. Applying results from group-level studies to individual cases creates the basis for ecological fallacy (or ecologic bias) just as inferring results from individual cases to the group level may lead to the atomistic fallacy (Diez-Roux, 1998). An ecologic bias is suggested when the group level or aggregated estimates of effects (e.g., of a particular variable on the outcome) does not reflect the true effect at the individual level. For example, the influences of a particular unemployment rate on a neighborhood may not translate into the same effects on a household in that neighborhood.

Specification of the model for validity. These and other kinds of challenges to negotiating the appropriate units of scale and specifying the correct model, however, can be addressed effectively and should not diminish the value of contextual influences of the larger environment on individual or micro-level phenomena. A number of strategies can be enlisted to help address some of these challenges to validity. Ensuring that the research design is actually measuring the phenomena at the selected geographic level is an important means of avoiding bias threats associated with moving between different levels of analysis in ecological studies (Schwartz, 1994). Not only does validity require that relevant variables are included in the model and irrelevant variables are excluded but also that the variables are meaningful to the level of interest and applicable to all members when measured at the group level. Thus, for example, rats maintain a range in territory often of less than 200 feet and so rat problems in one part of a census tract do not necessarily reflect rat conditions in all parts of the tract (Pickett, 2000). The ability to classify correctly the spatial range of rat problems with resident exposure would be critical to valid measurement.

Techniques of multilevel analysis can help guide the incorporation of variable measures to consider different levels of analysis and possible interactions between levels.

<u>Multi-Level Analysis as a Negotiation Between Units of Analysis</u>

Data collected in the social sciences often contain hierarchical components that describe characteristics of individual or micro-level entities while also considering information about grouped or organizational (macro) units such as socioeconomic status, neighborhoods, group memberships, workplaces, and schools. Contextual, or nested methods, known also as hierarchical linear modeling, involve two or more levels of data in which micro or primary levels of analysis are nested within macro groups or higher levels of analysis. A multilevel model can help answer questions about the explanatory or independent variables' influences on the outcome variable or dependent variable and upon each other for each level of analysis. The model can also account for "cross-level" interactions and partition out the variables that have the greatest relationships with variables on another level of analysis. The hierarchical linear model negotiates the gap between ignoring the effects of the contexts (i.e., the assumption that the groups are the same and interchangeable) and treating all of the groups separately, as if they had nothing in common (Kreft & de Leeuw, 1999).

Study Objectives

Research on the relationships between environmental exposures and asthma symptoms has generally focused upon individual risks related to sources of specific ‘triggers’ - allergens and irritants - from either internal household conditions (e.g., environmental tobacco smoke, cockroaches, dust mites, mold) or external pollution (e.g., ozone, particulate matter, sulfur dioxide, NO_2). Many of these studies have indeed shown connections between selected environmental factors and asthma symptoms. There is a paucity of research, however, that considers the occurrence of these individual triggers as part of an integrated ecological system. This trend is due, in part, to the difficulty in measuring synergistic effects of multiple triggers and also to the complexities of measuring exposures on mixed levels of analysis.

Also influencing the direction of research, however, is the prevalence of individualism and individualization of risk in the study of disease (Diez-Roux, 1998). Building upon germ theory the biomedical model of disease focuses on the individual and individual behaviors as the basis for prevention, cause, and treatment devoid of a larger environment in which individuals are situated. The predominance of individually oriented epidemiological studies not only detracts from a more complete understanding of health and disease but also may continue the trend in a cyclical fashion in which all epidemiological work is measured against the ‘standard’ of individualized measures. Further, the individual ‘standard’ continues to be the magnet for funding, peer review, and acclaim. The level of analysis at which the problem is conceptualized will realistically generate results and recommendations for interventions at the same level, including those from major industries focusing on pharmaceuticals and genetic research. The result is to minimize attention to contextual and, perhaps, more politically controversial factors that relate to social, political, and environmental disparities.

In an attempt to offset this narrowing of perspective, this study offers a model for evaluating a combination of ecological risk factors as a possible explanation for the residential distribution of patients from Harlem Hospital Center's Asthma Emergency Department (ED). The project explores the efficacy of combining geographic information system (GIS) mapping strategies and spatial data analysis with ecologic study design and epidemiological interdisciplinary approaches to identify and analyze potential "clusterings" of patients' addresses. An iterative process between visual displays of data distribution and a theoretical framework guided by the literature is used to help devise a research design which addresses methodological issues for testing the model. Indeed, the progress of the study design is informed by and evolves with each step taken as a necessary part of the development process.

Archival data on the study area were collected for the measurement of community risk factors such as housing quality, neighborhood quality, access to health care, and location of potential sources of pollution. Data collected on these risk factors and on patients' visits are used to test the following two research hypotheses and research question:

Hypothesis (1) The residential addresses for patients of Harlem Hospital Center's Asthma Emergency Department (HHC AED) living in Community District 10 during the study period are distributed differently than would be expected in the general population distribution;

Hypothesis (2) “Spatial Clustering” of patients’ residential addresses and differences in their geographical distribution can be explained through analysis of ecological risk factors such as neighborhood quality, housing quality, and/or access to health care services, controlling for the distribution of apartment units, income, and overall propensity for residents to use HHC ED’s services.

While the primary interest in this study is to better understand how environmental factors affect patterns of Asthma ED use in a low-income urban area, the application of GIS programs to support research objectives is also explored:

Research Question: How can GIS and spatial data analysis be used to identify appropriate geographic scales for analysis and facilitate evaluation of ecological risk factors?

Conceptual Basis for the Study

The study uses a number of methodological strategies to investigate the role environmental conditions play in patterns of Asthma ED visits from a contextual perspective. Research objectives for this project shift the emphasis from a focus on an individual unit of analysis to an ecological level towards an understanding of why asthma emergencies may be more prevalent in some neighborhoods than others. Once the distribution of addresses associated with Asthma ED visits is shown to be spatially clustered, methods are needed to provide the means for valid comparisons of areas in which the residents are exposed differently to environmental factors so that potential biases and error can be controlled.

The conceptual premises for the comparisons are derived from perspectives on the multiple potential triggers for asthma symptoms as discussed above. More specifically, chronic or low-level exposures of certain environmental triggers may predispose residents to acute asthma symptoms which, under certain conditions create emergency health situations. Symptoms may exhibit a dose-effect relationship when they occur in response to an increase in concentrations of triggers or may appear suddenly, as often occurs with exposure to chemical irritants.

While exposures have been measured on an individual household level, poorly maintained buildings create conditions that generate asthma triggers associated with infestation by rodents and roaches, poor heating, or water or moisture damage that support mold growth. Building level asthma triggers can affect occupants to different degrees throughout the building and even spillover to other building environments. Similarly, blighted neighborhoods with poor sanitation services or neighborhoods burdened by significant sources of pollution including diesel exhaust and other forms of particulate matter or VOCs can also create conditions that negatively affect residents' health. While a number of other factors may help explain why all similarly exposed residents are not equally affected (e.g., not all residents have developed asthma, variations exist in residents' health status or diet, residents may spend differing amounts of time in the environment, physical layout of the urban community, genetic predispositions) research methods that can clarify the role exposures in building and neighborhood contexts could offer a realistic explanation for patterns of adult asthma exacerbation in an urban setting.

CHAPTER II: METHODS

A number of steps were taken to set up an ecological study in which hypothesis testing could be managed, variables defined, and data are available for an analytic study of the association between environmental variables and asthma emergency visits. This section begins with a brief introduction to prior research on asthma emergency visits in the area and a closer definition of the study area including criteria selected to help define the study area. A multi-method approach to the study is next described including screening for presence of clustering of asthma emergency visits via spatial data analysis, applications of geographic information systems, strategies for managing the major threats to validity in an ecological study, and multilevel statistical modeling that is adopted for the task. The process of multilevel analysis has particular implications for defining geographic units of analysis and the variables that are specified for the model. Therefore a section is also dedicated to discussion of the critical relationships between the methodologies and classification of the available data.

Building Upon Pre- Existing Data

This retrospective cross-sectional ecological study begins with data for 2756 adult visits to Harlem Hospital Center's (HHC) Asthma Emergency Department (Asthma ED) between March 1997 and March 1998. The outcome measure is visits by local residents to HHC's Asthma ED aggregated for the study year by building addresses located within a portion of Harlem Hospital Center's service area. The visits included multiple or repeated visits by the same residents except for 19 visits by residents registering in the Asthma ED more than once in the same day. The complete dataset includes visit and patient ID numbers, dates of birth, dates of visits, and addresses obtained through a project of the Harlem Lung Center (REACH II, Ford, McLean, Findley, Meyer, & Richardson, 1998). Once obtained, residents' addresses were computer-mapped using geographic information systems (GIS).

GIS software was used to determine the longitude and latitude coordinates of a street address on a digitized map of the area in a process of "address match geocoding" (Cromley & McLafferty, 2002). For this study the program used TIGER/Line street centerline database and estimated the location of each address along the appropriate street centerline. The TIGER files contain a single line representation of streets with address ranges and other information such as a key to match street names that are valid for each street segment, the area between one intersection and the next. When an automatic match could not be produced because of misspellings or other irregularities interactive matching was used to allow review of each address and to identify an approximate location from the street files. Approximately 10% of the addresses, however, fell outside the address ranges available in the street files. These locations were then identified using references to other maps (Hagstrom, MapQuest, Sanborn Landbook Maps) from the study period or current site visits. In those cases other maps were consulted and extrapolations were made locations estimated for manual placement of the addresses.

Preliminary visual examination of the data gave rise to the hypothesis that some areas of Central Harlem may have a proportionately higher number of patients than other areas using HHC's Asthma ED. By examining variables identified in the literature such as housing conditions, neighborhood physical quality, income indicators, and access to health care, the present study proposes an ecological research design to identify socio-environmental patterns linked to use of the Asthma ED by residents of Central Harlem neighborhoods.

Defining the Study Area

Harlem Community Characteristics

New York City is divided into 59 community boards whose role in City government is to provide information, give advice, and advocate on behalf of their neighborhoods in matters of land use, budget, municipal services, and other community issues. Community Board 10 is one of the twelve Manhattan Community Boards and represents the neighborhoods of Central Harlem. According to the 1990 census reports, approximately 100,000 people live within the district's approximately 1.4 square mile land area. An estimated 98 percent of District 10 residents report ethnic minority backgrounds of which approximately 87% are of Black, non-Hispanic origin (Community District 10 Statement of Needs, 1997-1998), making Central Harlem the most ethnically homogenous of the East, West, and Central Harlem communities.

Primary employers include the health care industry, the education sector, light industry (not well defined), and some sweatshop industry. Many Central Harlem residents have severely limited access to economic resources with the percent of people relying on some form of public assistance increasing between 1990 and 1993 from 40.7 to 48.9 percent (Community Board 10 Statement of Needs, 1997-

1998). While reductions in smoking have occurred in many adults across the country, Harlem community residents were found to smoke at a rate of almost twice the national average (Meyer, 1998).

Among other problems identified in the Fiscal Year 1996 Statement of Needs, Community 10 Board pointed to pervasive abandoned buildings and lots in which the accumulation of garbage and debris attract vermin. The Statement of Needs report for 1997-1998 continued to identify sanitation problems associated with city-owned vacant properties. According to sources from West Harlem Environmental Action, Inc. (WEACT), and the New York City Department of Planning, East and Central Harlem tend to have more abandoned housing than do neighboring communities such as West Harlem and Washington Heights (C. Corbin-Marks, personal communication, February 6, 1997; W. Smith, personal communication January 5, 2001).

Central Harlem has gone through many changes in the last few decades. The community lost more than 15% of its stock of housing units between 1980 and 1990. Community District 10 (1997-1998) reported 14.6 percent of the land area in 1995 to be vacant with many vacant properties (lots and abandoned buildings) under city ownership. The 2000 Census indicated changes in some trends including an increase in population by 7.6% dominated by increases in population of persons of NonHispanic Asian or Pacific Islander (145%), Hispanic (96%), and White NonHispanic (45%) origins and a decrease in Black / African American NonHispanic by approximately 5%. The percent of the population on some kind of public assistance had also dropped to 34.3% in 2000. With vacant land falling to 5.8% of CD10 properties in 2004 (Department of City Planning, 2004) a trend for redevelopment and repopulation by new groups became apparent.

Maintaining services to vacant properties as well as for streets and superblock structures (i.e., typically residential buildings extending along an entire street block) poses substantial challenges particularly given critical cutbacks in the city departments of health, housing, and sanitation. Substantial areas of disinvestment alternating with areas of stability and new reinvestment initiatives are characteristic of both Community Districts 9 and 10.

Asthma in Harlem's communities. Along with this environmental and economic profile in Harlem the problem of asthma has grown to be one of epidemic proportions. Twenty percent of Harlem community residents are affected by asthma compared to 5% of the US population. Seventy per cent of asthma patients admitted to Harlem Hospital Center's Emergency Department rely upon this service as their primary source of asthma health care (Meyer, 1998). Furthermore, while pharmacological therapy is the primary modality for treatment of reversible airflow obstruction and hyperreactive airways in asthma, medications can consume substantial portions of a family's already strained income and compete with daily living priorities thereby putting treatment further out of reach (Bailey et al., 1992; Wing, 1993). Reports of mental stress, some of which can result from economic stress, have also been associated with an increase in asthma symptoms and poor management of the illness (Oh, Kim, Yoo, Kim, & Kim, 2004; Strine, Ford, Balluz, Chapman, & Mokdad, 2004).

Study Area Features

While it is important to define the study area independent of knowledge of the distribution or clustering of the Asthma ED visitor addresses to avoid the threat of bias associated with the results influencing the sample (Urquhart, 1992), definitions of appropriate scales of measurement should be a creative process that recognizes the reality of how activities can vary across geographic areas (Cleek, 1979). Selection of the study area boundaries using only administratively defined parameters such as community districts or zip codes may obscure some spatial features that can affect social patterns. Major roadways and transportation paths, business and park districts, and neighborhood characteristics often contribute to a system of reference that people use to help navigate the urban landscape and define community boundaries (Lynch, 1985).

With these principles in mind, a visual inspection of the raw Asthma ED patient addresses (i.e., without distributional or frequency calculations) with respect to other hospitals in the area suggested that some residents from Community District 10 living further from Harlem Hospital may very well be going to other emergency departments for care thus creating a bias in the population to be measured. The defining borders of the study area became a subsection of Community District 10 and the HHC service area defined by a combination of geopolitical divisions (community district boundaries on the east at 5th Avenue and Harlem River Drive; and west side at St. Nicholas Avenue, Edgecombe Avenue, and Bradhurst Avenue; inclusive of complete census tracts except for one in the northernmost area at West 157th Street), “natural” roadways, parks, and commercial strip patterns (stopping short of a major business district to the south at West 125th Street), and locations of other hospitals (See Figure 1).

Measuring Neighborhood Characteristics

Several alternative research designs and geographic scales were considered in building the methods. While variables were specified early in the theoretical framework of the model, final definitions of the variables were influenced by the sources and type of data that were available. Furthermore, the choice of scale is influenced not only by theory and the level of available data but also by the capabilities of the GIS program, statistical requirements, and measurement of variables with available data.

GIS as One Tool for Examining Spatial Distribution of Phenomena

As noted earlier, the GIS mapping program derives the geographic coordinates (i.e., longitude and latitude) of the residential address for each asthma ED patient for mapping and statistical analysis. Mapping data presents a variety of opportunities for visualization or description of data;

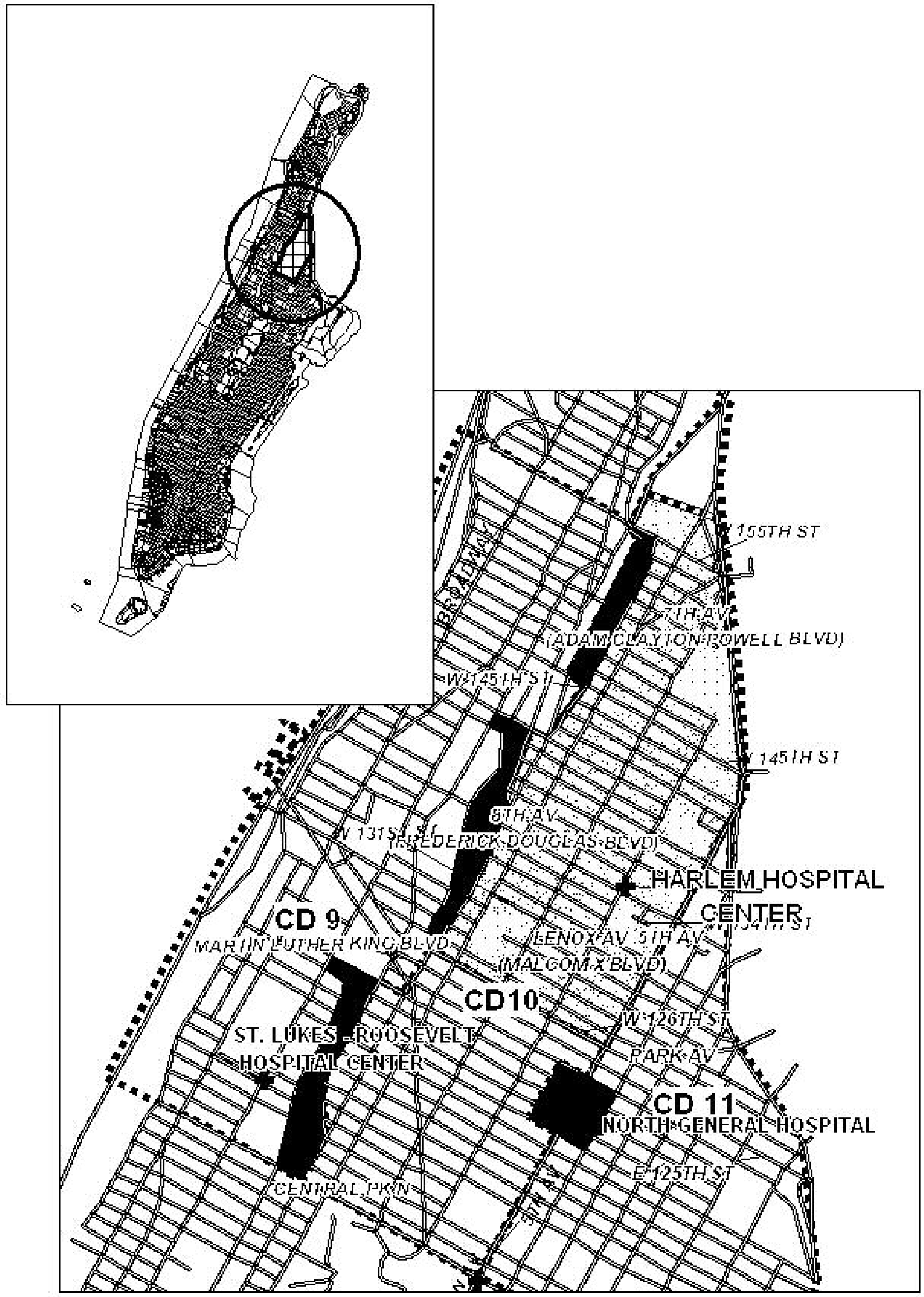

Figure 1. Study area bordered by W 126TH St. on the South, W 157TH St.on the North, St. Nicholas Ave. and Bradhurst Ave. on the West, and 5TH Ave. on the East. Shown with portions of CD 9, CD 10, CD 11 in Northern Manhattan.

exploration as a function of data mining, description, and analysis of the information on different scales; and modeling for the testing of hypotheses. The capabilities of the GIS software and applications for the databases used influenced the course of the methodology development in a number of ways, including: (1) estimating the location of building addresses which can be plotted, (2) suggesting study area boundaries which could be drawn based upon information about the physical characteristics of the area, (3) suggesting spatial patterns of distribution for some of the variables, and (4) offering a critical examination of possible data and suggesting possible variables. GIS serves as a 'tool' for creating a visual display that facilitates iteration between existing information and theoretical and methodological objectives.

Iterative advantages of mapping information. Mapping programs can support the "back-and-forth" movement between description and analysis that is an important process of data exploration. The geographic display of information provides a form of visual feedback that helps identify possibilities and limitations for work on different scales of analysis. For example, plotting Asthma ED event or address frequencies against thematic population maps (i.e., data displayed on a map that reflects changes in numbers, value, or intensity over space) on a census block level reveals the distribution of addresses with respect to population. Figure 2 illustrates how these images can reveal important limitations in relying upon block level population data. While average population amounts can be obtained for the blocks, people's residences may actually be concentrated in only certain areas of those blocks.

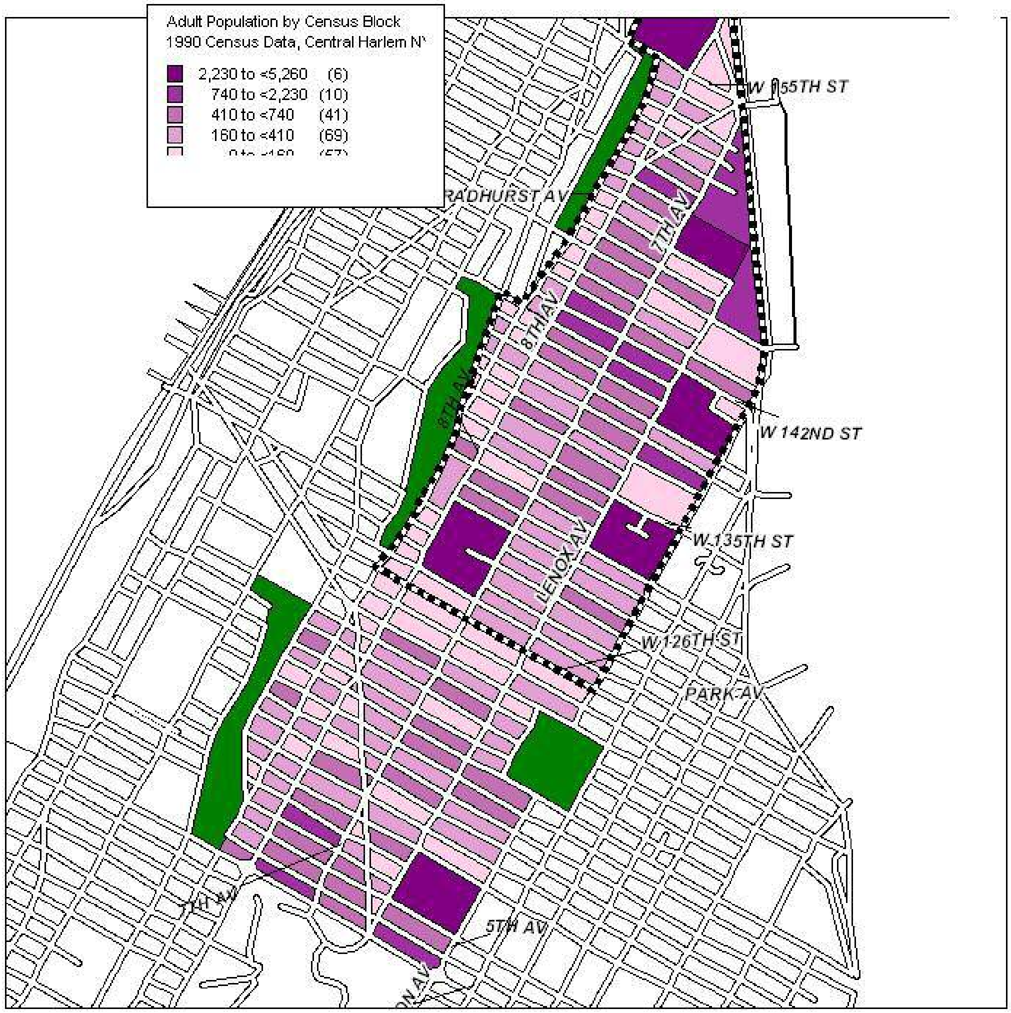

Figure 2. Thematic map of CD10 adult population using census block data.

An alternative means of measurement was needed for more detailed representation of neighborhood characteristics. In effect, the GIS tool offers enhanced flexibility in defining levels of analysis and facilitates a proper classification or “fit” of the available data to the appropriate scale.

Screening for Clustering

In defining the study area for the purposes of screening for clustering it was important to create boundaries that did not artificially split potential clusters. This was accomplished by including a “donut area” or buffer zone around the core study area boundaries to include the addresses of HHC Asthma ED patients who may live just outside the study area. The donut area encompassed Asthma ED events lying in the 2 to 3 blocks outside the border. Including these extra-study area data points acts to extend the boundaries and avoid a “border effect” that inadvertently cuts off real life clustering of addresses. Point Pattern Analysis (PPA) could then be used as a preliminary test of the hypothesis that residential addresses for patients of HHC’s Asthma ED are not evenly distributed and may display spatial clustering. PPA is a package of geostatistical programs that uses the latitude (*y*) and longitude (*x*) coordinates of GIS geocoded addresses as events, or points, to analyze spatial clustering. The program calculates a measure of spatial clustering for the observed spatial pattern of asthma patients and then compares that measure to corresponding values generated for ‘random’ spatial patterns. A large number of random patterns are generated. This provides a benchmark (a null hypothesis distribution) for comparison with the observed value. The results offer a fairly robust test of significance for indications of clustering (Openshaw, Charlton, & Craft, 1988; Urquhart, 1992).

Multiple applications of PPA are available to test for conditions of clustering at theoretically relevant distance parameters (e.g., the effects of differences in population, density, or residential units across areas on clustering) and to test if the phenomena (i.e., Asthma ED addresses) occur close in both time and space. The program's applications are thus capable of indicating not only whether spatial clustering exists but also of the geographical scale or distance at which clustering occurs. Since there can be delays or lags between the exposure to asthma triggers and resulting symptoms, Asthma ED events that occur in specific locations within a few days of each other offer support for the theoretical role of common local underlying ecological or temporal influences on Asthma ED use that cannot be explained by population density alone.

Preliminary spatial data testing. The objective of preliminary spatial data analysis was to test for unequal spatial distribution or clustering of Asthma ED events, i.e., reported addresses of visitors to the HHC Emergency Department, across the study area. Subgroups of the data arranged at different scales of time and geography were examined for patterns that might indicate that Asthma ED visitors come from some locations in the study area significantly more often than most other locations. This approach sought information on second order properties which show the presence of relationships (or spatial dependence) between two or more events (in this case Asthma ED visits) occurring in neighboring areas. The geographic scale was part of a small area or local effect that can be more sensitive to variations from the mean across a subregion of a larger area. Infestation of rats, for example, might exhibit a second order effect in areas of a community where sanitation is particularly bad and conditions are conducive to breeding. First order effects, on the other hand, reveal general differences in the mean values of events across broad areas of the map or that occur more globally (for example, as the distribution of population would cluster in parts of cities). Additional steps were needed later to examine how patterns of distribution of Asthma ED visits might be the same or differ from the residential distribution of the overall non-asthma ED visitors.

The spatial analysis for clustering performed in PPA relies on a Poisson assumption as the null hypothesis. The Poisson assumption provides that a point pattern is spatially random if events have an equal probability of occurring anywhere in the study area and the position of any event is independent of the position of any other event. Spatial clustering of all Asthma ED addresses for the study area was tested employing PPA's K-function (Chen & Getis, 1998).

K-tests examine the number of points within a certain distance of other points and how that changes with distance. The *X* and *Y* coordinates of a data event (i.e., the residential address of Asthma ED patient) are counted as they occur within a specified distance radius of each other data event. If two events are located within the specified distance radius of each other, the events represent a 'close' pair of events. At each distance, the number of *observed* pairs that are close in space is compared with the numbers of *expected* pairs that are close in space in random point patterns. As a comparison base for the observed values, the program generates a confidence interval of expected minimum and maximum numbers of close pairs for random point patterns. These are displayed on a graph of distance (X axis) versus number of close pairs (Y axis). Inspecting the graph indicates, not only whether or not spatial clustering exists but also the geographical scale, or distance, at which clustering occurs.

To screen for clustering at geographic scales relevant to the study area the distance parameters for the K-test were specified at 10-meter steps up through 200 meters. Each pair of geographic coordinates was also weighted with a value to reflect population ranges for the relative census block thereby offering a means of controlling for population on a preliminary basis.

Time-space statistical patterns. Clustering of asthma cases in time and space is tested using the Knox test. The Knox test differs from the K function in that it uses information about how close events are in both time and space. It produces contingency tables that help determine whether the number of *observed* pairs that are close in time and space is significantly different from the *expected* number of close pairs generated through a random process. Geographic coordinates of each point of the data set (i.e., Asthma ED event address) and the date of each asthma visit were used to determine closeness in time and space. If two asthma events occurred within a specified time interval and distance radius of each other, then the events formed a ‘close’ time-space pair. The numbers selected for the time and distance parameters served as “cut-off” values that define ‘close’ pairs.

Decisions on “cut-off” values are critically important and should be related to the phenomenon under study. Again, the literature and the conceptual framework helped guide these decisions. For example, because there may be either an immediate reaction or a delay (lag) between exposure to triggers and emergency status of symptoms several time parameters from 1 day to 7 days were used. Distance values were defined in part to reflect the units of analyses and to approximate the immediate addresses around a building or the areas corresponding to segment widths and lengths. Thus, distance parameters were entered for 30, 50, 100, and 200 meters. If Asthma ED events occur in specific locations within a few days of each other there may be greater support for the idea of common, local underlying ecological risks.

Running multiple comparisons statistical tests on the data set may produce significant results simply by chance. For purposes of this study, spatial data statistics are a preliminary test for clustering used primarily for descriptive purposes and therefore the need for multiple comparisons adjustments (e.g., Bonferroni method for multiple comparisons) is less important.

Minimizing Threats to Validity in the Ecological Study

The analysis of data that have meaningful relationships at different spatial scales or levels has implications for methodology. To avoid error, or "ecological fallacy" that results when group level or larger scale findings are inferred incorrectly to an individual level of analysis, data associated with environmental risk factors must be carefully classified according to the appropriate level of measurement. Data should be potentially meaningful to all members of the level.

Classification of data associated with ecological risk factors involves careful differentiation between levels of the variables measured to avoid error, labeled "ecological fallacy" by Selvin in 1958, in incorrectly applying group-level findings to an individual level of analysis. Towards this end, the research design builds upon an ecological approach with strategies to enhance the effectiveness and validity of the method.

Attempts at a sampling strategy by which data on environmental variables could be measured for hypothesis testing were complicated by the threat of misspecification of variables using data from different levels of aggregation or geographic scales, misclassification of data between levels, or an inability to identify enough groups that could satisfy statistical criteria for comparisons. A great deal of data was found to be available at the building level for multiple dwellings and as a result the entire "population" of multiple dwelling buildings within the study area was included in the analysis. Buildings represented an aggregated form of the variables relevant to one geographic scale (i.e., building level) but data for other factors to be considered such as income were only available at a larger level.

Ecological designs typically rest upon readily available aggregated data but at scales that do not facilitate the application of findings to individuals. Small steps in scale however, can help increase the relevance of variables between different levels since factors on each level must somehow mediate the effects of factors on the other level in order for there to be an effect (Diez Roux, 2004). The smaller the area used for classifying data the more likely grouped data will apply to individual levels (English, 1992). In addition, the reliance upon existing aggregated data typically available at larger scales or levels of organization (e.g., census tracts or zip codes) can limit the possibilities for obtaining adequate numbers of comparison groups needed for quantitative analysis, hypothesis testing, and power to reject the null hypothesis.

The Nested Model

A research method was needed that could respond to the variable relationships pertinent to theoretical framework at the different levels for which data were available and be capable of overcoming obstacles to valid statistical inference. As a result, a nested or multilevel approach was developed to examine the relationships between asthma cases and variables for all multiple dwelling residences and neighborhood areas within the core study area. The requirements for the model would be informed by how levels were defined for the analysis and the number of units available for analysis on each level; the variables specified, their scales for measurement, and the quality of the data available; and the available statistical operations. This next section discusses these various components of the multilevel model and the basis for the decisions made.

Defining levels of analysis. With the aid of the GIS program "new" geographic scales were drawn to respond to the levels at which available data were reported and to address risks to validity. Initially the new scales took on different sizes, shapes, and boundaries that were evaluated for accuracy by comparing them with characteristics of the actual site and archived maps (i.e., *Sanborn Landbook* insurance maps) and feasibility of measuring data aggregated to the desired scale (e.g., distances and barriers separating both sides of some avenues precluded their measurement in the same way as closer street sides without dividers). Ultimately, rectangular street segments were found to be most viable, defined as running from intersection to intersection in a manner that was consistent with community block address ranges and encompassing both sides of most east-west running streets (i.e., approximately 50 feet in width with no physical dividers) and separate sides of most avenues running north-south wider than 50 feet and with dividers. Segments offer a smaller geographic area than do census tracts or blocks, a strategy important for strengthening the validity of variable measures at both levels of analysis and increasing numbers for statistical requirements. As a result, a multilevel method was developed to examine the relationships between variables for two levels of analysis: multiple-dwelling buildings formed level 1 or micro unit of the nested model and street segments formed the level 2 group or contextual level and within the core study area.

Specification of variables and implications for validity. Some variables in this study are measured at both level 1 (building) and level 2 (segment) while other variables are only level 1 or level 2 measures in the model. Mixed-level designs can help address variables at multiple scales but again, variables on one level (e.g., the building level) may not be characterized in the same way--or have the same effects--as the same named variable on a different level (e.g., block or segment level). This type of misspecification may be avoided by refining definitions of variable exposures (Marsh, 1995), focusing on internal and construct validity (Schwartz, 1994), and specifying levels that are complementary. Grouping data into the smallest possible geographic units of analysis can help to address issues of cross-level specification as well as increase the number of groups available for analysis. Using repeated measures also enhance statistical power (Marsh, 1995) while clear definitions of the outcome and explanatory measures can limit the effects of misclassification and avoid systematic error.

Group level variables. Variables are defined to enhance construct validity, help avoid misclassification of data, and most accurately reflect the phenomena of interest at the designated level in an effort to explain how both individual and contextual factors affect the outcome. Generally group level data have been used where individual level information is unavailable or when there is interest in the effects of a particular group construct. For example, census data on income is typically available only at the block group level and that information may be measuring more the quality of life conditions in the neighborhood rather than the effects of the group income level on individual residents.

Diez Roux (2004) identifies a great need for the development of methodological approaches for group level measurement and efforts to move from crude proxies to meaningful neighborhood attributes that will improve causal inferences. The form that data takes at the second or group level has been differentiated by qualities and described as aggregate, derived, or integral variables. Aggregate data are typically summaries of micro or first level properties and do not usually reflect a distinct group level phenomenon. Group level variables, or derived variables, are mathematically constructed from summaries of individual level information to provide different kinds of information, and integral variables can offer relevant information about a unique group level phenomenon and not just totals of individual level values. All three forms of group level variables are characterized in this study. The group explanatory variable is said to have an effect on the individual level outcome when it contributes to explanation of outcome variation beyond variation found between individual (i.e., building) level measures (Susser, 1994).

The definitions of group level variables, also known as contextual variables, are often similar to micro or first level measures and there can be considerable ambiguity about what the group level variable is measuring. For example, the building-level *violations* data are presumed to represent the overall quality and conditions of a building. *Building violations* data aggregated to the street segment created a group-level measure that reflects overall quality or condition of the street segment and may also be a possible indication of disinvestment. Alternatively, building-level *apartment units* aggregated to the street segment (i.e., group-level), divided by the number of residential addresses and further divided by the length of the segment formed a derived measure that could offer a measure of density for the segment, a clearly distinct group construct.

Integral variables, on the other hand, “describe group characteristics that are not derived from characteristics of its members” (Diez Roux, 2004, p. 105) and can be a different construct than a similar measure at the individual level. *Segment wealth* was an integral group variable that offered a segment level measure of affluence generated from comparisons of average segment property values for all residential buildings and based upon census tract data from the U.S. Census Bureau, Block Canvassing and Real Estate Valuations (Cole’s Cross Reference Directory, 1997).

The Asthma ED outcome variable. The outcome variable, Asthma ED visits, was measured at the building level, the lowest level of analysis, even when considering the effects of the segment level variables. Building level Asthma ED visits were calculated as count data of the total number of visits per building address. Because violations data is not readily available for single-family or duplex residences, only visits associated with multiple dwellings were included in building level analyses although the few asthma visits associated with other addresses (n=16) were included in segment level counts for descriptive purposes.

Asthma ED visits measures the number of residents of the study area who had reported to Harlem Hospital Center's (HHC) Asthma Emergency Department during the study year March 1997 through February 1998. Each variable and corresponding level(s) of analysis appear in Appendix A.

The Asthma ED AKA outcome variable. Some buildings had more than one address, known as AKA ("also known as") addresses. Most AKA addresses belong to a different street segment, for example, when a building is on a corner and one address is located on a street and a second is located on an avenue or building addresses are "back-to-back" on different street faces. Typically the AKA address is associated with a unique entrance to the building. In recording the outcome variable, the sums are recorded in two different ways for both level 1 and level 2 analyses: one measure includes counts for only the reported address while the second includes Asthma ED visits listed under all addresses (i.e., multiple addresses for the same building). All addresses for the same building share the same data for explanatory variables (e.g., violations, ownership, apartment unit numbers). This form of aggregation is in response to Asthma ED visitors' registration at the ED under only one address when there may be additional Asthma ED visits from the same building but different address. For example, a patient who registers with the ED using the address of 2361 7th Avenue was counted as one Asthma ED visit for this specific address. This building, however, has an AKA address of 145 West 138th Street. There are a total of 3 Asthma ED visits for this AKA address that would not otherwise be counted in the "Asthma ED" variable. The "Asthma ED AKA" variable is created to allow us to count <u>all</u> asthma visits for a particular building. The assumption is that all residents of a building could have been affected by the general condition of the building for which "Total Violations" is a proxy, notwithstanding the possible existence of multiple (AKA) addresses. A complete count of all residents reporting to the Asthma ED from that physical building cannot be understood without considering "Asthma ED AKA" measures under all addresses associated with that building. While city databases such as those obtained from *Housing Preservation and Development* (HPD) cross-reference the AKA addresses where they exist and have listed the same housing information for each address other sources of information may refer to only a single address.

<u>Key Variable Definitions</u>. Some contextual or level 2 segment variables in the study were derived from level 1 building measures and others reflected theoretical constructs unique from building level features. The following environmental constructs outline the study's theoretical framework for an elevated risk of HHC Asthma Emergency Department utilization: (1) *Building Quality*, (2) *Neighborhood Quality,* and (3) *Pollution Exposures*. Each construct is defined as an explanatory variable specified at either level 1 and/or level 2 units of analysis.

(1) <u>Building quality variables.</u> *Housing violations* data for the study year were available at the building level to measure multiple conceptual features. *Total violations* represented the overall quality of the building(s) based upon total documented violations. Violations that were more closely linked to conditions commonly associated with asthma triggers (i.e., roach, rodent, heat, and moisture-related violations) were grouped separately and later combined to create a composite variable *trigger violations.* Violations data are also available for years before and after the study year with the number of years varying by building. A violations history variable had been considered to reflect chronically poor conditions but the idea later abandoned because of the variability in lengths of violations histories among buildings and possible resulting bias.

V*acancy* was noted on the building level if a building was totally or partially vacant. Locations of buildings on a *corner* and *type of building ownership* were recorded as categorical measures on the building with discrete measures (0 = not applicable, 1 = applicable), and totaled for the level 2 segment value.

(2) Neighborhood quality variables. *Housing violations* are aggregated from the building level for the entire segment to represent housing stock conditions for the segment and the potential exposure of residents to "spillover" from vermin harborages and poor conditions in problem buildings. Buildings that were *partially* or *completely vacant* were categorized as such. Segment level sums were obtained for v*acant lots, partial building vacancies*, *total building vacancies*, and a composite of all vacant properties for the segment were measured as indicators of disinvestment and neighborhood decline, a relationship supported by earlier studies (Cohen, Mason, Bedimo, Scribner, Basolo, & Farley, 2003). *Density* was a segment level measure of the relationships between the number of apartment units divided by the number of buildings and over the length of the segment. The neighborhood construct is actually operationalized as street segments.

(3) <u>Sources of pollution exposures</u>. This construct is intended to serve as a surrogate for the numerous sources of potential exposure to chemical contaminants. The complicated, if not impossible task of measuring multiple and diverse outdoor environmental contaminants in the study area resulting from expected or unexpected emissions is represented more simply by the locations of actual or potential sources of pollution. Thus, the pollution variables measure potential exposure, rather than actual pollution emissions. Pollutants identified by the federal Environmental Protection Agency (EPA) and/or local community groups include criteria air pollutants (i.e., ozone, lead, nitrogen dioxide, particulate matter, sulfur dioxide, and carbon monoxide); hazardous air pollutants released by stationary sources of air pollution; and hazardous waste generation or management with potential releases to the ground or air [1]. The EPA defines *hazardous waste* as

> "a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may -
>
> (A) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed." (Solid Waste Disposal Act of 1976, 42 USC §6903).

[1] There were approximately 39 more dry cleaner businesses, an important source of VOC's, identified by other sources (e.g. WEACT, Coles Directory) in all Harlem communities than listed in EPA's *Envirofacts*.

Data were measured on the building and segment-level and in subgroups defined as *in-building sources* (present/not present in multiple-dwelling buildings); *dry cleaners / parking facilities/gas stations* (common sources of VOCs), and *other EPA sources* (e.g., other emissions from buildings; *Mass Transit Authority* subway maintenance chemicals, exposure to airborne metals and other maintenance by-products, and chemical industry sources. The constructed categories are based upon sources of VOCs (volatile organic compounds) common to the community and known to irritate respiratory systems and other less obvious sources of VOCs.

Dr. Reynold L. Trowers, Director of Emergency Medicine for Harlem Hospital Center observes also that patients often associate local construction activities with exacerbation of their asthma symptoms. As a result, *construction permits* issued or active for 1997 and 1998 were obtained from the New York City Department of Transportation to represent temporary street and sidewalk work exposures. *Bus routes* information (on a bus route, more than 1 bus route within 100 meters) and the *number of buses* passing within 100 meters of a building annually were obtained from maps and schedules for 1998 and 2000, respectively.

Control measure variables. A number of variables were measured to control for other influences on the dependent variable Asthma ED visits. These variables may operate as control variables to help manage spurious or false relationships and chain or multiple cause relationships and include intervening variables and suppressor variables that might mediate such relationships.

(1) Apartment units. Measured as total apartments in multiple dwelling buildings and also total apartments summed at the segment level, this variable served as a proxy for household numbers and is used to estimate segment density.

(2) Non-asthma emergency visits. Data on *non-asthma ED visits* from Harlem Hospital Center for the study year were used as a comparison measure to account for the propensity of residents to use HHC ED for a variety of nonemergency reasons such as preference of care, convenience, proximity, ease of access, etc. This variable is also useful in estimating the propensity for residents to use the emergency department at Harlem Hospital as compared to the EDs at other health care facilities such as Columbia-Presbyterian Hospital, St. Lukes-Roosevelt Hospital, North General Hospital, Mt. Sinai Medical Center, and Metropolitan Hospital. This patient service phenomenon was taken into account in analyzing the associations between environmental variables and HHC ED asthma visits to demonstrate that explanatory variables had independent relationships with Asthma ED visits apart from overall emergency department use patterns. With the assistance of two Harlem Hospital Center physicians, Dr. Jean G. Ford, chief of Pulmonary Medicine and a principal investigator from the earlier asthma study and Dr. Reynold L.Trowers, Director of Emergency Medicine, data were obtained on adult non-asthma emergency visits from the study area during the study period and include dates of visits and diagnostic codes.

(3) Access to alternative sources of health care. Distances between health care centers and street segments were a second level variable used as a general measure of proximity to alternate sources of care for adult asthma and include neighborhood health centers and surrounding hospitals. The variable categorized distances between an outpatient source of adult asthma treatment available to very low income residents and any part of a street segment within 150 meters, between 150 and 300 meters, or more than 300 meters. This variable was also used to control for the proximity of the emergency department at Harlem Hospital as compared to other sources of outpatient care.

(4) Relative Wealth. The effects of income on health maintenance are well known in the literature and for asthma many of the connections can be the same. People with lower incomes may be less able to afford medications and quality diets, have less access to high-quality health care services, and more likely to live in substandard or perhaps specialized (e.g., services for homeless people) housing and in less desirable areas. The *Cole Directory* contains information on wealth ratings geared towards marketing interests. The construct offers an income measure that can provide a higher or lower wealth rating for streets when they are compared to the relevant census tract averages for tax assessment property values (personal communication, R. Noonoo, Cole Directory Service[2] 6/12/03).

Threats to Validity

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[3] The Cole Reverse Directory is compiled from telephone directories and carried from year to year unless notified otherwise (personal communication, Linda Hanneman, 2/01).

The complexity involved in exploring relationships between asthma and environmental triggers as well as the limitations of methodologies often used to approach these relationships warrants a great deal of deliberation as well as creativity to overcome obstacles to meaningful study. A number of steps are taken to improve the validity of this ecological design as an analytic rather than as a descriptive study with the objective of grounding the problem of inner-city asthma symptom control in community and environmental justice contexts. A summary of strategies adopted in the methodologies and the data management to reduce or eliminate threats to validity can be found in Appendix B.

Selection of Data And Measures

Moving from the planned methods to actual application of methodologies for best management of the data can require modifications in definitions of variables or data sources in an iterative process to maximize validity in less predictable living environments. Highlights of such strategies as they are worked out in this project are described in this next section.

Locating Appropriate Data Bases

In the course of developing the methods to support the study, an inquiry was made into potential sources of appropriate data. The feasibility of obtaining data at more local levels of analysis than are typically available in ecological studies was critical to increasing the validity of the study. As the methods took shape it became clear that they would initially serve as guidelines to an iterative process that was necessary for specifying variables on the appropriate level and addressing concerns for validity.

Negotiating Data from Multiple Sources

Efforts to identify feasible sources of information targeted the agencies typically possessing such data including the NYC office of Housing Preservation and Development (HPD), NYC Department of Planning, NYC Housing Authority (NYCHA), NYC Department of Health, NYC Department of Buildings (DOB), NYC Department of Transportation (DOT), NYC Department of Sanitation (DOS), NYC Department of Finance, US Environmental Protection Agency (EPA), and the US Census Bureau. Local organizations providing data and/or guidance included Harlem Hospital Center, The Greater New York Hospital Association, West Harlem Environmental Action, offices of local representatives and Community District 10, and the Mailman School of Public Health, Columbia University. The *Sanborn Landbook* insurance maps and *Cole Cross-Reference Directory* provided annual information on city streets and buildings.

As the levels of analysis became better defined through the methods development, variables had to be specified for each relevant physical aspect of the community. Efforts to obtain data on the scales of interest, however, were not always successful and required modifications of some of the variable definitions initially considered. At times data for the study year were available for the scale of analysis only in a raw form that either the agency was unwilling to provide (for example, rodent complaints or remediation on vacant lots by address could not be extracted from the Department of Sanitation despite repeated requests across different internal levels of authority and contacts with external authorities such as the community board, or the offices of the Borough president and Councilman Perkins) or was otherwise difficult to acquire (i.e., located in dusty basement catacombs). Other data such as traffic counts existed only for a handful of areas (e.g., traffic counts) and could not be used.

A surprising amount of data was available however, at the building level – and sometimes apartment level – or at the street address level. Detailed information about housing violations, their descriptions, their history, and who cited them, building ownership information, and building use and use history, was available from different sources. Key decisions had to be made, therefore, on selecting the most efficient sources and means of accessing data that were not always in a form readily available for research at the levels of analysis selected for this study.

In some cases information missing from one data source could be found in another while some information was available from multiple sources (e.g., *HPD* and *Department of Buildings* for violations data; *HPD, Sanborn Maps, Cole's Cross-Reference Directory, NYC Department of Finance,* and other NYC databases for data on numbers of apartment units). When information sources conflicted, decisions were made to rely first on the primary, the most relevant, or the most complete source of data (e.g., *HPD)*, or guided by logical considerations. For example, if a property was classified as a vacant lot in one data source but also had units reported in a second source the unit numbers were counted and the property was not counted as a vacant lot. Property classifications were generally drawn from *Department of Finance* indices. When more detailed clarifications were necessary, however, regarding the legal use of a structure, records from the *Department of Buildings* database was consulted in greater depth.

Reconciling Data Uncertainties

While the *Sanborn Landbook* maps were rich in building information available for the years under study, at times there were gaps in critical data such as address ranges, unit numbers, and land use types. The classification of some address ranges to the appropriate segment (i.e., block between intersections) in some cases was resolved only by visiting the site. Site visits for this purpose were made some time after the study year and the possibility of changes in address location over the years had to be considered. On two occasions, intersections existed in the *Sanborn* maps while the actual location revealed no intersection among a solid street face. In these situations, the classification of addresses was interpolated based on existing conditions in conjunction with other archival information.

Description of Buildings and Segments Included in the Study

Multiple-dwelling buildings, as opposed to single-family buildings, were selected for measurement on the variables primarily because of their predominance in the study area and the availability of housing violations data. All buildings and segments in the study area with multiple-dwelling residential addresses could potentially be included in the study. There were initial concerns that some street segments might contain an excessive number of single or 2-family properties for which violations data were not available. Single and 2-family buildings represented a small number of dwellings in the area compared to multiple dwelling buildings (less than 300 dwelling units compared to over 50,000 units of multiple-dwelling buildings). As a result, one- and two-family residences were not included in the analysis and their omission was not considered a threat to the validity of the study because of their small numbers. Asthma ED visits associated with non-multiple dwelling residences, however, were retained for segment level counts. Upon review of NYC Building Classification Codes from the Department of Finance for residential and non-residential buildings, 17 of 337 segments identified in the core study area contained at least 20% addresses that were commercial or other non-residential properties. Many of these commercial properties were mixed use stores or offices with apartments and had data available. Four segments had between 70% and 83% commercial or other non-residential addresses; of these, 3 properties had violations data available. The fourth segment containing 80% commercial or other non-residential addresses and no relevant data available was removed from the study sample. A total of forty-eight street segments were removed from the analysis because they had no multiple dwelling addresses while 17 other segments were removed for containing only one multiple dwelling with ‘0' or unknown data reports. Two hundred and seventy-two segments consisting of 2770 buildings remained in the study for analysis after all adjustments were made.

Identifying Relevant Addresses

Building addresses were also removed from the analysis when the search conducted on the various databases used (i.e., HPD, Department of Buildings, Sanborn) indicated the address was invalid, was a non-residential structure, or that it could be classified under a different a category (e.g., vacant lot, source of pollution). The number of addresses removed or reclassified totaled 236. ED visits and apartment units from excluded addresses, however, were counted for the purposes of point pattern analysis and segment level totals.

Classification of Data

Data are classified according to whether the measure reflects conditions affecting building quality (first level), segment quality (second level), or both. In addition to the geographic scale decisions were required regarding the organization of the data and the role the time frames of Asthma ED visits would play. The form in which data were available, the levels of analysis, and implications for construct validity and statistical analysis all guided these decisions.

Data organization. The outcome variable data set (Asthma ED visitor addresses) was organized in different subgroups to reflect all visits for all study area residents for the study year and to be adjusted for multiple same-day visits (patients with repeated visits); for only new visits per month per person (unique monthly visits of patients); for only one visit per person for the study year (no repeated visits); for time of year; or any variation of those possibilities. Each group of data organization offers advantages and disadvantages and the theoretical framework was again used to help guide the decision-making process. Using the data set with no repeated visits offers a picture of where addresses are located overall without the complications of excessive visits by individuals. Analyses for time/space patterns, however, require all visits of a data group be used. While it is possible that a repeated visits data set could result in clusters simply due to the locations of a few very ill or 'ED-oriented' individuals, with population density considered, the patient repeated visits data set might also reveal locations in which some individuals are particularly vulnerable to chronically occurring factors or triggers unique to the immediate area. Furthermore, the larger numbers available in the repeated visits data set help control for random variation, serve to increase power, and provide a consistent number of addresses or sites for statistical analysis. An additional compelling reason for the use of repeated visits data set in this study was the need for data that correspond with measures of overall HHC ED utilization for the same area, a means by which to account for variability in ED utilization.

Decisions about time-space levels of data analysis. While preliminary statistical screening showed significant time and space clustering of Asthma ED events for 4 non-continuous months and occurring in 4 different seasons, a decision was made to use the entire dataset for analysis in the study year. There are both advantages and disadvantages, however, to using the entire dataset over subsets for analysis. As indicated earlier, use of the complete data set provides larger numbers facilitating more reliable statistical analysis helping increase power, controls for random variation, produces standard deviations and means that reflect the larger population, and provides a consistent number of addresses and sites for analysis.

In working with the complete data set there is a disadvantage of losing sensitivity for more subtle patterns that emerge in the smaller data sets. For example, a cluster of asthma events close in spatial proximity and in time in a neighborhood may be linked to a temporary increase in exposure to pollutants (for example, as might occur with a chemical spill or a traffic back up). When these same numbers are merged with data from a larger area, however, the greater study area numbers may mask the importance of the more local events. The disadvantage, however, is outweighed by the improved validity of results with the full data set, particularly given the important theoretical role for underlying environmental factors.

Subgroups of the data set each consist of a different number of addresses or Asthma ED visits (e.g., n=112 Asthma ED visit addresses for April, 175 for May, 144 for September) for analysis. These variations can make interpretation of findings difficult, for example, where some months may have more addresses/ events (i.e., visits to the ED) with little or no clustering while other months may have fewer addresses/events but have evidence of greater clustering. Use of subgroup data sets can offer more information on the time, space, and time/space occurrence of clustering and allow subtle effects or patterns to emerge for those dimensions. At the same time analyses, on a smaller data set can result in chance effects as the result of random variations; small changes give the appearance of greater effects. So, while subgroups of the data set suggest the presence of clustering, the complete data set forms the basis for measurement of variables and analysis of an unequal distribution of Asthma ED visits.

CHAPTER III: BUILDING A MODEL FOR MULTILEVEL ANALYSIS

This Chapter focuses mainly on the development of statistical models to manage the multilevel analysis and the irregularities of field data. Creating model formulas for the purposes of predicting an outcome provides an approximation of the relationship between an explanatory variable and a dependent variable, or outcome. Multivariate multi-level models can manage several variables simultaneously. The models provide an estimate of the change of the outcome variable for a single unit change in the predictor variable while accounting for random error, excluded variables, and co-correlations between predictors. Finding the best model formula is an iterative process that continues until a number of statistical indices of "fitness" are satisfied. The models developed for this study facilitated testing of the hypothesis that Asthma ED visits are influenced by housing violations, sources of pollution, and other conditions and vary when those factors vary by building or neighborhood. Furthermore, the modeling can offer the tools to make inferences from the study area population involved in the research to a wider group within particular guidelines (Snijders & Bosker, 2000).

The conceptual framework guides decisions about the environmental variables to consider, the relationships of these variables as part of the ecology of residential buildings and segments, and the role of control variables in explaining Asthma ED visits associated with clusterings. The nature of the data and preliminary statistical findings also contribute to pivotal decisions associated with fitting the multilevel model to the present data sets. The best "fit" of the model to the data will include management of variables by entering them in different combinations and reconfiguration of some measures for enhanced model stability, all consistent with the theoretical basis for the study.

Perhaps the greatest influence on approaching the research design is the complexity of asthma-environment relationships. While there are well-documented environmental conditions that affect an individual's asthma severity, those conditions often vary with the individual and with location on both a global scale as well as with smaller metropolitan subdivisions. In the interest of countering what Diez-Roux (1998) referred to as the "methodological individualism" currently prevalent in epidemiology, this research incorporates both macro- and micro-level variables to begin to identify specific contextual factors that are known to have diverse and important effects on neighborhood health outcomes. Meaningful applications of this approach, however, require "the development of models of disease causation and testable hypotheses that extend across levels and explain how individual- and group- level variables jointly shape health and disease" (Diez-Roux, 1998, p. 217).

The model proposes to approximate the hypothesized relationships between Asthma ED visits and neighborhood environmental variables. Ideally, the model will be simple enough for interpretation but adequate to describe theoretical relationships. Explanatory research can facilitate selection of the best variables for the model based upon theoretical foundations. The model proposed in this study contained several explanatory and control variables selected on both theoretical and mathematical grounds.

Conceptual Framework for Hierarchical Linear Modeling

Preliminary screening of the data for evidence of clustering provided an early indication of the merit for the much larger cross-sectional study. The findings supported the hypothesis that Asthma ED visits in the study area were not equally distributed (findings reported later in the Results Chapter). The apparent clustering of the Asthma ED outcome variable and the subsequent hypothesis that the clustering could be explained by ecological variables presented a number of challenges for analysis. A multilevel methodology was developed to evaluate the linear relationships of the variables with data aggregated on two different levels, the building as the first or individual level (the level at which the model explains the event) and the street segment as the second or group level. With hierarchical linear modeling (HLM), the main tool for multilevel analysis (Snijders & Bosker, 2000), the variables can be analyzed for their influences on each other at one level and for their influences on variable relationships occurring at another level. Furthermore, because buildings within the same street segment are expected to be similar in some ways and segments are also part of a geographic continuum their lack of independence violates conventional statistical assumptions of complete independence between objects of study and therefore requires a different statistical approach.

This particular approach to modeling is also intended to identify any contextual effects that segment level characteristics might have on building (i.e., individual) phenomena. Contextual effects would be indicated if the means for building level Asthma ED visits changed when group level explanatory variables were entered into the model. The applications addressed the research objectives of formulating and testing hypotheses about environmental effects at multiple levels with partitioning of variance and covariance components among levels (Raudenbush & Bryk, 2002). A number of issues including the nature of the groups and their measures, the objectives for statistical inference, the theoretical framework, and the purposes of the study helped guide the specification and changes for the model (Kreft & Leeuw, 1998).

Descriptive Statistics Information

Frequencies and other descriptive information used to describe data in a few numbers were obtained on building (level 1) and segment (level 2) data and discussed later in Results. Descriptives revealed kurtotic (clustering of data with long tails) or skewed (distributions have long tails) for many of the variables thus violating conventional statistical assumptions for normal symmetrical distributions. Major departures from normality of both dependent and independent variables presented a substantial statistical challenge for the hierarchical linear model requiring modifications to the model approach and the explanatory variables. Continuous explanatory variables at the building level and segment level (*trigger violations, buses per year, pollution sources, segment density, segment vacancy, segment ownership*) and control variables (*apartment units, non-asthma ED visits)* exhibited evidence of extremely non-normal distributions prompting transformations to normalize these data and facilitate interpretation of the measures. Data can be transformed in a number of ways and by different constants to smooth out variation and simulate more normal distribution.

Managing the Asthma ED Outcome Variable in the Model

The Asthma ED outcome variable was characterized by discrete frequency counts and a highly kurtotic distribution thus requiring a statistical tool that could manage the violation of the normal distribution assumptions. Instead of transforming the outcome data, as was the case with the explanatory variables that were assumed to represent a normal distribution (see Results for further detail), a Poisson distribution was used in the hierarchical linear model. A Poisson assumes a non-normal distribution of the dependent variable and therefore allows a test of the prediction parameters for count (i.e., frequency) data of the occurrence versus nonoccurrence of events under these conditions. This distribution is used to estimate the probability that the number of observed cases would occur within a given region by chance.

Identifying Fixed and Random Effects

Establishing the distinction between variables that are fixed and variables that are random is a primary step in an analysis of what is known as mixed models. The objectives of the analysis are used as one aspect for defining which variables are entered into the model as random and which are entered as fixed but there is some ambiguity about when each are specified for this statistically relevant practice. The basis for specifying variables as having fixed effects is that all values of the variable are known quantities, or, for example, come from a finite population where all values are known. For this study *corner location* of a building is an example of a fixed variable because the building is either on the corner or not and there are no variations. Both fixed and random effects were considered for variables on both level 1 and level 2 toward understanding whether the source of any differences in Asthma ED visits lies with the buildings or if street segments have a contextual influence. Group variables based upon the mean value of the group members will typically be considered for their random effects since there is a range of differences each member has from the overall mean and that each group has from the overall inter-group mean.

The study objectives were focused primarily on the fixed effects of *building violations* and sources of pollution on the dependent variable Asthma ED visits. These explanatory variables were considered fixed effects in that all values of the variables were thought to be known and not subject to measurement error, as would be an IQ measurement (Kreft & De Leeuw, 1999). Other building level explanatory variables (i.e., *bus* route, *corner building*, *in-building pollution*, *vacant building*, *type of owner*) are also fixed and exclude those variables which contain measurement error and may be considered a random variable.

To understand the importance of segment group differences in variations from the expected or mean values, for each level of analysis there were calculated mean characteristics for the fixed effects and differences in variances and covariances that reflected random effects. Each building had a residual, or error term that referred to its difference from the grand mean of all buildings in the study and to express that part of the outcome variable that cannot be estimated by the linear formula. Segment-level building means for continuous variables were first centered around the grand mean to obtain the estimate for the expected outcome values for building level variables. On the segment level there were again fixed value variables which include aggregated forms of level 1 data (also known as derived variables) as well as *bus route* information, *segment wealth, access to alternative healthcare,* and *segment density* as a random variable (all integral variables). Random effects were also reflected in the unexplained variance of the group level effect on the individual building level outcome values. A grand mean was obtained for non-categorical variables and was varied around the segment means. In this way the model can provide a measure of how segments differ in their influence on the individual level outcome and how much of the variance an explanatory variable can account for. As additional independent variables are added to the model the amount of explained variance gained or lost and different associations between variables may be identified and addressed. When segment level variables are entered into the model and variation among buildings disappears the group level variable may be said to explain the variation among the buildings in a demonstrated cross-level or contextual effect.

Random intercept model. The intercept might be understood as the value the dependent variable (Asthma ED visits) takes on when non-categorical (i.e., continuous) variables are at their mean values and categorical variable values are at 0 value. The intercept was allowed to go random thereby establishing an intercept or mean value for the outcome measure that would vary with each group. Permitting a random intercept is consistent with the hypothesis that differences in the locations of Asthma ED visits (i.e., segment-level clustering) could be explained by environmental risk factors (or explanatory variables). Thus, each variable measured could have a different effect on the Asthma ED visit outcome and segment-level measures could also produce a different outcome effect. Slopes, however, were not permitted to vary with the group but remained “fixed” as the measures of different groups were not being compared. The decisions were consistent with the hypotheses and conceptual framework which were not immediately concerned with how the segments differed on the explanatory variables. Rather, the focus was to determine if the specified explanatory variables were related to level 2 (i.e., segment or context) effects where greater values on an explanatory variable could demonstrate main effects on the outcome, Asthma ED visits. The restricted analysis provides the next step for assessing the existence of contextual effects and may then be developed for further analyses.

AKA Addresses: Tackling the Problem of Double Counts for Building Data

The data set was organized to record Asthma ED visits for the primary building address (i.e., the address reported to the ED) as well as for ‘AKA’ addresses. Recall that ‘AKA’ addresses referred to multiple addresses for the same building (usually corner buildings) with the same unit and violations numbers reported and Asthma ED visits by address. The count of Asthma ED visits was recorded for each building. For those buildings with one or more AKA addresses Asthma ED visits were totaled for AKA address and Asthma ED visits from the primary address and entered into a separate data column. Thus, two Asthma ED measures had been entered for each building: the first reflected Asthma ED visits for the primary address only and the second measure reported all Asthma ED visits for all addresses associated with that building (i.e., including AKA building addresses). Unduplicated building level Asthma ED visits totaled 1257 (i.e., non-AKA totals where visits are counted only by their addresses and not totaled for all visits in a building with more than one address). This total differs from the totals for segment level Asthma ED visits (N=1273) because segment-level data included visits associated with addresses not included in the building-level measures (e.g., non-multiple dwelling buildings).

Modeling geographic directions. The solution for managing the analyses with complete Asthma ED visits for each building without double counting other variables was to create separate models for different geographic directions. Since most "AKA" buildings were located on corners, models were designed to consider north-south running buildings and segments separately from east-west oriented structures. Buildings and segments were coded as '1' if they were on a north-south axis, '2' for east-west. This conceptualization was supported by important differences in the characteristics of many of New York City streets and avenues including street width and the presence of dividers that sometimes separate the sides of avenues. These features had initially prompted differences in defining the segment level of analysis for the study design.

Selecting the Best Procedure for the Modeling

When the model was defined as having both fixed and random variables a SAS mixed model program, PROC MIXED (procedure for mixed linear models) was specified for the analyses. The results of early models are used to facilitate improving the model for better fit through an iterative approach. Results of the

PROC MIXED estimates indicated that not only was there non-normality of distributional characteristics (i.e., means, variances, and covariances) but there were also problems with deviance statistics (i.e., tests for lack of fit between the model and data) and therefore problems with the model fitting the data. In particular, there was a tendency for overdispersion in the model which can lead to large error terms (i.e., unexplained variance) indicating the existence of a factor influencing clustering at the building level had may not have been accounted for.

Because of the major departures from normality, however, the mixed model now becomes more complicated and the multiple linear regression process (HLM) that can usually be applied to multilevel designs required modification. In its place, hierarchical generalized linear modeling (HGLM), a form of generalized linear modeling intended for multilevel studies, was considered the appropriate format to manage the non-normal Asthma ED visit distribution. HGLM is also well suited when there are small data counts and is modeled as an expected value of the count. Research on this approach and appropriate software is ongoing to develop the most effective statistical applications for the procedure (Snijders & Bosker, 1999). One HGLM statistical application is *GLIMMIX*, a general linear model for mixed distributions in a mixed model program that can be used to account for the relationship (or nonindependence) between buildings in the same segment when building level analysis is embedded or nested in street segment level data.

<u>Identifying variables for the models.</u> Variables were first entered into the building-level model based upon the preliminary bivariate correlations and theoretical associations. Creating subsets of conceptually related variables and fitting a submodel to each subset is also an exploratory strategy for identifying the strongest predictors that can then be entered into the overall model (Raudenbush & Bryk, 2002). Deviance statistics, produced when the models are run with the selected variables, account for the remaining variance and help to determine the best-fitting model for analysis (Kreft & Leeuw, 1998). The goodness of fit of the model is understood in part in the context of differences between the deviance measures of multiple models fitted to the same data; the larger the values, the poorer the fit.

<u>Analysis of the dispersion coefficients</u>. The models produce a measure of overdispersion, a condition more common than is underdispersion and which indicates the amount of spread or variation among the data in the model. Overdispersion resulting from preliminary models was calculated by dividing the Pearson Chi Square estimate by the total model degrees of freedom (North-South building level Pearson Chi-Square / DF=1.60; East-West building level Pearson Chi-Square / DF=2.79). Values greater than 1 indicate overdispersion, less than 1 indicate underdispersion. The dispersion of the early models suggested that the Asthma count data at the building level demonstrated variances larger than permissible under Poisson conditions. A review of the data suggested that the ‘0’ apartment unit buildings (i.e., buildings coded with 0 units, n=237) was problematic for the analysis. Additional information on these buildings was sought from original databases. Many formerly '0' unit buildings were subsequently removed from the data set when they could not be classified as a multiple-dwelling for purposes of analysis. Some of the removed buildings could be reclassified into other variables (e.g., *vacant buildings, pollution sources*) but ultimately all '0' unit buildings were eliminated from the building level analysis. The adjustment made improvements on the overdispersion measure (North-South building level Pearson Chi-Square / DF=1.33; East-West building level Pearson Chi-Square / DF=2.39). This final modification to the data resulted in a total of 2556 buildings (North-South n=690, East-West n=1866) and 268 street segments (North-West n=165, East-West n=103) for analysis.

Obtaining baseline and total variance measures. A "null" or empty model was run to get a measure of the intraclass correlation to help convey information on the amount of similarity or homogeneity of buildings in a street segment. This estimate is prior to including any explanatory or control variables in the model and provides a ratio to estimate how much of the variance of Asthma ED outcome visits already existing within the segments (among the buildings) can be explained by the variance that exists between the segments, as below:

$$5p_1 = \frac{\text{variance between segments}}{\text{total variance}}$$

The result is an estimate of the existing variances and differences in clustering between segments that can be compared with the changes in variance accounted for when explanatory variables are entered into the model. It provides the basic partitioning of variances in the data between the different levels of analysis and is also the fraction of variance that might be explained by the group variable.

Managing Subgroups of the Variables

Preliminary correlations between variables were obtained using the Pearson r. These coefficients are discussed in the chapter on Results. It became clear while examining building level data that some variables had an insufficient number of records to support analysis. In addition, reducing the number of variables would help to increase stability in the model (Kreft & Leeuw, 1998). Decisions were made to combine subcategories of variables into larger total aggregates as explained in following cases:

Pollution Sources

All building (level 1) and segment (level 2) data on sources of pollution had been classified according to the two categories defined earlier, sources originating from dry cleaners/parking facilities/gas stations and other EPA-defined hazardous waste sources. These sources account for stationary sources associated with VOCs (volatile organic compounds) as opposed to particulates, dust, or temporary exposures. On the building level these sources were identified as either being located in a residential building (coded 1, N=47 occurrences of *in-building* sources of pollution) or not (0). On the segment level the pollution category classifications still held and were summed for all sources, irrespective of whether they were located in a residential building (N=104 total occurrences of segment level pollution sources) because summing *in-building* sources did not seem conceptually relevant for the group variable.

Subcategories were found to have too few records for statistical purposes, however, and were aggregated into a total for all sources of building level pollution. Combining sources of pollution is defensible since the primary form of pollution for most of the locations is VOCs that have been associated with bronchial irritation and known triggers for asthma exacerbation (Norback, Bjornsson, Widstrom, Bowman, 1995). Segments were also coded for whether or not there existed more than one source of pollution (1=yes, 0=no).

Violations Data

Similarly, violations data had been classified quantitatively at both levels of analysis according to evidence of problems related to moisture, rodents, heat, or roaches, all believed to contribute to asthma exacerbation. The subcategories of data were then aggregated first to a subgroup *trigger violations* (n=1591 violations associated with trigger conditions known to be related to asthma exacerbation, summed over 2556 buildings) as well as for total violations (N=13,926) to create a surrogate indicator of overall building quality to offer a larger data set for examination. Violations were summed to the street segment level as one indicator of the overall quality of a segment by virtue of the building condition and potential "spillover" of problems (e.g., rat and roach harborages) in one building to others.

Vacancy Counts

Subcategories of *vacant properties* were also collapsed for both the building and segment level measures. On level 1 the measure was a 2 level variable, with absence of building vacancy coded as '0' and a *vacant building or* *partially vacant building* was coded as ‘2’. On the segment level *vacant lots* was coded as 1, the segment total for *building vacancy* coding remained the same as for building level coding. All codes were summed for each category and a total for all vacant properties was obtained as a measure of disinvestment or abandonment.

Types of Building Ownership

Again, ownership information was recorded in subcategories that were also aggregated as composite variables where appropriate. For example, the *HPD ownership* variable consisted of several subcategories associated with HPD operations or programs such as Central Management and 7A housing as well as DAMP (Division of Alternative Management) and “Mitchell Lama” Housing. These subcategories were later collapsed under a *HPD* ownership category. *HDFC* (Housing and Community Development Fund) and *TIL* (Tenant Interim Lease) programs were also later combined as a special form of transitional and tenant ownership.

After all variables were combined as noted, there remained a total of 10 building level 1 independent variables of which 8 were explanatory variables: *trigger violations, in-building pollution sources, corner location of building, type of building owner, building vacancy, on a bus route, more than one bus route located within 100 meters, number of buses per year within 100 meters*; two variables were used to control for other potential sources of clustering: *number of apartment units, number of non-Asthma ED Visits* (with and without AKA counts); and two dependent variables, *Asthma ED visits* and *Asthma ED visits* *with AKA counts*). Segment level 2 variables totaled 13 independent factors including 5 explanatory variables aggregated from the building level 1 data: *trigger violations, vacant properties, total pollution sources, type of ownership,* and *corner buildings.* There were four additional segment level explanatory variables: *on bus route, number of construction sites, more than one pollution source,* and *segment density.* Also originating with first level data were control variables *apartment units,* and *non-asthma ED visits* (with and without AKA counts). *Access to alternative care* and *relative wealth* were 2 second level variables.

<u>Defining Non-Asthma Emergency Visits as a Comparison Group</u>

Another variable requiring closer examination and ultimately modification involved the comparison group of non-asthma ED visits. Preliminary Pearson bivariate comparisons showed significant relationships between Asthma ED and all non-asthma ED visits. As explained earlier, all diagnostic categories for all non-asthma ED visits during the study year were included for a total of over 5000 records. This comparison group was almost five-times the size of the Asthma ED group and included all diagnoses. An examination of the diagnostic groupings revealed that some diagnoses could potentially have links to environmental factors. Thus, the non-asthma data was thought to be contaminated by these confounding diagnoses and contributing to spurious associations with the Asthma ED variable. There was also substantial overdispersion, a statistic indicating the quality of the model and the overall spread or distribution in the data. Overdispersion is associated with low standard errors and can increase the chance of Type I errors.

To address this dilemma and identify a suitable comparison group that would control for propensity to use the HHC ED for inappropriate or other reasons, each non-asthma ED visit was categorized by its diagnostic classification, with exclusions of diagnoses that could clearly be related to environmental exposures. Correlations were run between each diagnostic category and the Asthma ED outcome variable and 5 categories that had insignificant associations were identified. A composite variable combining infectious and parasitic diseases, diseases of the nervous system and sense organs, diseases of the musculoskeletal system and connective tissue, and normal pregnancy was created to serve as the non-asthma ED third variable comparison group (N=852 nonasthma ED visits for all buildings).

Initially the study included only those buildings that had at least one asthma visit. Concerns were raised, however, that excluding non-asthma multiple dwelling buildings might miss the very conditions that were being tested and could bias the study given their substantial numbers (n=2130). Including non-asthma buildings resulted in rather extreme skew and kurtosis, however, requiring transformation of the non-categorical variables.

CHAPTER IV: RESULTS

A number of steps were completed towards the objective of determining if environmental factors were significantly related to Harlem Hospital Center Asthma ED visits. The first stage in the study showed through spatial data analysis that there were significant spatial patterns (clusterings) in the addresses associated with Asthma ED visits. After demonstrating that the residential addresses of Asthma ED visitors were not distributed equally across the study area but instead exhibited a local clustering effect, environmental qualities hypothesized to be risk factors were defined, measured, and entered into models created to explain links to asthma emergency care utilization. These models showed main effects for explanatory factors in the buildings and the street segments in which the buildings were located. Thus, the findings establish a contextual effect of ecological risk factors on building level Asthma ED visit outcomes. Results for this multistage process are reported below.

Spatial Data Analysis for Clustering of Asthma ED Visits

Spatial data analysis was performed on all 1669 points of the outcome data representing all visits to the Asthma Emergency Department during the study period March 1997 through February 1998. The data included all recorded visits (corrected for 19 visits from the same patient in the same day) from the study area and a surrounding 'donut' area added on to avoid a boundary effect and separation of existing clustered addresses. A K-function performed on the data set and weighted with population estimates from census block data as a preliminary control for population distribution revealed clustering from distances of approximately 10 meters through 140 meters (see Figure 3).

The data set was also disaggregated by calendar month as a way to allow for greater sensitivity to subtle time and space patterns and to facilitate computer-generated analyses that can become dysfunctional when the data set overwhelms the computer resources. Knox tests for point pattern analysis indicated significant findings for space and time interactions at p values of .05 or greater in each of 4 months of the 12-month study year for a total of 13 findings of significant clusterings (see Table 1). Seven of these clusterings occurred within a designated radius of either 30 or 50 meters of an address and 6 clusterings occurred within 100 meters radius. All significant clusterings occurred at 2, 3, 5, or 7 day intervals, suggesting that there may have been lags between some exposures and visits to the Asthma ED. Specific locations of significant time-space clusterings could not be identified because of limitations of the GIS computer software. Significant months reported were April (Asthma ED visits, n=112), August (n=124), October (n=159), and December (n=117) with more than half of the significant findings (7) reported in the month of August. No significant clusterings were found in any month where Asthma ED visits occurred in relation to each other at greater than or equal to 200 meters.

The Knox findings indicated that in some neighborhood areas the number of Asthma ED events that occurred within a 30-, 50-, or 100-meter

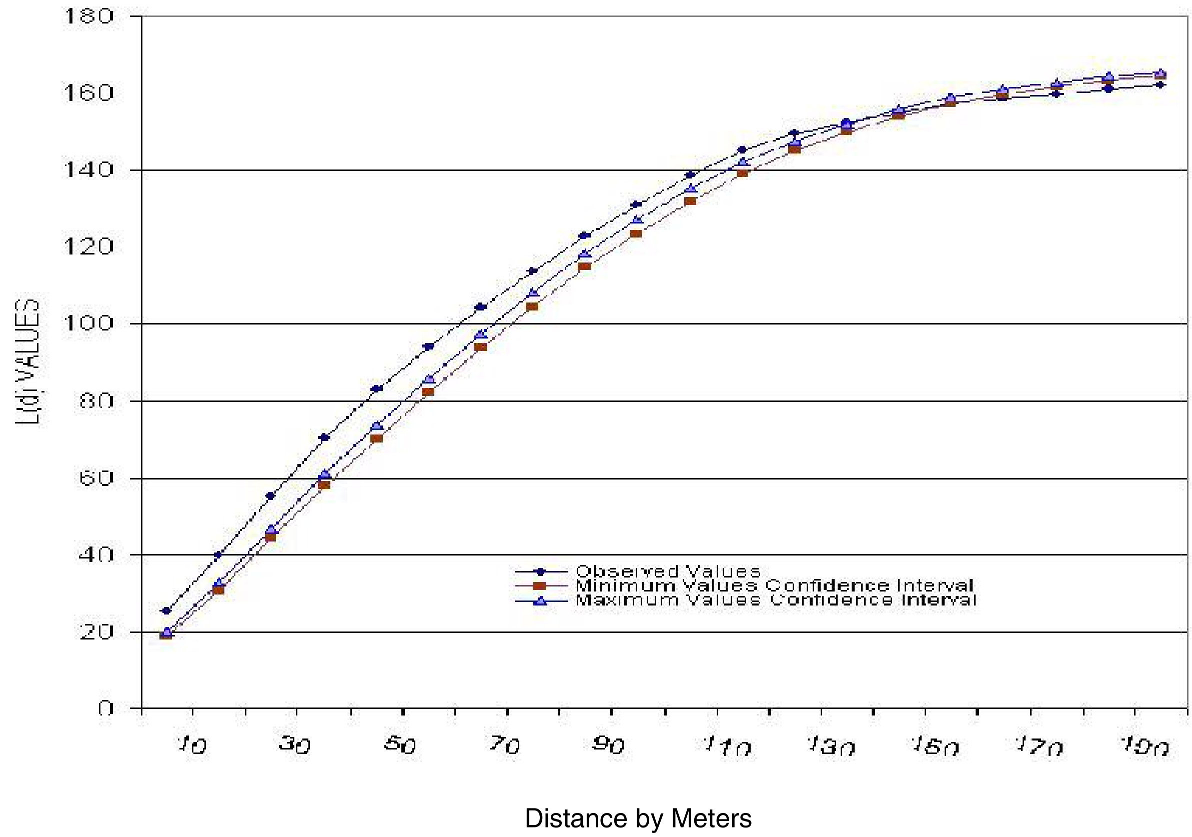


Figure 3. K function with population weights indicating clusters of Asthma ED vists. Includes “donut” area to avoid border effect, N=1669

Table 1
Knox Chi Square Summary Table of Trends and Significant Findings for Space & Time Distributions of Visits to Harlem Hospital Asthma ED, 3/1/97-2/27/98

Period **And # of** *Asthma ED Visits*	***Distance (d) in meters and Time (t) in days***														
	d/ 30 t/ 1	***d/ 30 t/2***	***d/ 30 t/3***	***d/ 30 t/5***	***d/ 30 t/7***	***d/ 50 t/1***	***d/ 50 t/2***	***d/ 50 t/ 3***	***d/ 50 t/5***	***d/ 50 t/7***	***d/ 100 t/1***	***d/ 100 t/2***	***d/ 100 t/3***	***d/ 100 t/5***	***d/ 100 t/7***
Jan n=163	*	*	*	-	-	*	-	*	-	-	*	-	*	-	-
Feb n=120	*	-	*	-	-	*	-	**	-	-	*	-	*	-	-
March n=122	*	-	*	-	-	*	-	*	-	-	*	-	*	-	-
April n=112	*	-	*	*	-	*	*	p< .05	p= .02	p= .06	*	-	*	-	-
May n=175	*	-	*	-	-	*	-	*	-	-	*	-	*	-	-
June n=163	*	-	*	*	*	*	-	*	*	*	*	*	*	*	*
July n=133	*	-	*	-	-	*	-	*	-	-	*	*	*	*	-
Aug n=124	*	p= .02		p< .01	p= .058	p= .07	p= .002	p< .01	*	-	*	*	p= .04	p= .03	p< .01
Sept n=144	p= .06	*	*	*	-	*	*	*	-	-	*	-	*	-	-
Oct n=159	*	*	p= .08	p= .09	p= .03	*	-	*	-	-	*	-	*	-	*
Nov n=137	*	*	*	*	-	*	-	*	-	-	*	-	*	-	-
Dec n=117	*	*	*	-	-	p= .07	*	*	*	p= .0545	p= .06	p= .03	*	p= .02	p< .01

Note. Data events include the study area with 'donut' area to avoid border effect. N=1669.
* Test resulted in non-significant results.
- No test performed.

radius and within a few days of each other was significantly greater than would be expected under random conditions, thus supporting the first research question showing that Asthma ED visits were not distributed equally in the CD
10 area of interest.

Descriptive Statistics Reports

Figure 4 shows frequencies of Asthma ED visits as a function of number of *apartment units* in a thematic map using graduated symbols. The asthma visits are presented as ratios or percents of the building level total of *apartment units.* In spite of the irregularities of street address geocoding which shift addresses to one side of the segment, the map shows Asthma ED visits clustered by varying ratios in some areas and not in others, by building and along segments, and controlling for *apartment unit* numbers. Figure 5 adds nonasthma Emergency Department data to show how these frequencies compare to the distribution of Asthma ED visits. While some of the nonasthma clustering occurs simultaneously with the asthma clustering there are also areas of dissimilarity. Descriptive information including mean, sum, range, and distributional characteristics (i.e., kurtosis and skew) for building and segment level noncategorical variables for both geographic directions are shown in Table 2. Table 3 contains the descriptive reports for building and segment level categorical explanatory variables. Building-level reports indicated that the outcome variable Asthma ED visits was positively skewed (i.e., many low-end values and a few high values) with positive kurtosis (i.e., too long a tail to the right of the distribution indicating observations cluster more). This asymmetry

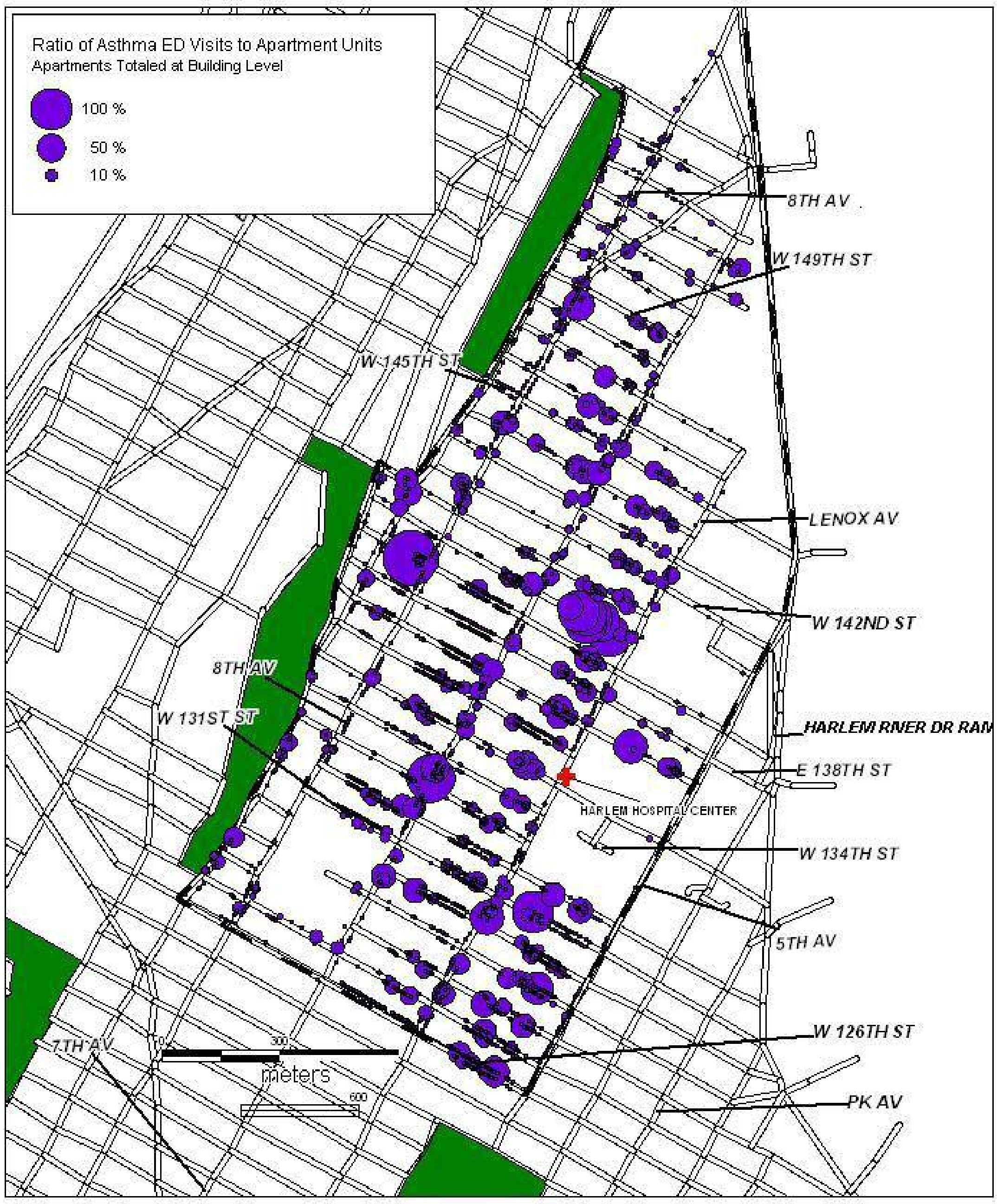


Figure 4. Thematic map showing Asthma ED frequencies compared to total apartment units at the building level.

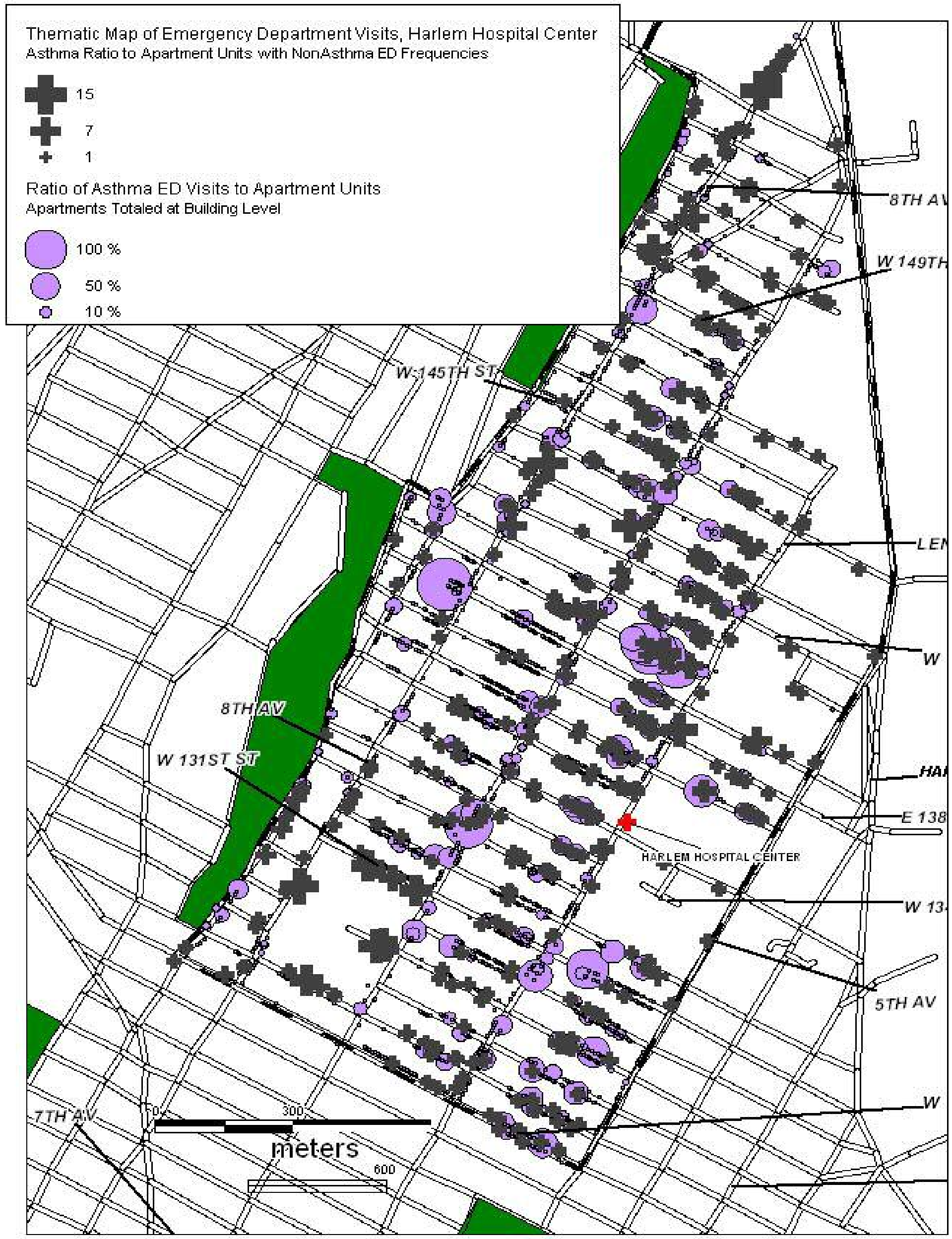


Figure 5. Thematic map showing ratio of Asthma ED visits to apartment units. Non Asthma ED visit frequencies added to compare distributions.

Table 2
Descriptives for Non-Categorical Explanatory, Control, and Outcome Variables

BUILDING LEVEL NON-CATEGORICAL VARIABLES

	N	**Mean**	**Std Dev**	**Sum**	**Minimum**	**Maximum**	**Skew**	**Kurtosis**
Asthma Visits	2556	0.5766	2.0426	1474	0	24	5.6876	38.9431
# Buses W/I 100m Per Year	2556	79556.0532	94849.0431	203345272	0	619684	2.4281	6.5746
Total Bld Violations	2475	5.6220	27.0981	13920	0	535	10.6322	147.8184
Moisture Violations	2475	0.2291	1.3884	567	0	30	12.1143	188.6007
Rodent Violations	2475	0.1830	0.964	453	0	19	11.1702	172.6556
Heat Violations	2475	0.1046	0.8759	259	0	22	16.4052	350.1630
Roach Violations	2475	0.1261	0.6597	312	0	11	9.2601	110.9375
Trigger Violations	2475	0.6428	3.1660	1591	0	54	9.6404	115.7567
Apartment Units	2556	20.4377	37.7568	51033	1	211	5.9701	41.2268
NonAsthma Visits	2556	0.384	1.231	982	0	19	5.828	48.644

Table 2
Descriptives for Non-Categorical Explanatory, Control, and Outcome Variables (cont)

SEGMENT LEVEL NON-CATEGORICAL VARIABLES

	N	Mean	Std Dev	Sum	Minimum	Maximum	Skew	Kurtosis
Asthma Visits	268	5.62	8.73	1505	0	57	2.539	7.938
Segment Density	268	.18445	.29290	49.432	.002	3.180	5.893	47.012
Total Bld Violations	267	52.1	98.29	13920	0	617	3.226	12.172
Moisture Violations	267	2.12	4.70	567	0	30	3.741	15.841
Rodent Violations	267	1.70	3.41	453	0	23	3.375	13.746
Heat Violations	267	.97	3.12	259	0	33	6.276	51.041
Roach Violations	267	1.17	2.31	312	0	13	2.801	8.236
Trigger Violations	267	5.96	11.40	1591	0	69	2.987	9.404
Apartments Units	268	190.42	207.81	51033	7	1600	2.180	7.635
NonAsthma Visits	268	3.66	5.88	982	0	39	2.711	9.080
# Of Street and Sidewalk Constructions	254	2.52	4.71	639	0	43	4.629	29.321
Vacant Lots	268	.66	1.81	178	0	16	4.429	25.227
Vacant Buildings	268	1.33	2.78	357	0	17	3.272	11.986
Partially Vacant Buildings	268	.34	.82	90	0	6	3.520	15.556
Total Vacant Properties	268	2.33	4.23	625	0	33	3.411	15.528

Table 2
Descriptives for Non-Categorical Explanatory, Control, and Outcome Variables (cont)

SEGMENT LEVEL NON-CATEGORICAL VARIABLES

	N	Mean	Std Dev	Sum	Minimum	Maximum	Skew	Kurtosis
Dry Cleaner/ Parking/Gas Station	268	.22	.65	59	0	6	4.447	27.125
Other EPA Pollution	268	.21	.56	56	0	4	3.589	16.502
# Corner Buildings	268	1.34	1.04	358	0	5	.506	.021
Private Owner	268	7.24	12.03	1939	0	70	2.939	8.903
Hpd Owned /Managed	268	1.35	2.15	361	0	16	2.644	9.886
Nycha Owner	268	.41	1.29	110	0	9	3.821	15.740
Til And/Or HDFC	268	.28	.82	75	0	6	4.018	19.034
Misc Owner	268	.13	.50	36	0	4	5.093	30.934

Note. Asthma ED visits includes multiple building addresses. Values are raw, non-transformed.

Table 3
Descriptives for Categorical Variables

BUILDING LEVEL VARIABLES

	N	Mean	Std Dev	Sum	Minimum	Maximum
On Bus Rte	2556	0.2801	0.4491	716	0	1
On > 1 Bus Rte	2556	0.2026	0.4021	518	0	1
In Building Pollution	2556	0.0188	0.1358	48	0	1
Dry Cleaner, Parking. Gas Station	2556	0.0063	0.0789	16	0	1
Other EPA Pollution	2556	0.0125	0.1112	32	0	1
Corner Buildings	2546	0.1406	0.3477	358	0	1
Private Owner	2521	0.7691	0.4215	1939	0	1
HPD Owner	2521	0.1432	0.3503	361	0	1
NYCHA Owner	2521	0.0436	0.2043	110	0	1
Til Or HDFC Owner	2521	0.0298	0.1700	75	0	1
Other Owner	2521	0.0143	0.1187	36	0	1
Vacant Buildings	2556	0.1342	0.3409	343	0	2
Partially Vacant Building	2556	0.0329	0.1783	84	0	3
Geographic Direction	2557	0.4440			1	2

SEGMENT LEVEL VARIABLES

	N	Mean	Std. Dev	Sum	Minimum	Maximum
EST. Wealth	259	.74	.44	191	0	1
Clinic within 150 M of Segment	259	.21	.41	57	0	1
Clinic between 150-300 M of Segment	268	.29	.46	78	0	1
Clinic > 300 M 300 M From Segment	268	.50	.50	133	0	1

was in part the result of many buildings with ‘0’ Asthma ED visits. Since the outcome data involved counts and, given that the distribution showed decided skewness and kurtosis, the analysis of Asthma ED visits assumed a Poisson distribution rather than a normal distributional assumption for the calculation of significance levels for the explanatory variables.

Recall that the existence of buildings with more than one address typically on corners (i.e., “AKA” buildings) resulted in classification of buildings and segments in terms of their location on the north-south or east-west geographic axis. Subsequent descriptives and statistical operations are reported by these geographic directions.

Transformation of Variables

Many of the noncategorical variables also demonstrated severe violations of statistical assumptions due to non-normality. Because of their kurtotic nature, most continuous variables required log or square route transformation. While this was the case for buildings and segments in both geographic directions there type of transformations sometimes varied with the geographic direction. The variable East-West building level *non-asthma ED visits* was extremely kurtotic and as a result the *GLIMMIX* procedure encountered convergence problems (difficulty completing statistical operations) when estimating the parameters. To help address this problem, East-West *non-asthma ED* building data were recoded into discrete ordered categories labeled 1 (1-2 events), 2 (3-4 events), and 3 (5 or greater events) for each address where a *non-asthma ED visit* was recorded.

Private owner in the building ownership variable and *corner location* did not need to be transformed for the segment level in either geographic direction. *Apartment units* measures for the East-West segment level were also not transformed. The transformations reduced the problems of skew and kurtosis for the explanatory variables by smoothing out some of the extreme variation.

Examining Preliminary Correlations

Pearson correlations were obtained for building and segment level variables prior to creating composite variables by combining selected similar variables as described in the previous section. The combined variables included *trigger violations* (the combined form of individual category violations)*; pollution sources* (2 subcategories of VOC pollution sources); and *ownership* (combining HDFC and TIL housing in one category and another for HPD-related groups). Correlations were also calculated for the explanatory variables and the outcome variable. These preliminary analyses were used to identify variables that appeared to be the most predictive of the outcome.

There are practical approaches to interpreting the strength of the relationships as suggested by the Pearson correlations. Cohen's guidelines for effect size, for example, suggest that correlations in the range of .10 are small, those of .30 are of medium strength, and correlations of about .50 are considered a large effect. Interpretations of correlations for the purposes of effect size, however, should not be made out of context. Thus, there may be implications for seeming small correlations depending on policy or ethical decisions, comparisons with other correlations, or upon the standard against which the correlation is measured (Hemphill, 2003).

Environmental factors. After the data were organized by north-south and east-west geographic directions to avoid duplicate counts of AKA building information, correlations were also obtained for variables by geographic direction. Tables 4 and 5 display the strongest correlations for environmental variables and potential covariates considered important in the conceptual framework or that were found to be meaningful in predicting Asthma ED visits for each direction. At the building level, the correlations for *trigger violations* and Asthma ED visits in the North-South were .12 (raw) and .15 (transformed). For the East-West buildings the correlations were .13 (raw) and .14 (transformed). *Trigger violations* was formed by combining individual *moisture-, rodent-, roach-, and heat-related* violations as a way to focus on those violations representing environmental conditions supported by the literature and to offset the limited numbers available in the subcategories of violations. Location as a *corner building*, *on a bus route*, and *in-building* sources of pollution were also correlated with Asthma ED visits on level 1 in both directions. For North-South buildings, correlations for *corner location* were .10 (raw and transformed); for being *on a bus route* correlations were .08 (raw and transformed); and for *in building sources of pollution* .17 (raw and transformed). East-West level 1 building correlations for *corner location* was .14 (raw and transformed); for location *on a bus route* was .07 (raw and transformed); and for *in building sources of pollution* .19 (raw and transformed). The building level *vacancy* factor measuring

Table 4

Pearson Correlations for Building Level Environmental Variables, Transformed and Mean Centered

	EAST-WEST BUILDING CORRELATIONS					
	Apartment Units	Trigger Violations	Vacant Buildings	On Bus Route	Corner Buildings	Asthma Ed Visits
Asthma Ed Visits	0.38069 <.0001 1820	0.14218 <.0001 1811	-0.09450 <.0001 1866	0.06683 .0039 1866	0.13513 <.0001 1857	1.00000 1820
Total Trigger Violations	0.19508 <.0001 1801	1.00000 <.0001 1811	-0.12001 0.0015 1811	0.07457 <.0001 1809	0.15808 <.0001 1811	0.14218 <.0001 1811
Corner Building	0.16455 <.0001 1801	0.15808 <.0001 1809	-0.08558 0.0002 1857	0.08601 0.0002 1857	1.00000 1857	0.13513 <.0001 1857
Inbuilding Source Of Pollution	0.15504 <.0001 1820	-0.01797 0.4448 1811	-0.03146 0.1744 1866	0.06544 0.0047 1866	-0.01797 0.4897 1857	0.19281 <.0001 1866
# Of Buses Per Year Within 100 M	0.10943 <.0001 1820	0.01750 0.4566 1811	0.00025 0.9914 1866	0.14834 <.0001 1866	0.12549 <.0001 1857	0.02191 0.3443 1866
Hpd Owned/ Managed	0.05785 <.0139 1807	-0.09757 <.0001 1797	0.12896 <.0001 1840	0.06141 0.0084 1840	0.02373 <.3095 1837	-0.02485 0.2867 1840
Private Owned	0.12789 <.0001 1797	0.12789 <.0001 1797	-0.03729 <.1098 1840	-0.03002 0.1981 1840	-0.04496 0.0540 1837	-0.08446 0.0003 1840

Table 4
Pearson Correlations for Building Level Environmental Variables, Transformed and Mean Centered (cont)

NORTH-SOUTH BUILDING CORRELATIONS

	Apartment Units	Trigger Violations	Vacant Properties	On Bus Route	Corner Buildings	Asthma Ed Visits
Asthma Ed Visits	0.46140 <.0001 677	0.15283 <.0001 664	-0.11686 .0021 690	0.07654 <.0444 690	0.09507 <.0125 689	1.00000 690
Total Trigger Violations	0.21691 <.0001 661	1.00000 0.4754 664	-0.18263 0.5547 664	0.02297 <.0001 663	0.20551 <.0001 664	0.15283 <.0001 664
Corner Buildings	0.18910 <.0001 677	0.20551 <.0001 663	-0.04434 0.2451 689	0.01633 0.6688 689	1.00000 689	0.09507 0.0125 689
Inbuilding Source Of Pollution	0.15255 <.0001 677	-0.02816 0.4688 664	-0.01252 0.7427 690	0.04353 0.2534 690	0.00672 0.8603 689	0.17095 <.0001 690
# Of Buses Per Year Within 100 M	0.13484 <.0004 677	0.05672 0.1443 664	0.00280 0.9415 690	0.29137 <.0001 690	0.06801 0.744 689	0.04811 0.2069 690
Hpd Owned/ Managed	0.01567 0.6853 671	-0.12383 0.0014 660	0.18698 <.0001 681	-0.10094 0.0084 681	-0.04318 0.2608 680	-0.06822 0.0752 681
Private Owned	-0.12815 0.0009 671	0.19959 <.0001 660	-0.07599 0.0475 681	0.01726 0.6530 681	0.07002 <.0680 680	-0.06823 0.0752 681

Table 5
Pearson Correlations for Segment Level Environmental Variables, Transformed and Mean Centered

	EAST-WEST SEGMENT CORRELATIONS					
	Apartment Units	Trigger Violations	Total Vacant Properties	Wealth	Corner Buildings	Asthma Ed Visits
Asthma Ed Visits	0.19330 0.0504 103	-0.06214 0.5349 102	-0.21445 0.0296 103	-0.04640 0.6483 99	-0.10394 0.2961 103	1.00000 103
Total Trigger Violations	0.52936 <.0001 102	1.00000 102	0.37853 <.0001 102	0.20455 0.0433 98	0.31645 0.0012 102	-0.06214 0.5349 102
Corner Buildings	0.38175 <.0001 103	0.31645 0.0012 102	0.32456 0.0008 103	0.32878 0.0009 99	1.00000 103	-0.10394 0.2961 103
Multiple Sources Of Pollution	0.16455 0.0967 103	0.04097 0.6827 102	-0.04978 0.6175 103	-0.12599 0.2140 99	0.04082 0.6822 103	0.09758 0.3268 103
Segment Density	-0.26261 0.0074 103	-0.28540 0.0036 102	-0.29991 0.0021 103	-0.18315 0.0696 99	-0.27878 0.0044 103	-0.01707 0.8641 103
Hpd Owned/ Managed	0.40152 <.0001 103	0.38409 <.0001 102103	0.62575 <.0001 99	0.26381 0.0083 103	0.41415 <.0001 103	-0.14226 0.1517 103
Private Owned	0.62762 <.0001 103	0.40618 <.0001 102	0.52787 <.0001 103	0.22469 0.0254 99	0.35804 0.0002 103	-0.14638 0.1401 103

Table 5
Pearson Correlations For Segment Level Environmental Variables, Transformed And Mean Centered (Cont)

	NORTH-SOUTH SEGMENT CORRELATIONS					
	Apartment Units	Trigger Violationss	Total Vacant Properties	Wealth Properties	Corner Buildings	Asthma Ed Visits
Asthma Ed Visits	0.40074 <.0001 165	-0.04321 0.5816 165	-0.21144 0.0064 165	0.03031 0.7036 160	-0.15278 0.0501 165	1.00000 165
Trigger Violations	0.12051 0.1231 165	1.00000 0.4754 165	0.05595 0.2368 160	0.09406 0.0006 165	0.26500 0.5816 165	-0.04321 165
Corner Buildings	-0.04597 0.5576 165	0.26500 0.0006 165	0.11491 0.1417 165	0.05578 0.4836 160	1.00000 165	-0.15278 0.0501 165
Multiple Sources Of Pollution	0.18011 0.0206 165	-0.02425 0.7572 165	-0.13939 0.0742 165	-0.04464 0.5751 160	-0.19262 0.0132 165	0.10313 0.1874 165
Segment Density	0.52902 <.0001 165	0.00664 0.9325 165	-0.17006 0.0290 165	-0.06859 0.3888 160	-0.22918 0.0031 165	0.24944 0.0012 165
Hpd Owned/ Managed	-0.05090 0.5162 165	0.03156 0.6874 165	0.43389 <.0001 165	0.04319 0.5877 160	0.13860 0.0758 165	-0.21240 0.0062 165
Private Owned	0.00359 0.9635 165	0.28833 0.0002 165	0.24990 0.0012 165	0.17697 0.0252 160	0.32267 <.0001 165	-0.17919 0.0010 165

partially and completely vacant buildings was negatively related to Asthma ED visits.

Correlations between Asthma ED visits and environmental variables showed weaker relationships at the segment level. Segment density in the north-south direction, however, had moderately strong positive correlations with Asthma ED (r=.249). Total of other EPA registered sources of pollution that did not include dry cleaners, parking facilities, or gas stations were also related to Asthma ED visits in the North-South segments but not in the East-West segments. On the other hand, total vacancies were negatively associated with Asthma visits in both geographic directions.

Third variables for control. As expected, building level a*partment units* was moderately correlated with Asthma ED visits. *Non-asthma ED visits* also had a strong association with the Asthma ED outcome both before (r=.45 building level and r=.81 segment level) and after the *non-asthma ED visit* variable was modified to a subset of the complete dataset (r=.54 North-South building level; r=.48 segment level; r=.42 East-West building level; r=.40 East-West segment level, all transformed variables) to minimize those diagnoses that had an environmental etiology or could be managed in an outpatient medical practice.

The Null Model: Assessing Baseline Correlations and Variability

In fitting multilevel models, the first step involves fitting what is called a null or empty model, i.e. a model with no explanatory variables. There are three reasons for fitting such a model.

The first is that the null model provides information about the extent to which there is variability in Asthma Ed admissions across the set of buildings. If significant variation does not exist, there is no point in proceeding with model building. On the other hand, if significant variation does exist, it sets the stage for partitioning the variance into that which is attributable to building characteristics and to segment (or contextual) characteristics.

Secondly, the null model provides information on the extent to which Asthma Ed visits from building to building are correlated with one another. This is assessed through the use of an intraclass correlation coefficient, which, unlike a Pearson correlation, ranges between 0 and 1. The higher the intraclass correlation, the more likely it is that Asthma Ed visits in any particular building are associated with Asthma Ed visits in buildings that are adjacent to it in a segment. The correlation is presumed to arise from possible segment (or contextual) characteristics. If segment/contextual factors are important, then their introduction into the model will reduce the magnitude of the intraclass correlation coefficient.

The third reason the null model is useful is that it provides evidence of the average Asthma Ed visits across the set of buildings.

North-South Buildings

The intraclass correlation obtained from the null model was relatively high (.7003). That is, there was more variation in effects on building level Asthma ED visits to be explained by segments (61.3%) than by the buildings. The estimate of variation to be explained by the segments was obtained by taking the value for the residual variance between segments from the North-South building null model and dividing it by the sum of the same residual value plus the building level variance from the null model. The intercept estimate for the same null model was significant (t = -4.85; P = <.0001) indicating that the average number of Asthma ED visits was significantly different from zero. When the parameter estimate (.7003) was exponentiated, the average Asthma ED visits per building was .50. Thus, the null model calculations show that there were significant differences in building level Asthma ED visits most of which could be explained by variations at the segment level.

<u>East-West Buildings</u>

The intraclass correlation for buildings in the East-West direction was somewhat lower (.29) than for North-South buildings. Therefore, there was less variance in Asthma ED visits to be explained by the segments with group or segment level factors potentially explaining as much as 29% of the variability in building level Asthma ED visits.

The East-West building level null model intercept is also significant (t = -4.84, p = <.0001) showing that the average number of ED visits differs significantly from zero. The parameter estimate for the intercept was -0.6967 and when exponentiated, yielded an average of .50 Asthma ED visits per building.

Final Model Regression Analysis

As explanatory variables were added to the models there were observed changes in the significance of the variables at both the building and segment levels of analysis. Results for each level and combined level I and II models for each geographic direction are shown in Table 6.

North-South Building Level Explanatory Predictors

In the North-South building level models, an increase in *trigger violations* was a highly significant predictor of increases in Asthma ED visits (p=0.0013) so that for every one-unit increase in *trigger violations* data there may be expected an 8.71% increase in Asthma ED visits. Buildings located on a *bus route* were also associated with increased Asthma ED visits (p =.0381) meaning there are 1.95 Asthma ED visits for buildings on bus routes compared to the average (.50). *Corner buildings* (p<.0001) were also linked to 1.76 Asthma ED visits (again, compared to the average). *In-building pollution* sources, however, was not a significant predictor of Asthma ED visits. *Building vacancies* were inversely associated with Asthma ED visits indicating, not surprisingly, that, as the number of vacant properties increased, the number of Asthma ED visits decreased. Asthma ED visits were significantly higher in buildings with more apartments units (p<.0001).

North-South Segment Level Effects

At the segment level, explanatory variables were different than at the building level. For the North-South models, *segment density* had a direct and positive relationship to the outcome variable (p =.0017). Buildings located on segments with higher densities were associated with 65.67% more Asthma ED visits with each one-unit increase in *segment density*. Buildings embedded in segments with greater numbers of *trigger* violations were also likely to have more

Table 6
Final Multilevel Models for Building Level, Segment Level, and Combined Levels for North-South a
West Asthma ED Visits

BUILDING LEVEL MODELS

Predictor Variable	**North South Building Level**			**East-West Building Level**		
	Estimate	***T Value***	***P Value***	***Estimate***	***T Value***	***P Value***
Trigger Violations	0.08350	3.24	0.0013	0.06453	2.73	0.0064
In-Building Pollution	NS	NS	NS	1.1525	5.70	<.0001
Bus Route	0.6653	2.09	0.0381	NS	NS	NS
Corner Location	0.5657	4.26	<.0001	0.3872	2.83	0.0059
Vacancy	-0.9022	-3.39	0.0013	-1.1582	-3.92	0.0002
HPD Owner	NS	NS	NS	-0.4330	-1.93	0.0586
Private Owner	NS	NS	NS	-0.6208	-3.86	0.0002
Nonasthma ED	0.5264	6.86	<.0001	0.7270	12.15	<.0001
Apartment Units	0.7075	8.57	<.0001	NS	NS	NS

SEGMENT LEVEL MODELS

Predictor Variable	**North South Segment Level**			**East-West Segment Level**		
	Estimate	***T Value***	***P Value***	***Estimate***	***T Value***	***P Value***
Trigger Violations	0.1415	1.81	NS	0.06958	1.82	0.0723
Segment Density	0.5048	3.19	0.0017	0.2817	1.88	0.0636
HPD Owner	-0.6267	-3.53	0.0006	-0.2647	-2.57	0.0117
Private Owner	-0.2229	-4.68	<.0001	-0.04629	-5.63	<.0001
Nonasthma ED	0.6961	6.75	<.0001	0.05001	3.95	<.0001
Apartment Units	NS	NS	NS	0.001528	2.40	0.0185

Table 6
Final Multilevel Models for Building Level, Segment Level, and Combined Levels for North-South and East- West Asthma ED Visits (cont)

COMBINED LEVEL MODELS

Predictor Variable	**North-South Levels 1 & 2**			**East-West Levels 1 & 2**		
	Estimate	***T Value***	***P Value***	***Estimate***	***T Value***	***P Value***
Building Trigger Violations	0.1043	3.64	0.0003	0.06360	2.64	0.0084
Segment Trigger Violations	-0.00303	-0.03	NS	0.08976	2.02	0.0465
In-Building Pollution	NS	NS	NS	1.1341	5.64	<.0001
Building Corner Location	0.6526	4.89	<.0001	0.4397	3.22	0.0019
Building Vacancy	-0.8525	-3.25	0.0019	-1.1589	-3.84	0.0003
Building Private Owned	NS	NS	NS	-0.4461	-3.26	0.0017
Segment Density	0.4545	2.82	0.0055	0.4651	3.75	0.0003
Segment HPD Owner	-0.3165	-1.75	NS	-0.3113	-3.07	0.0028
Segment Private Owner	-0.1293	-2.68	0.0082	NS	NS	NS
Building Nonasthma ED	0.5888	7.02	<.0001	0.6604	10.52	<.0001
Segment Nonasthma ED	0.3312	2.84	0.0052	0.04162	3.37	0.0011

Note. NS = Not Significant

Asthma ED visits (p =.072). Buildings located on segments having more buildings in *private* ownership or owned by *HPD,* however, were associated with fewer Asthma ED visits.

North-South Combined Levels Model

Significant associations for North-South building level *apartment units* and location on a *bus route* ceased to be significant in the combined model. *Trigger violations* continued to be highly significant at the building level (p =.0003) but segment level *trigger violations* were no longer significant. As more buildings on a segment were owned by *HPD* there were still fewer Asthma ED visits but the effect was now marginal (p = 0.0813). The relationships of other variables in the North-South analyses to Asthma ED visits remained essentially the same with the full model consisting of significant predictors with building level *vacancy, corner building, and trigger violations; building and segment level non-asthma visits; segment private ownership, segment density*, and marginally segment *HPD ownership*.

Building And Segment Level Variance for North South Models

Building level 1 variables were less important than level 2 segment variables in explaining differences in the amount of building level Asthma ED visits in North-South models. Only 2.9% of the variance in building level Asthma ED visits could be explained by including the North-South level 1 building model but group-level segment factors were responsible for 61.3% of the Asthma ED visit variance. Adding the North-South level 2 model (i.e., segment / group variables) explained an additional 47.2% of the segment differences (i.e., 61.3%) in Asthma ED visits.

East-West Building Explanatory Variables

Again, building level *trigger violations* was significantly related to Asthma ED visits ($p = .006$). That is, for every one unit increase in building level trigger measures there was a 6.7% increase in Asthma ED visits. While being located on a *bus route* was not related to Asthma ED visits in East-West as it was in North-South buildings, post hoc tests indicated that a building's location on a *corner* was significantly related to more Asthma ED visits in the East-West building model ($p = .0059$). An East-West residential building containing an EPA regulated form of pollution was also more likely to produce a greater number of asthma visits (3.17 vs. .50, $p < .0001$) than a building without such pollution. Finally, there were relationships between forms of ownerships and Asthma ED visits. Buildings under *private ownership* were associated with fewer Asthma ED visits ($p = .002$) and *HPD ownership* was marginally related to fewer visits as well ($p = .058$).

East-West Segment Level Effects

The variables that were significant in North-West segments were also significant for East-West segments. *Private and HPD ownership* continued to be associated with significantly fewer Asthma ED visits and *trigger violations* were again marginally significant ($p < .07$). *Segment density* was meaningful only as a trend in East-West segments ($p < .06$) while *apartment units* was significant for East-West but not North-South segment asthma visits ($p = .0185$).

Explanatory Variables in East-West Combined Model

In the combined East-West model *in-building pollution source* and *corner building location* remained significant building level positive predictors of asthma visits and *vacant properties* continued to be significantly associated with fewer Asthma ED visits at the same level of the model. *Private ownership*, a variable that was significant at the segment level only model, now falls out of the segment level component of the combined model but remains a significant predictor of fewer Asthma ED visits in the building level component of the combined model. *HPD ownership* continues to be significantly associated with fewer Asthma ED visits at the segment level component of the combined model but not at the building level. *Segment density* is now highly significant (59.22% increase in Asthma ED visits with an increase in *segment density*, p =.0003) in the combined model segment. *Trigger violations*, previously marginal at the segment level, is also now significant at both the building (p =.008) and segment (p =.0465) level after controlling for other variables.

East-West Building and Segment Level Variance

Adding the level 2 East-West model actually explained a considerable 77.6% of the possible 29% variance. Likewise, because the East-West buildings were less correlated the East-West level 1 building model accounted for 26% of the differences in building level Asthma ED visits compared to the North-South level 1 contribution of 2.9%.

Comparisons Between North-South and East-West Segments

Segment density and the *corner location* of a building were significantly associated with increased asthma visits in both North-South and East-West directions. While building level *trigger violations* were also significant independent predictors of asthma visits in both directions, there was an additional contextual or segment level effect of *trigger violations* in the East-West direction as indicated by the final models which combined both building and segment levels of analysis. Differences between North-South and East-West segment level apartment and building totals are shown in Table 7 with greater variability in East-West segment totals of buildings compared to North-South segments, as depicted in Figure 6.

Variation between segments. There was more variation in asthma visits that could be explained by differences in North-South segment variables than might be explained by North-South building level variables. Often only one or two large buildings comprised a segment (a total of 51 segments contained only 1 or 2 residential buildings). *Segment density*, calculated as the total number of apartment units over the total number of residential buildings over the length of the street segment, was one segment level variable that had significant effects on variations in building level asthma visits. Figure 7 illustrates the basic differences in segment density based on geographic direction. For density calculations, buildings were counted by the number of addresses, not by the range of addresses as they were for variable measures. A mean density index of .23 was calculated for 18,424 units distributed among 1206 buildings on North-

Table 7
Segment Apartment and Density by Geographic Direction

NORTH-SOUTH SEGMENT BUILDINGS AND APARTMENTS

	Segments		**Buildings**	**# Apartment Units**
	Valid	165		
	Missing	0		
Mean			7.31	111.39
Median			7	76
Mode			6	54[a]
Minimu			1	7
Maximu			31	1600
Sum	690		1206*	18424

[a] Multiple modes exist. The smallest value is shown

EAST-WEST SEGMENT BUILDINGS AND APARTMENTS

	Segment		Buildings	# Apartment Units
	Valid	103		
	Missing	0		
Mean			28.05	316.29
Median			22	286
Mode			7[a]	20
Minimum			1	8
Maximum			76	788
Sum	1866		2889*	32609

[a] Multiple modes exist. The smallest value is shown
* For purposes of segment density building totals are based upon individual addresses, not ranges.

NORTH-SOUTH SEGMENT DENSITY INDEX[a]

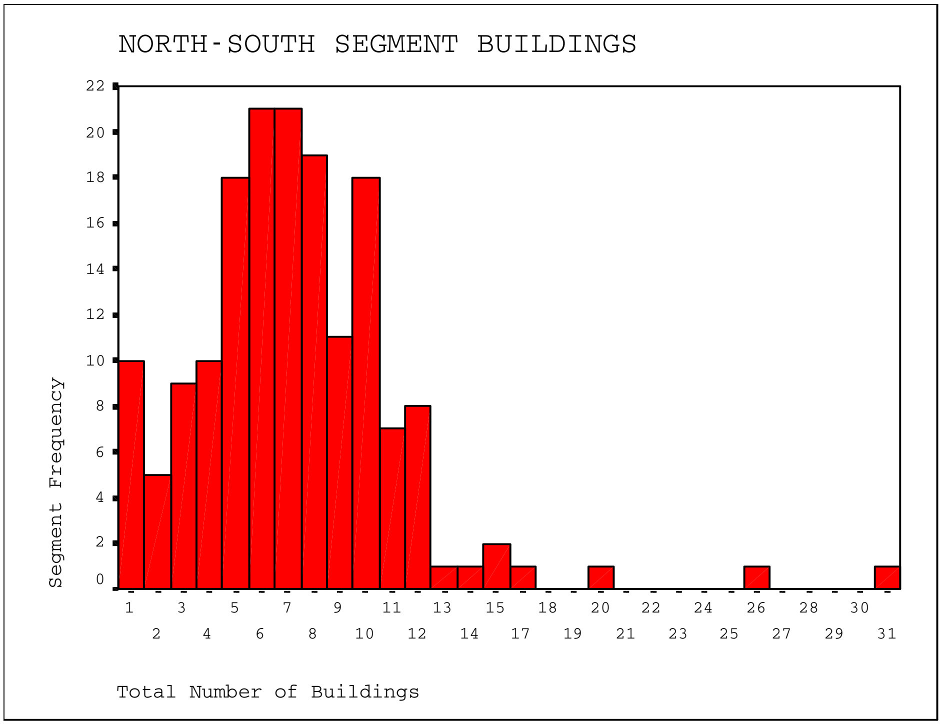
Segments		Segment density index
N	Valid	165
	Missing	0
Mean		.22503
Median		.14000
Mode		.100[b]
Minimum		.010
Maximum		3.180
Sum		37.130

[b] Multiple modes exist. The smallest value is shown

EAST-WEST SEGMENT DENSITY INDEX[a]

Segments		Segment density index
N	Valid	103
	Missing	0
Mean		.11944
Median		5.0000E-02
Mode		.030
Minimum		.002
Maximum		1.540
Sum		12.302

[a] Segment density calculated as the number of apartments divided by buildings over segment length.



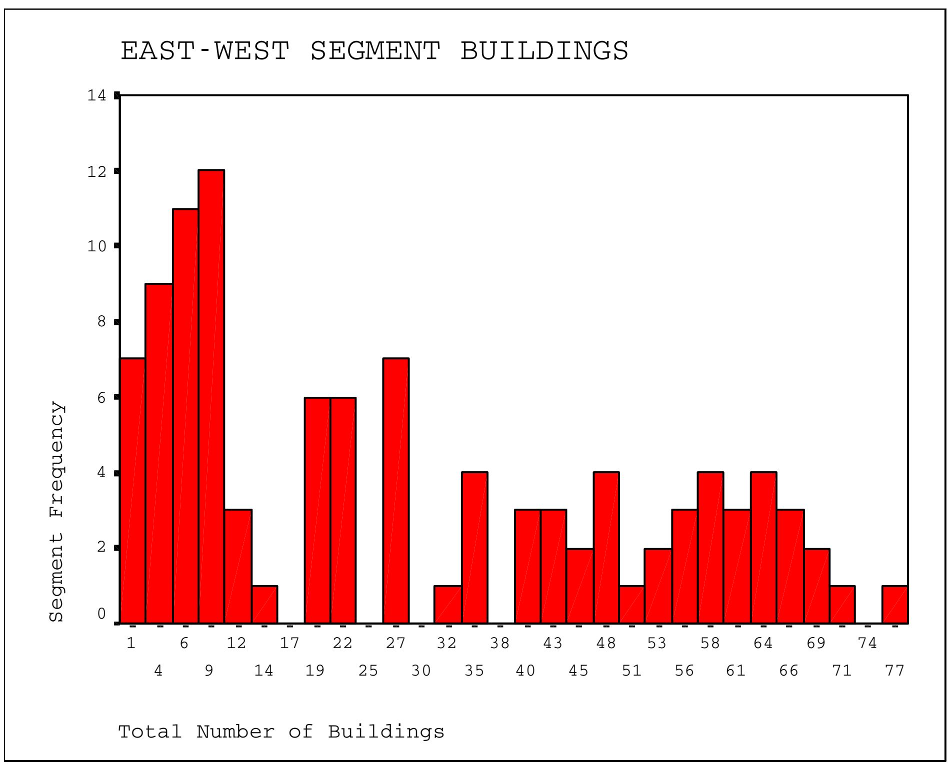
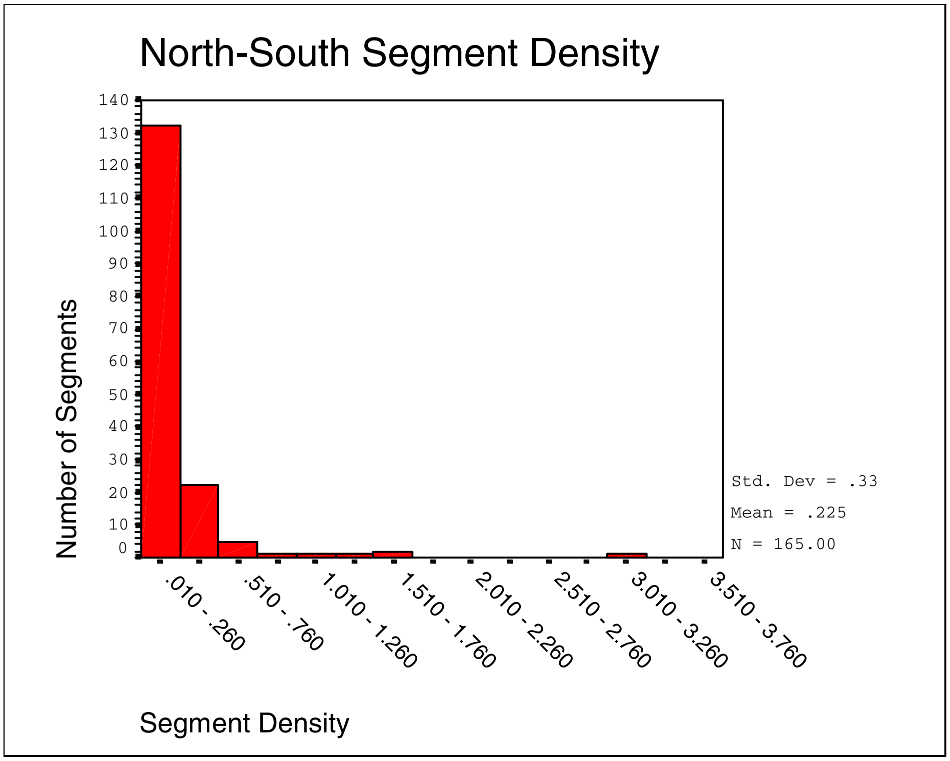


Figure 6. Histograms comparing numbers of buildings for North-South and East-West segments



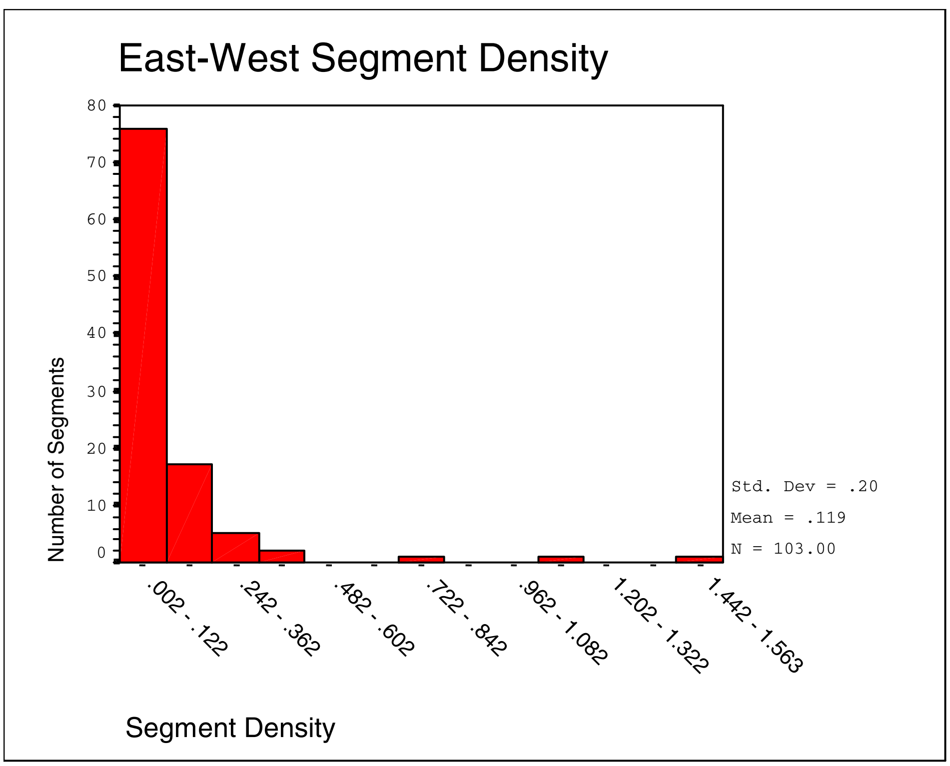


Figure 7. Frequency charts comparing density measures for North-South segments with measures for East-West segments.

South segments. This is compared to a mean East-West segment density index of almost half at .12 for 32,609 apartment units dispersed among 2889 buildings. There were also greater ranges in *segment density* estimates for North-South segments, from .010 to 3.180, than for East-West segments which ranged from .002 to 1.54. Follow-up calculations suggested that for every one unit increase in *segment density* there was more than 57% increase in Asthma ED visits as explained in the North-South combined model and 59% increase in the East-West combined model.

<u>Non-Significant Variables in the Multilevel Model</u>

Only variables that were significant at least at one level of analysis were included in the final models. Variables that demonstrated no meaningful relationship with the outcome variable or other variables through bivariate correlations or theoretical associations were not entered into the final models. In order to avoid "saturation" of the preliminary models in which too many specified variables result in a micro-partitioning of the variance and difficulty with interpretation, variables were entered into preliminary models in different combinations through a "step-up" strategy (Raudenbush & Bryk, 2002, p. 257-258). Variables are removed as their contribution to the explained variance and "fitness" of the models diminished. Building level 1 explanatory variables that were not included in the final models were number of buses within 100 meters of building and more than 1 bus route within 100 meters of building. Segment level 2 non-significant explanatory variables were total number of sources of pollution, existence of more than 1 source of pollution, and number of construction sites.

Access to alternative health care was a control variable that was also non-significant at the segment level.

CHAPTER V: DISCUSSION

Research linking environmental conditions to asthma has made substantial contributions to the identification of factors that exacerbate symptoms by focusing upon either individual or contextual levels of analysis. However, efforts to draw associations between these distinct levels of organization and to understand their respective roles in predicting asthma symptoms have been more difficult given a number of methodological and statistical challenges to the analysis of data from different levels of organization. Other studies have examined and identified positive relationships between asthma and proximity to sources of pollution at zip code and census tract levels (Oyana, Lwebuga-Mukasa, & Jamson, 2004; Oyana, Rogerson, & Lwebuga-Mukasa, 2004) or have developed models of environmental stressors based upon both quantitative and qualitative surveys (Farquhar, 2000). The present study incorporates for the first time a nested design that demonstrates the relationship between asthma emergency visits and a proximal spatial scale at the building and street segment levels. It offers a series of strategies developed through GIS, multilevel methodologies, and statistical applications that can help fill the gap between individual level risk factors for asthma exacerbation and contextual or ecological influences while accounting for correlations between explanatory variables and confounding variables at both levels.

This final chapter reviews the findings most central to the guiding theoretical framework as well as some other factors that may offer insights into the patterns of geographic clustering of Asthma ED visits. While explanations for some expected and unexpected multilevel relationships will be offered, other findings may serve only to raise additional questions. In the conclusion of the Discussion section, limitations of the study are discussed and courses of action are proposed for improving neighborhood research and guiding further research.

The Spatial Clustering of Asthma ED Visits

Data from a previous study that created a separate database of Harlem Hospital Asthma Emergency Department visits and were analyzed by spatial data analysis confirmed initial impressions that there were more Asthma ED visits associated with some buildings and neighborhoods than with others. General census population data were added for a weighted spatial data analysis in which a census block population value was assigned to each address. There was still significant clustering of addresses of asthma visits after controlling for population distribution. Population estimates based upon the census block scale, however, represented a larger geographic area than the levels of analysis selected for the study. Data for the geographic scales at which population information was needed – the building and segment levels – was not readily available. *Apartment unit* counts were available at the building level and could be aggregated for a segment level measure, thereby providing a surrogate measure to control for variations in population across the area. This first formal step in the analysis served not only as a screening tool for spatial clustering of asthma emergency visits but also suggested the distances at which clustering occurred that could inform definitions for spatial levels and specifications of variables. In this case, clustering was indicated at distances consisted with some of the more narrow building widths of approximately 8-10 meters up to widths that encompass an entire East-West street segment, and distances in-between.

The Knox measures further revealed Asthma ED visits that were correlated in both geographic space and in time based upon distances and time lags that were theoretically relevant to the action of asthma triggers. The correlations demonstrated some groupings of Asthma ED visits close in both time and space at greater frequencies that would be expected to occur randomly. Contingency tables were set up for frequencies of pairs of visits that were close in time, pairs that were close in space, and pairs that were close in both time and space for both the observed and the expected calculations. Chi square statistics calculated to determine if the observed and expected values were different showed significant clustering in every season although not in every month. Only those clusters associated with an interval of at least 2 lagged days were significant at distances of from 30 meters to 100 meters. These findings suggest a different factor or factors having influence on Asthma ED visits at different times of the year with sporadic spikes that could not be explained by grass or pollen triggers. Interactions between street and building pollution and weather should be explored for their potential role in Asthma ED clusterings.

Examining Mutual Influences of Multiple Levels

It was the intent of this study to bring contextual variables into research on environmental conditions affecting Asthma ED visits in ways that approximated living environment ecological conditions. Nesting building level variables in the context of segment (or group) variables provided an opportunity to evaluate statistically the mutual influence of environmental factors on Asthma ED visits measured at different levels. Combining levels through hierarchical modeling not only partitioned the variance by the various contributing variables allowed a greater understanding of how explanatory factors were influenced by conditions operating at either the building or segment level. The core of the multilevel process is indeed based upon the principle that an event is the result of a combination of underlying influences operating at different levels of organization through either linear or non-linear relationships. It is this key framework that offers a potential link between epidemiological studies of individually-oriented risk factors and the ecological or community conditions that may support those risk factors.

The hypothesized position that housing and neighborhood environmental conditions could explain residential patterns of Asthma ED visits was supported by the research and demonstrated through the development of six hierarchical generalized linear models. Five environmental factors from building level and/or segment level conditions were individually and significantly predictive of Asthma ED visits when considered in combination with all of the other variables in the model. The variables – *trigger violations, corner building location, location on a bus route, segment density,* and *in-building pollution* – contributed to models that were uniquely fitted depending upon the level of analysis and the geographic direction of the street segment.

Characteristics of Modeled Geographic Directions

Results of the models show different relationships between hypothesized variables and building level Asthma ED visits that vary with the geographic direction of the avenues or streets and with level of analysis. Of primary importance for both geographic directions, however, is the significance of *trigger violations*, *corner location* of buildings, and *segment density* in predicting Asthma ED visits for the study year. These predictors were independently significant even after having controlled for the number of *apartment units* and *nonasthma ED* visits.

Trigger Violations

Those housing violations most directly associated with previous research on individual level environmental triggers were found to be a highly significant predictor of building totals of Asthma ED visits independent of any other variable in all building level analyses for both geographic directions. The *trigger violation* summary variable was created as a result of insufficient counts / inadequate variability of individual trigger violation categories of *moisture-related violations, rodent violations, roach violations,* and *heat violations* and offered a more meaningful measure of asthma conducive housing conditions than the overall *total violations* variable initially constructed.

The combined analyses of level 1 and 2 models present an overall objective for a nested model to estimate the explained variance for each variable in the presence of other significant variables. For every one-unit increase in *trigger violations* (e.g., a 1% or other designated constant unit increase) at the building level in the North-South combined model there was an 11% increase in building level Asthma ED visits. In the East-West combined model, the increase in Asthma ED visits was 6.57% for every unit increase in building level *trigger violations*. The multilevel design does not provide for an actual R^2 to describe the effect size of the models. Estimates can be offered, however, as interpretations of the variance accounted for based on the intraclass correlations and model calculations. That is, 61.3% of the North-South building level model variance can be explained by differences between the street segments, and the combined model can account for 47.2% of that variance. For the East-West building level variance 29.9% could be explained by differences between street segments with the combined model explaining 77.6% of that variance in building level Asthma ED visits.

It is useful to review the relationships of significant variables at each level of analysis for a better understanding of the variable relationships at the combined level model. This may particularly be the case with *trigger violations* because the group or segment level variable is derived as an aggregate sum of building totals. In both geographic directions, segment level *trigger violations* showed only a trend toward a significant relationship with Asthma ED visits gaining in significance only in the East-West combined level analysis when building level variables were added to parse out the variances from correlated variables at specific levels. Building level *trigger violations* mattered most in predicting Asthma ED visits in the North-South direction, again indicating the major role that buildings played in the North-South segments. In the East-West segments, however, *trigger violations* were not only important at the building level but also became a significant predictor at the segment level when building level *trigger violations* was included in the combined model. *Trigger violations* in the East-West segments was responsible for a 9.39% increase in building level Asthma ED visits for each unit increase in the violations variable. This pattern suggests that the East-West segment totals for *trigger violations* have a greater influence on Asthma ED visits when individual buildings also have high counts of *trigger violations*. Said in another way, a high total count of *trigger violations* count summed across many buildings on a segment would not predict asthma visits unless individual building *trigger violations* counts were also high. The phenomenon is reminiscent of the dose-response and threshold effect needed for the occurrence of disease as demonstrated by Rosenstreich et al. (1997) where a relationship was found between asthma morbidity and high levels of cockroach allergen.

Variables Associated with Sources of Pollution

Another variable central to the theoretical framework is the location of sources of pollution in the neighborhood. Only buildings on streets oriented in an East-West direction demonstrated a significant relationship between sources of pollution located within residential buildings and Asthma ED visits.

In-Building sources of pollution. The *in-building source of pollution* variable recorded residential buildings containing sources of pollution and was a highly significant predictor of Asthma ED visits in East-West building level 1 model combined level 1 and level 2 models. . Different categories of pollution based upon exposure to VOCs (volatile organic compounds) were combined because of inadequate counts to form a single category that included chemicals associated with dry cleaners, hydrocarbons arising from gasoline service stations, byproducts of incomplete combustion in parking lots, and other forms of hazardous waste. In the higher density North-South segments, there were 18 *in building sources of pollution* reported while in the typically lower density East-West segments they numbered 30. Eleven of the total number of *in-building* sources were associated with dry cleaning, gas stations, or parking lot operations while the remaining *in-building* pollutant sources were hazardous material or waste operations that included private remediation businesses and public housing operations. While a much larger study sample of sites would be needed to determine if any one source of *in-building* pollution causes greater distress for residents with asthma, the findings here indicate that sources of pollution located within residential buildings warrant closer examination for their effect on residents of the same building, perhaps particularly in buildings at lower densities as in East-West buildings.

Building location. The *corner location* of buildings was highly and significantly related to Asthma ED visits in both the North-South and East-West building and combined level models. Most AKA buildings were corner buildings and not all corner buildings were AKA buildings. Care was taken to capture the total number of Asthma ED visits recorded under different addresses for the same building.

In addition to the AKA status, however, the *corner location* of a building may represent exposure conditions from high traffic patterns associated with most of the North-South avenues as particulates and other pollutants associated with trucks, cars, and buses can penetrate the avenue side of the building and portions of the street side of the building, again perhaps particularly in lower density buildings. Accelerating buses discharging greater amounts of particulate matter (WE ACT, Inc., November 15, 2000 press release) and Idling vehicles at intersections may create unique exposure conditions that could affect corner buildings differently from other buildings.

Bus routes. The impact of diesel bus traffic and bus depots on the residents of Harlem communities has long been a major public health concern. Although one bus depot is located in the study area, the site was not included as a unique bus exposure measure because of the lack of variability for the measure and the relatively few residences located near the depot. The site was, however, included in counts of exposures to *multiple bus routes* and *buses per year.*

Of the 690 North-South oriented buildings, 586 were located on bus routes. While only 104 buildings were not on bus routes, the F test for differences between groups is robust enough to produce valid results for significance so that a building's location on a bus route was an independent risk factor at the building level and associated with higher numbers of Asthma ED visits after accounting for other variables in the model. Location of a building *on a bus route* was significantly related to Asthma ED visits independent of *corner* *location* and *building apartment unit* numbers and only in the North-South building level model. Bus routes tend to run north-south (i.e., on avenues) with few exceptions and so the significance of the *bus route* variable on the North-South building level model and not the East-West model was not unexpected. *Bus routes* are also confounded in this study with all traffic-related pollution but were chosen as a measure of the important role of diesel-source particulate matter as a pollutant, for the accessibility of data, and for the acceptable face validity they offer as a proxy for roadways with heavy vehicular traffic. Location on a *bus route* fell out of the model, however, when it was combined with segment level variables which included *segment density* as a significant and new variable.

Segment Density

Higher *segment density* was an independent predictor of asthma visits in both the North-South and the East-West combined models accounting for all other variables in the model. The fact that *segment density* was independently related to the outcome is not surprising in that a greater number of households in an area would suggest a greater likelihood of Asthma ED visits. The *segment density* construct is distinguished from simply the number of apartments within a certain space to represent how apartments (or households) are distributed through buildings and over the length of a street segment. The fact that *apartment units* dropped out of the combined models for both geographic directions suggests that density, not number of units, was important in predicting building level asthma when building level *trigger violations* was also highly significant.

The role of *segment density* in Asthma ED visits may be most meaningful, however, in the understanding of the effects of other variables. For example, when *segment density* is entered into the combination model with *location on a bus route* variable, the formerly significant *bus route* variable falls out of the model. Since most buildings on the North-South segments are on *bus routes* it may be the case that *segment density* may be an intervening variable that mediates a chain relationship between exposure of residents to *bus route* pollutants and asthma visits. The sheer number of apartment units associated with larger buildings, often dominating complete segments in the North-South direction may work to distribute or "dilute" the pollutants in different ways through the building.

Segment density may mediate the effects of environmental variables on the building level Asthma ED visits but the mechanisms are unclear and call for closer examination. For example, a large building with the greatest number of interconnected stories and apartment units "exhibits a considerable stack effect" in the cold weather wherein the reduced pressure indoors draws in polluted outdoor air at the street levels distributing it throughout the building and exhausting the heated indoor air through leaks in the upper levels of the structure (Yocum, 1982, p. 521). Wind pressure can create pressure differences depending upon the location of doors and windows, moisture can affect the reaction rate of some pollutant gases such as sulfur dioxide and ozone (a product of vehicle exhaust hydrocarbons and sunlight), and outdoor pollution can subject residents to higher levels of indoor air pollution depending upon distance to the traffic and quality of air exchange among other factors (Miguel, 1995). Miguel also found that HVAC systems were unable to reduce inhalable particulate matter concentrations (IPM) effectively and that traffic emission intruded significantly into ground-level areas. Investigations into the relationships between building interiors and layout, sources of pollution, and asthma emergencies within the building may uncover important information about the processes of exposures.

Segment density became more significant in East-West segments in the combined level 1 and level 2 model when building level *vacancy* was taken into account suggesting that the fewer buildings that are either totally or partially vacant, the greater the segment density and the greater the number of Asthma ED visits.

Relationships between Non-Asthma ED Visits And Asthma

While relationships between environmental exposures and public health concerns have received much attention in the literature, such research under ecological conditions is not well suited for direct, single cause - same effect conclusions. Multicausal models, however, provide opportunities to test for a direct effect of multiple variables on an outcome independent of other causal factors. In this study the models permitted an analysis of a broader combination of potential environmental causes so that an environmental factor's effect on the outcome is related to the presence of other factors in the particular context

(Franck, 2002). For example, factors may be present in different combinations (including different times or spatial arrangements) and different quantities so as to explain when air-borne pollutants may only irritate mucous membranes or may aggravate respiratory or heart conditions, cause cancers, or cause premature death. In living environments individual factors in the models significantly associated with asthma visits may also combine with other factors to cause still other effects. The phenomena of the *nonasthma ED* variable may be such an example of the complexity of multicausal relationships.

The *nonasthma ED* variable was intended to serve as a surrogate measure for the propensity or inappropriate use of Harlem Hospital Center's Emergency Department. The criteria for selecting a sample of visits from the total of more than 5800 visits was to identify and retain diagnoses whose etiology was not associated or was minimally associated with an environmental factor and that could be managed in settings other than the emergency department. In each model, non-asthma ED visits was a control variable that was significantly and positively related to the Asthma ED visits outcome. In both geographic directions, the correlation between Asthma ED and nonasthma ED visits was greater at the building level than at the segment level. In spite of this association, however, other explanatory variables were still independently and significantly associated with Asthma ED visits. A valid explanation for these patterns may indeed be elusive without further in-depth investigations but two possible explanations seem plausible.

First, given the condition of many buildings in the study area it seems reasonable that some of the same conditions that aggravate asthma symptoms also cause other medical complaints. For example, of 2556 buildings 657 (26%) had reported violations with an average of 21 violations per building and 109 buildings had more than 100 documented building violations. Four hundred of the buildings with violations (61%) had anywhere from 1 to 54 *trigger violations*, conditions known to be associated with asthma symptom exacerbation. *Nonasthma ED* visits were also correlated with *trigger violations* for both North-South and East-West geographic directions as well as with *in-building pollution* and *multiple sources of pollution,* suggesting an independent role for these ecological factors in less obvious health concerns.

Although attempts were made to select nonasthma ED diagnostic categories with minimum known environmental associations to serve as a good control variable there were still some diagnostic categories that could be associated with the same conditions as those associated with asthma visits, most notably viral infections, fungus-related conditions, allergies, and rheumatoid factor (an antibody also found in tuberculosis and parasitic infections suggesting possible environmental associations, Mosby Medical Encyclopedia, 1992), among others. As an example, a review of housing research and policy reported on a double-blind study of 597 houses in the United Kingdom (Platt, Martin, Hunt, & Lewis, 1989, cited in Howden-Chapman, Isaacs, Crane, and Chapman, 1996) and found that adults living in damp and moldy dwellings reported a wide range of symptoms including nausea, blocked noses, backache, aching joints, and “bad nerves". People living in dry housing had significantly fewer symptoms, controlling for socioeconomic status. Identifying comparison diagnostic groups not confounded with environmental conditions may continue to be difficult.

Second, people with the poorest health outcomes (asthma or other conditions) and who have the least access to resources (e.g., health insurance) may be concentrated in the same neighborhoods which are parts of the community that are particularly burdened by sources of pollution and a deteriorated housing stock that might be considered "housing of last resort". Polednak (1997) has also discussed the concentration of poverty and the concomitant neglect of neighborhoods that become the last resort housing environments for residents with few economic resources and often-great health problems. Living in deteriorated housing can tap limited funds (e.g., due to purchases related to pest extermination, faulty plumbing systems, undependable food storage facilities, the need for portable heating elements) and undermine efforts to maintain health independent of the race or income of residents (Kingsley, 2003) creating cyclic ecologies of illness reinforced by the physical environment.

For those residents living in deteriorated housing environments and relying on minimal economic resources, the local emergency department may provide an important and familiar service in their ongoing health care management. In fact, studies have shown that up to one-third of adults living in inner city communities use the emergency department as a primary source of asthma care (Malveaux, Houlihan, & Diamond, 1993). In Harlem, approximately

70% of patients who used Harlem Hospital's Emergency Department rely on the ED for their primary asthma care (Meyer, 1998). Trowers (personal communication, June 3, 2005) explained that many residents have never experienced the benefit of a productive ongoing relationship with a doctor. Not only are there few primary care physicians available but also medical residents temporarily on staff will often leave for another kind of practice. Furthermore, the ED provides a "one-stop" service for patients who may require x-rays, blood-work, and / or immediate courses of medication.

Building Ecology

In considering the role of ecological factors in exposures associated with asthma symptom exacerbation a broader construct of building ecology comes into play. The urban living environment can possess a unique character consisting of physical and social features on multiple levels that are changeable and that play a role in the larger context of neighborhood and community. Qualities of the physical environment have a transactional influence on social activities which in turn influence the physical environment for a combination of effects.

In evaluating the relationship of the built environment to health outcomes a number of factors on different geospatial scales become relevant. The different scales can range from relationships between a building and its occupants (e.g., residents) to relationships with official and social contacts (e.g., code enforcement, property owners, other residents) and other spaces, structures, activities, and larger environmental qualities (e.g., degree of vacant properties, density of segments) and can create complex combinations of events that can have direct or indirect effects on health behaviors. Many different ecological qualities have been considered in this multilevel study that were selected for their pertinence not only to the morbidity of asthma but also to the social and physical characteristics of the area. The combination of events thought to be related to asthma emergency visits may work together to help disentangle the effects of different factors at various levels and raise additional questions through both anticipated relationships and unexpected results.

Unexpected Findings

A number of the research findings were unexpected either because relationships with the outcome and other variables were established where none were expected or because anticipated relationships between variables did not emerge.

Geographic Direction of Street Segments

At the outset of the study, it was clear that there were distinct differences between routes running in different geographic directions, most obviously differences in length and width. Most North-South segments are avenues that are considerably wider than streets often containing dividers and, for those reasons, divided into segments of opposite sides consisting of even-numbered addresses and odd-numbered addresses. Street segments on an East-West axis were most often narrower than their north-south counterparts, did not contain dividers, and included both sides of the street (i.e., even-numbered addresses and odd-numbered addresses). Furthermore, the need to avoid double counting of building data for structures with AKA addresses was the basis for modeling North-South segments separately from East-West streets.

The research revealed that buildings on North-South segments differed in other important ways from buildings on East-West segments. Segments running East-West tending to be more heterogeneous, i.e., total apartment units varied much more between segments and there were 37% more buildings than on North-South segments. There were also more differences in Asthma ED visits between East-West buildings than between buildings on North-South segments as indicated by the intraclass correlations (29.9% and 61.3%, respectively). This might be explained in large part by the greater number of East-West buildings and therefore greater opportunity for buildings to vary in outcome and explanatory variable measures. Other differences as noted earlier included sources of pollution and segment density both important factors for predicting Asthma ED. The distinctive characteristics of buildings and segments based on their geographic directions emerged as a compelling finding with implications for further investigation and for context-relevant interventions.

Associations with Building Ownership

The models suggested that *HPD* owned residential buildings were significantly related to fewer Asthma ED visits. Preliminary correlations had also indicated that *HPD owned* buildings, particularly those under Central Management, were negatively associated with building level *total violations* data but moderately and positively related to segment level *total violations*. Earlier research by Saegert and Winkel (1998) had, in fact, revealed that city owned buildings had among the poorest management and building quality conditions. A review of the findings to resolve the discordance between the reports found that, controlling for building level *vacancy* in the combined North-South model, the contribution of *HPD ownership* becomes marginal. It is possible that *HPD ownership* is really a proxy for vacancy rates. Building level *vacancy*, building level *private ownership*, and segment level *HPD ownership* all remained negatively and independently predictive of Asthma ED visits in the East-West combined model. A review of Pearson correlations between *vacancy* and *HPD Central Management ownership* revealed significant and positive relationships for East-West buildings, East-West segments, North-South buildings, and North-South segments that did not occur with most other forms of ownership. Only segment level *private ownership* correlations for both directions approach the high *HPD ownership* correlations with *total vacancy* .

Buildings with high numbers of vacancies are not likely to show high numbers of asthma visits or reports of *trigger violations* for the simple fact that there are fewer, if any, people occupying the buildings. Pearson correlations between *HPD ownership* and *trigger violations* and *private ownership* and *trigger violations* however, were both significant in East-West segment measures. The nature of the relationships between the forms of building ownership and housing conditions and neighborhood conditions are well beyond the scope of this study but may suggest important links to patterns associated with disinvestment and anticipated redevelopment activities that have deleterious effects on neighborhood level asthma health outcomes.

Non-Significant Variables

Factors expected to play an important role in explaining Asthma ED visits but which, in fact did not, included the control variables of *distance to health care clinics*, and *segment wealth*. Clinics providing asthma care appeared to be fairly well distributed and located in north, south, east, and west regions of the study area although in some cases they were separated by sizeable distances. While private information on household income is typically not available on small or individual scales, a segment *wealth* rating relative to the average value rating of all residences in the particular census district was used in this study to control for the role of income in segment differences. There was very little variation in wealth ratings across the study area with ratings for all segments ranging between the two lowest wealth zones - low and medium-low.

In addition, some environmental factors hypothesized to affect residents' asthma also did not enter the models. Two of these environmental factors were related to exposure to bus emissions: buildings with *more than 1 bus route* within 100 meters and the number of *buses per year* passing within 100 meters of a building. Five hundred eighteen buildings were scored as being located within 100 meters of multiple bus routes. The 100-meter criterion was selected for the precipitous decline of particulates noted at that benchmark but it is not clear how characteristics of the urban landscape affect the application of this parameter. Pollution concentrations may exhibit sudden changes particularly in complex urban environments (Briggs, 1992) and exposure to pollutant concentrations can vary considerably even over small areas. (Huang &

Batterman, 2000). It may be that features such as heavy tree cover, super block buildings, tall office buildings, or other physical land use features of the area mediate the exposures of some residential buildings.

Street construction also was not significantly related to the asthma outcome. Counts of construction permits issued during the study period ranged from 0 to 43 for a total of 639 and a mean of 2.52 per segment. One hundred segments had no construction permits reported (39%) and approximately 60% of segments had fewer than 2 construction project permits. While a lack of variation in the number of counts could be responsible for the absence of results, other questions such as the size of the project, the nature of construction materials used, or the length of time of exposure to the neighborhood are raised about the actual nature of the activity that might mediate the production of trigger irritants related to asthma symptoms.

In the case of point sources of pollution, the *in-building* pollutant source variable was significantly related to asthma visits but not the segment level *multiple pollution* sources. It may be that only close contact with the identified sources such as volatile organic compounds within a residential or occupational structure may trigger asthma symptoms.

Addressing Threats to Validity in Ecological Research

The multilevel analysis of the Asthma ED visit outcome variable demonstrated how variables ay different spatial scales might be linked in meaningful ways to improve the validity of making inferences between those scales. A series of examples of potential threats to validity and solutions posed by this ecological study is described in Appendix B. In this modified ecological study, GIS visual mapping methods were found to be instrumental not only as a screen for clusterings but also for defining environmental variables and creating new spatial districts to be used as units of analysis. Moving between different levels of analysis can pose validity challenges when findings from one level are applied to another as in the case of ecological fallacy. The flexibility to form new spatial units helped address some of the threats to validity by creating levels of analysis that increase in scale by small steps, thereby increasing the mutual relevance of measures to members at both levels.

Living environment data created a number of challenges one of which was the importance that the data to be used was relevant to the levels at which inferences were to be made (Diez-Roux, 1998). A series of conceptual, methodological, and statistical approaches helped manage specification of variables and classification of data to appropriate levels of analysis. Efforts to address requirements for adequate numbers of measures, correlated variables, and violations of statistical assumptions helped stabilize and strengthen the model.

Incorporating the GIS technology was useful for creating a contextual level of analysis with proxy measures meaningful at the individual building level as well. For example, *trigger violations* aggregated at the segment level had a direct effect on Asthma ED visits in East-West buildings. In North-South buildings, *segment density*, estimated from apartment units by buildings by segment distance, had an effect on the individual building level and mediated the effects of being on a bus route. The problems associated with making inferences from group-level or aggregated data to individual levels, a major weakness of customary ecological design (National Research Council, 1997), are minimized when geographically-defined scales of analysis, variable definitions, and datasets are relevant to members at all levels of analysis. In this case, for segment level 2 variables to have an effect on the building level asthma outcome, properties of the segment or group construct must be capable of intervening on the quality of each building. Working at a slightly larger scale with direct and meaningful associations for the individual level increases the relevance of the segment variable to the building thereby improving the validity of the inference between the levels.

In addition, the relative homogeneity of population demographics in the area compared to neighboring communities creates conditions for smaller within-group variability and therefore greater likelihood that group-level measures based on individual level aggregations will affect individuals similarly (Diez Roux, 2004). Although homogeneity means minimal variation and reduced opportunity for measuring the outcome under different conditions of the explanatory variables it also reduces the chances that less visible compositional differences in the population (e.g., cultural healing practices, atypical economic status) affect the outcome.

Data and Methodological Limitations

Limitations of the GIS Tool

The strength of GIS applications in multilevel and ecological study lies in the opportunity to view data from a variety of perspectives and for the flexibility in creating new districts, or in this case, units of analysis. *MapInfo* software can present frequency data thematically so that areas that are characterized by higher prevalence of an event can be readily "eyeballed" against the prevalence of other events. The information is ad hoc, however, and so comparisons were only speculative without the assistance of statistical analysis. Other software programs (e.g., *ArcView)* have a greater capability for spatial analysis in that it can more readily link statistical processes to smoothing of data intensity variations over a given geography.

Constructing new districts. One important advantage of the mapping program is the ability it afforded for creating new spatial scales for analysis that can improve the validity of measures on different levels. There are limitations in working with the actual design of the new districts, however, which still rely on the availability of data that can be classified at the new scale.

Intermediate scales such as those that include properties within a 50-meter radius of each building being measured may provide useful information about adjacent properties than what is available at the segment level. This level of data collection and management of statistical requirements related to overlapping properties and data, however, pose logistical challenges for dealing with physical conditions of living environments and relationships between buildings. Thus, while there is great flexibility is defining new geographic scales, the levels of analysis may not be readily amenable the data analysis.

Tiger line files. Database files that create the foundation for street maps work in different ways to code street addresses. TIGER/Line files are a readily available product that estimate the locations of addresses within a range of addresses belonging to a street. Accuracy of address matching is good but a number of issues can create errors. For example, misspellings or other errors in the matching of the address list with the street database file and errors in street segment ranges or changes through development can lead to incorrect location of buildings (Cromley & McLafferty, 2002). The degree of accuracy between automatic matching and actual location of an address can vary but high-density or urban locations have been found to demonstrate the least amount of error in at least one investigation (Cayo & Talbot, 2003). The TIGER/Line files available for this study often represented addresses bunched more in one part of a street than distribute across the entire street. This appeared to be the case more on streets than avenue. Because the geocoding interpolates addresses based on their expected location the locations don't always represent differences in the footprint of buildings or updated address changes (C.Chung, personal communication, January 10, 2006).

Working with the Best Available Data

For this retrospective multilevel analysis it was important to identify data that corresponded to not only the desired level of analysis needed for testing the hypothesis but also to the study year. There were often more than one source of data for variables and comparisons between the sources were made for the most complete, reliable, and valid information possible. Collecting and mapping data, defining street segments, and cross-referencing databases created an iterative process that not only helped confirm the accuracy of information but also facilitated visual inspection and reflection toward more informed decision-making.

There are inherent difficulties with retrospective studies based upon archived data. Several maps were actually consulted and coordinated over the course of the research for a number of reasons. Because maps vary in precision as representations of the physical dimensions and estimation of location, there may be discrepancies in the data characterization. Streets are not all the same width, buildings are not all the same size, and mapping in various 2-dimensional scales portrays the cityscape with only a degree of approximation. Furthermore, data are available from some maps and not others and are represented differently at different scales. As a result, street maps, census maps, insurance maps, community district maps, and transportation maps are among those cross-referenced and used to validate the estimates. Numerous visits to the study area were made to survey street width estimates and land-use patterns, areas of building deterioration, quality of empty lots, and accurate street segment address ranges, among other purposes.

Most of the data sources tapped are well-established and the validity of the measures was checked by redundancy from different sources. There are potential events, however, that could, in reality, affect the quality of the data collected. For example, there is a lag between the time changes are made in a building or violations are reported and when they become part of the public domain. These issues were addressed in this project by arriving at default decisions (e.g., selecting the unit numbers reported in one source when another source conflicts with a report of vacancy) and casting a broader time frame for accepting violations complaints (i.e., including violations for the entire years of 1997 and 1998 rather than for only the study year March 1997 through February 1998). While it is also quite possible that neighborhoods, buildings, or even residents will vary in their reporting activities or their vigilance in having violations corrected, it is beyond the scope of this study to explore any patterns or reporting or collection methods that might suggest uneven data reporting. It is expected, however, that the substantial numbers that are entered into the analysis allow for an error term that will adjust for any such random variations.

Databases are not static. Over the last few years more information has become available from on-line data sources allowing greater access to smaller scale data. Changes in data available in this manner are ongoing (e.g., Department of Buildings later posted on the website Certificates of Occupancy that can help identify land use practices retrospectively) and can offer more information or require further clarification through other means. Although even more labor intensive given the frequency in which any available links must be explored before information can be extracted, additional information became available later during the analysis stage that could help clarify some data issues.

The socio-physical environment, too, can change rapidly and opportunities to capture time-bounded events such as construction and development projects, pollution events, and fluctuations in local services are quite limited. For example, between 1994 and 1998 during the “Harlem Renaissance Revival”, at least six different redevelopment projects on a variety of scales were either ongoing or proposed for different sites within the study area. The windows for ‘real-world’ investigations are set in time frames that often require more extensive research to capture a slice of environmental conditions. As physical conditions change so may the juxtaposition of variables that influence patterns of illness. As a result, follow-up studies that again consider contextual variables would be important to help explain if or how subsequent changes in the urban landscape alter the findings from previous investigations.

Dividing the Study Area by Geographic Direction

While creating models based upon the geographic direction of the street made sense because of the general differences in segments and buildings characteristic of these directions, in doing so there was also a certain loss in statistical power. As noted earlier, the East-West segments were characterized by buildings that varied considerably in *apartment units* and Asthma ED visit outcome among other measures. Measurement of varied conditions requires many more cases than measurement of more homogenous settings. In multilevel regression techniques, entities within the same area with similar values have residuals that are dependent and result in a reduced sample size (Merlo, 2005). In addition, there was overlap (and adjustment for same) of AKA building level data between North-South and East-West models that, in effect, reduced the number of “independent” observations that could be used for analysis. The

Glimmix program used for evaluating the models relies on adequate numbers for efficient processing of the models and therefore the downward adjustment of the sample sizes created some difficulties with the program's convergence.

Generalizability

Although the study incorporated a large number of buildings and street segments, generalizability of findings to other locations will be limited by population demographics and the ecology of a study area. Data were aggregated at the building level and compositional characteristics of building residents were not measured for their possible relationship to building type or quality or segment and any related effect on the asthma outcome. Similarly, while segment level income information was available and included as a control measure, income measures throughout the entire study area showed little to no variability. Application of findings to areas with greater income variability should be regarded cautiously.

Findings of this study may, however, be applicable to areas of inner cities that share similar neighborhood environments as well as parallel resident demographics. Neighborhood environments that consist among other things of building ecologies characterized by a mixture of high and low density buildings and segments should be considered candidates for possible generalizations. Certainly many of the factors considered in the analysis exist in abundance in other communities. Under the appropriate community conditions, the research design itself, in addition to the explanatory factors, should also demonstrate high ecological validity as the overall plan and tools used for measurement are transferable to systems in other urban contexts (Winkel, 1987).

Representation Of Asthma As Emergency Visits

As in other cities people with the lowest incomes often rely on the local emergency department as a primary care provider. The outcome data in this study was based completely on visits to Harlem Hospital's Asthma Emergency Department. The findings, however, may not be representative of the environments of people who do not use the ED for their asthma emergency care. Those who manage asthma emergencies in other ways such as effectively using emergency medicine, going to family practitioners or health care centers, cultural or family remedies, or in other ways are not accounted for here and may bias the results of the study. Because the study focuses on Asthma ED visits to Harlem Hospital, data on residents who have asthma but manage their condition in other ways were not included.

Characteristics of Residential Patterns

Another potential limitation may occur in conjunction with residential histories of Asthma ED visitors. The study operated on the assumption that residents spent enough time in their immediate living environments (building and/or segment) to be effected by exposures to existing triggers. There was no measure of changes in building level occupancy or length of occupancy of residents as the level 1 unit of analysis was the building. Because the effects of exposures may be immediate or may be cumulative, new or recent residents could have different reactions than longer tenure residents. Other possible biases may exist with respect to this same issue, for example, as the actual location of people when symptoms began compared to the address provided at the emergency department.

Calls for Incorporting Contextual Interventions

Clearly, more work is needed to identify and address those variables that link health outcomes with environmental contexts. A good deal of the investigation of allergen triggers of asthma symptoms and potential remedies are confined to the individual or, at best, immediate home environment (see National Institute of Environmental Health Sciences Press Release #05-02 and #05-18). In this ecological study, individual level measures are actually building level measures – sometimes aggregated from more micro sections of the building (e.g., apartments, hallways) and sometimes reflecting macro building characteristics. While additional compositional information about tenants and building conditions would be informative for planning interventions Franck (2003) suggested that:

> "It is the structure of the environment, which explains why the observed correlation may vary across regions or social environments."

Multilevel Research As A Link For Epidemiology

The contemporary paradigm of "risk factor epidemiology" has focused on independent contributions of individual level variables (Diez Roux, 2003, p. 94). Analyses typically do not include context or combine risk factors in a meaningful way as do causal chains that recognize "interference" between factors in their effects on the outcome (Franck, 2003). This study considers the role of risk factors not of individual residents but that exist in every day environments and that combine different levels to affect each other's role in explaining the Asthma ED visit outcome. Multilevel models have provided a meaningful link between an individual level focus and ecological study.

Development of ecological and multilevel methods that enhance the validity of measurement on various geographic scales can help broaden a public health frame of reference that expands the design of solutions from a narrow definition of individual responsibility to responsive community environments. Until, however, there is a more comprehensive identification, appreciation, and acceptance of inextricable relationships that exist between levels of community health management

> "…programs that attempt to redress the social experience needs of vulnerable populations with specific individual behavior-change approaches will meet with limited success" (Bloomberg, Meyers, & Braverman,1994).

Changes in underlying systems that support health outcomes may indeed support changes in individual health behaviors.

The conclusions of a recent review of studies of public health interventions related to housing by Saegert, Klitzman, Freudenberg, Cooperman-Mroczek, and Nassar (2003) echoed the sentiment of Bloomberg, et al. (1994). The authors called for interventions at multiple levels of organization from individual behavior and housing environments to community organization and public policy for improved success of objectives. Effective interventions will require a shift to an ecological paradigm with an interdisciplinary approach to addressing multilevel phenomena, a concept Corburn (2004) refers to as “ecosocial epidemiology”. Corburn advocates democratizing research and including the participation of community members and local knowledge as essential components for identifying the unique character of the neighborhood, how the issues are shaped in context of this uniqueness, and how “physical and social infrastructure of communities affect health above and beyond a combination of individual "risk" factors” (p. 544). Understanding the texture of public health contexts and the social resources available to support meaningful interventions are critical for success.

This study demonstrates how archival data can be tapped as one step in the process of demonstrating the important role that community contexts can have in patterns of illness. Clearly there are opportunities that exist in technology, methodology, and statistical programming that support valid research. Community members can help translate the available data into relevant and useful information. The obstacles to research that incorporate information from the different levels of community life may ultimately be less related to validity issues and more associated with lack of support by institutions and funding sources.

Contextual Interventions Without Gentrification

Planned changes to deteriorated housing and neighborhoods are often associated with urban renewal or redevelopment initiatives that wipe out neighborhoods and displace their residents. Wallace’s classic exposition on “planned shrinkage” (1982) outlines the associations between the displacement of residents and neighborhoods by various means and the dispersion of behavioral and public health problems. Residents with serious health concerns may experience disruption in their health care networks and routines when they are displaced from their neighborhoods. Wallace (1982) also points to the limited effects of isolated building-level interventions when they are surrounded by larger contexts of urban decay (Michael Dear cited in Wallace, 1982). Thus, community management policies that permit extensive deterioration of properties and hoping for the time when land acquisition becomes economically attractive to developers subject residents to unhealthy building and neighborhood conditions. Multilevel interventions should include initiatives to ensure that existing properties are maintained and populations are not dislocated by redevelopment activities in ways that disrupt social networks and health care contacts.

Policy Implications for Findings

The findings point to a number of policy implications that could be practical even relying only upon Asthma ED visits as the outcome as this study did. The fact that 70% of Asthma Emergency Department patients of Harlem Hospital utilize the department’s services as their primary care source for asthma suggests a number of potential interventions. First, emergency care services are among the most costly services available to all persons 24 hours per day. With the erosion of other public health and social health care programs the role of the ED in health care has broadened to the point of overcrowding and threats to the emergency care for those who need it the most **(**Committee on Pediatric

Emergency Medicine, 2004). Reducing the reliance upon the ED for asthma care may be accomplished in a number of ways.

In general, access to quality non-emergency health care must be addressed. Obstacles to asthma care management have included poor or no insurance coverage; inconvenient clinic locations, operations, or hours; insufficient staffing, and long waiting periods (Meyer, 1998). Inability to access appropriate medical information, equipment, and medications has also created problems. Residents of areas like Central Harlem where income of many households if not most is low or very low are particularly vulnerable to reduced public care services.

The neighborhood environmental factors in this study associated with asthma emergency visits are also areas to be addressed. The research helps pinpoint specific community conditions related to housing violations and sources of pollution that are associated with higher numbers of Asthma ED visits. Some of the tools for managing environmental conditions, such as building code enforcement and initiatives to create cleaner burning vehicles, are already in place and require comprehensive applications. City services to inner city neighborhoods such as sanitation and public health maintenance of property conditions are critical and will need intensification in some areas more than others. Furthermore, the research supports the idea that abandonment or disinvestment of buildings and sometimes entire street segments may very well be making residents sick. Policies that permit this practice whether through explicit reduction of municipal services or implicit neglect of properties with the objective of street-scale redevelopment must be reviewed and corrected.

Finance administration entities such as the Health and Hospital Corporation, trade organizations such as the Greater NY Hospital Association and United Hospital Fund, and legislative bodies which include the New York City Assembly Committee on Health oversee conditions affecting health care and health care expenses. Whether in an advocacy capacity for hospital cost-containment or for patient care these organizations can play an important role in correcting many of the conditions contributing to patterns of Asthma ED care.

Recommendations for Improving Neighborhood Level Studies

Additional data sources need to be developed to facilitate the empirical exploration of possible links of community environments with urban health. While there continues to be an important role for census level data for comparison of regional, national, and global trends, reliable and readily usable local-level data is needed to support methodologies for small area studies that seek to incorporate neighborhood contexts into individual health outcomes quantitatively. New York City agencies and other resources are already steeped in valuable local information and much of the data are easily accessible via on-line or mainframe databases. However, the digitalization of public data is “uneven” with many records still difficult to access at the lowest scale or meaningful level (e.g., street address) or with time lags in updates between the different agency archives. Coordination of diverse sources of data might at first appear a daunting task but would arguably be a cost-effective means of maximizing the benefits of existing information. The simple fact that the present study substantiates the usefulness of existing data underscores the importance for work to make this data more readily available and consistent across agencies. Contextual data specifically targeted to specific public health issues such as asthma could produce even more compelling results.

There is also a need to develop group level variable constructs further. Many of the group level variables in this study were derived or aggregated forms of individual level data or integral variables defined by only one or two dimensions (e.g., segment *wealth*; *multiple sources of pollution* for increased exposure risk; *vacancy* measures for disinvestments) when the constructs may be representative of more complex phenomena. Development of composite or criterion variables to measure more complex constructs such as *disinvestment, neighborhood quality,* or *environmental exposure burden* or *cumulative risk* could help create new discussions for planning policies towards improved public health.

Recommended Areas for Further Research

Cross-level interactions and interaction effects between variables within levels were not investigated in this study largely due to theoretical reasons. For one, there was an absence of a theoretically relevant basis by which to examine interactions. While there has been speculation in the literature about synergistic effects of multiple trigger irritants or allergens, limited laboratory experiments have focused on potentiation effects of a specific irritant followed by exposure to an allergen. Second, aggregation of data to the group level limits the examination of potential cross-level interactions. The possibilities of interactions and synergy between multiple environmental risk factors at the building level should be explored. Several of these factors at the building and segment levels were significantly and independently related to the number of Asthma ED visits at the building level. Further research designed to investigate potential interaction effects, both cross-level and within the same level of analysis, might evaluate the strength of the associations between ecological factors and Asthma ED visits as they differ by buildings or segments and in the presence of synergistic relationships.

The *trigger violations* variable found to be highly significant in predicting Asthma ED visits was a composite of individual violations associated with conditions conducive to asthma morbidity. Although the Rosenstreich study (1997) focused on inner-city children while the present study involves adults findings from a number of studies indicate that among several allergens tested cockroach allergens may have a greater effect on sensitized residents living in inner city environments (Gelber, Seltzer, Bouzoukis, Pollart, Chapman, & Platts-Mills, 1993; Gruchalla, Pongracic, Plaut, Evans, Visness, Walter, Crain, Kattan, Morgan, Steinbach, Stout, Malindzak, Smartt, & Mitchell, 2005; Kang, Wu, & Johnson, 1992; Sperber, Kendler, Yu, Nayak, & Pizzimenti, 1993). Research on similar effects of rodent and mold allergens has not been conducted. A larger population study to obtain greater variability in counts of individual trigger violations may provide additional information to further disentangle not only the main effects of individual violations but also the possible interaction effects and synergy between housing violations and other environmental conditions.

Additional spatial scales might also be added to the modeling for more in-depth understanding and theoretical development of the environmental basis of asthma morbidity. Levels of analysis might include rooms in apartments, complete apartments, or sections of high-density buildings along with larger neighborhood based spatial scales or building, neighborhood, and community district scales. Whatever the scales, conceptual frameworks must guide decision-making concerning the relevant levels of analysis and variables.

Furthermore, while this study has provided evidence that neighborhood conditions can affect health outcomes and specifically the event of asthma emergency care, case studies of troubled neighborhoods could help identify primary issues driving the environment-health patterns as well design appropriate interventions. Diez Roux and others (2001) have suggested comparison of a small number of purposively selected and well-defined contrasting neighborhoods on which a great deal of detail might be generated through qualitative and quantitative methodologies. Residents and community group representatives can often identify such neighborhoods where “it rains in the building more than it rains outside”, rats were common, and garbage pick up was sporadic, as they did with West 140th Street between 7th Avenue and 8th Avenue (Martin, 1994). This street segment had among the largest number of Asthma ED visits in this study. “There was almost total disinvestment by the private sector,” (Frank Braconi, Executive Director of the Citizens’ Housing and Planning Council cited by Martin, 1994) and, in 1994, most of the buildings were city-owned and operated.

There is also a need to further differentiate between various dimensions underlying deteriorating neighborhoods and to understand the relationships with practices at the larger community context. Exeter, Feng, Flowerdew, and Boyle (2005), for example, identified important distinctions between the effects of population decline in small areas generally and population decline in areas of deprivation which have a greater positive effect on mortality. Understanding of connections between poor health outcomes and deteriorated communities would benefit from more in-depth, overtime study of particularly troubled neighborhoods in context, perhaps to help create more broadly valid variable definitions and reveal or confirm more generalizable patterns.

Central Harlem is the most ethnically homogenous of all three Harlem communities with almost 85% of residents of African-American heritage and almost 50% of residents in 1994 receiving some type of income support. Street segments in the study area vary little in their estimated level of affluence and there was no apparent correlation between New York City Housing Authority (NYCHA) buildings housing perhaps some of the lowest-income residents and Asthma ED visits. There may still be compositional effects, however, such as individuals of poorest health status or with other special needs (e.g., substance abuse, histories of incarceration, homelessness) who may be concentrated in particular neighborhoods.

Conclusion

While researchers have made critical findings in environmental connections with asthma morbidity, the significance of these findings can change with multilevel comparisons. The research discussed describes a technique for partitioning out multiple influences on asthma health outcomes thus offering a more thorough understanding of the role for different factors.

Many local community groups have become invested in taking inventories of data and conditions in their neighborhoods that can facilitate research efforts. Community-University partnerships can enhance this effort and support should be made available to local groups to augment the data already available from public sources. Community groups should also be assisted with funding, training, and other resources needed to carry on their work and their participation as colleagues in the research process should be encouraged to help direct investigations and interventions. Finally, researchers privileged with the opportunity to develop and communicate knowledge about contextual factors affecting public health have a responsibility to actively apply this knowledge to advance the public health agenda in multiple forums and levels of civic organization. Knowledge without application "will meet with limited success".

Appendix A - Variable Definitions & Levels
Environmental Risk Factors for Asthma Emergency Care

Variable Construct	Measures - LEVEL I	Measures - LEVEL II
	Building Level	*Segment Level*
HHC Asthma ED Adult visits from study area grouped by building	Actual numbers from all potentially multiple dwelling buildings. Buildings reporting >0 units or missing values are included if they could be multiple dwellings. ED addresses reported from non-residential addresses (e.g., park, library, school) have been omitted from the data set of buildings for measuring variables.	ALL visits except same-day visits are counted, including those from non-residential addresses.
Housing Quality	Total # housing violations for each building measured for the study period broken down into subset #s for categories of rodent, roach, moisture, & heat violations. Subcategories summed as total trigger violations.	Total housing violations and totals for each category for all buildings in segments. (category values are subsets of total violations). Subcategories summed as total trigger violations.
Pollution Source Exposure	Presence (1) or Absence (0) of a pollution source within residential building. Sources are defined as - parking facilities/dry cleaners/gas stations - other EPA facilities	Total # of pollution sources by category in the segment, including those in residential buildings. >1 Pollution source in segment (categorical 1= more than one, 0=not more than one) # of street/sidewalk construction sites in segment for year
Bus Exposure	1- # yearly buses w/in 100 m of building (continuous variable) 2- On bus route (categorical variable) 3- Building has >1 bus route w/in 100 m (categorical variable)	
Corner Location	Categorical variable 1=yes, 0=no	# of corner building addresses
Density of Segment		# of units in segment ---------over------ # of buildings in segment ÷ length of street segment

Appendix A - Variable Definitions & Levels
Environmental Risk Factors for Asthma Emergency Care
(continued)

Variable Construct	Measures - LEVEL I	Measures - LEVEL II
Vacant Properties	Individual property addresses are coded as categorical variables: 0 = not vacant 1 = vacant lot 2 = vacant building 3 = partially vacant building	The segment level measures total number of vacancies and number of each category of vacancy on a street segment. Total number of vacant lots on segment. Continuous variable.
Ownership	Categorical variable: private, NYCHA, HPD, HDFC/TIL, other	Total # by ownership type per segment
Access to Alternative Health Care		Any part of segment is within radii of 150 m, 300 m, and beyond 300 m of alternative medical services (i.e. clinic).
Non-Asthma ED Adult non-environmentally related ED visits from study area.	Same as above	Same as above.
Number of Residential Units	# Building Apartment Units	Total # of apartment units per segment
Wealth of Street Segment		Compared to average value for total family residences in census tract. 1 = very low 0 = other

Appendix B - Issues and Strategies for Threats to Validity in Measuring Environmental Risk Factors for Asthma Emergency Care

Source of Threat	***Strategies***	***Methods***	***Data***	***Statistics***
I. ANALYSIS OF CLUSTERING				
1. Residents of study area may be going to other area EDs.	Define study area with borders distant from other emergency services. Consider physical (streets, parks) and psychological borders.	GIS map of locations of HHC ED visitors addresses (not frequencies). Map all EDs in area.	Addresses of all hospital EDs in area.	
2. Other- health care sites may be drawing residents from some locations away from HHC ED.	Identify alternative health care sites.	Map addresses of alternative health care providers and measure estimated distances from street segments to alternative sources of health care.	Addresses of neighborhood-based centers for adult asthma care.	
3. There may be a general propensity for Central Harlem residents to go to HHC ED rather than an alternative health care site.	Identify a suitable comparison group.	Construct a comparison variable to measure overall use of ED services.	Non-asthma ED visits are often related to similar housing conditions. Identify a Dx code for control of propensity to use ED.	Estimate number of visits equal to number of Asthma ED visits.
4. Screening for clusters can miss ED events straddling study area boundary.	Include donut area ED events to avoid "boundary effect".	Define donut area of approximately 3 blocks beyond study area.	Include Asthma ED visit addresses for donut area.	Spatial data analysis includes donut area ED event addresses to screen for clusters.
5. Aggregation of outcome data at larger scales and time periods can mask clusterings.	Experiment with organizing outcome data in different subgroups.	Aggregate outcome data on monthly and seasonal subgroupings to screen for clustering.	No explanatory or third variables included.	Large data sets use substantial computer resources for spatial data analysis. Subgroups can facilitate analysis.

Appendix B - Issues and Strategies for Threats to Validity in Measuring Environmental Risk Factors for Asthma Emergency Care (continued)

Source of Threat	***Strategies***	***Methods***	***Data***	***Statistics***
LEVEL OF ANALYSIS				
1. Organization of data in monthly subgroups for analysis can produce significance by chance due to multiple comparisons.	Spatial data analyses are performed on subgroups for descriptive purposes.	Final analyses are completed on total data set.	Identify explanatory and third data for the study year.	Full data set offers greater confidence for avoiding *Type I* error, incorrectly rejecting the null.
2. Existing administrative divisions with readily available data are large areas. Variable conditions on the group level may not apply to all members of the group.	Increase numbers for analysis Identify sources of data available for smaller levels of analysis	Building is individual level of analysis GIS maps new segment group level of analysis. Multilevel methods can measure relationships of variables on each level as well as interaction between levels.	Identify building level data by address.	Increased numbers improve likelihood of rejecting null, to control for random variation, to obtain tighter confidence intervals around the parameters, and to obtain SD & mean that reflect larger population – improves external validity
3. Conditions in buildings and segments with Asthma ED visits may be the same as conditions where there are no visits.	Include buildings and segments with no reported Asthma ED visits.	GIS map of all multiple dwelling buildings in study area.	Addresses for all multiple dwellings in study area.	Numbers of buildings are increased for increased power of rejecting H_0.
4. Buildings in an area are likely to be related in time and space (non-independent), show correlations between variables, and have unequal group sizes.		Multilevel methods can measure relationships of variables on each level as well as interaction between levels.		Hierarchical Linear Modeling (HLM) adjusts for co-correlation between variables (multicollinearity), non-independence between components, unequal group sizes, and provides separate error terms for each level of analysis and for interaction.

Appendix B - Issues and Strategies for Threats to Validity in Measuring Environmental Risk Factors for Asthma Emergency Care (continued)

Source of Threat	***Strategies***	***Methods***	***Data***	***Statistics***
LEVEL OF ANALYSIS				
5. Specification of variables may not provide for direct measurement of exposures. Direct measures of building and segment *trigger violations*, i.e., allergen and temperature, are not viable. Measure of exposure over time of different parts of building to pollution is not realistic. Proxy measures are used.	Geographically smaller group units of analysis with greater within group homogeneity assume that all members are similarly exposed to sources of contaminants. Identifying time and place of Asthma ED events can account for trends, latent effects of exposure, or peak exposures. Place and time are used as indirect indicators of exposure and underlying ecological risk factors.	Create group level units smaller than administrative divisions.	Identify sources of data relevant to smaller group units. Obtain visit dates of ED events and create subgroups by months for cluster screen.	Spatial data analysis Knox test can screen for significant clusters of events occurring simultaneously in time and space. May suggest periods of peak exposure.
6. Ecological Fallacy: Group measures do not necessarily apply to all members of the group. Measurements of the same variable on different level may actually be measuring different concepts (construct validity).	Geographically smaller group (local) units of analysis are more likely to relate to individual units.	Street segments are defined as group level unit of analysis; consist of both street sides and one side when streets / avenues are wide.	Most variables are formed as derived, aggregated from first level data to provide a "true group-level construct" while a few are integral (measuring completely different concepts at the second level).	Some variable definitions are modified during preliminary analysis for better model fit and to correspond to data actually available for all or most units.

Appendix B - Issues and Strategies for Threats to Validity in Measuring Environmental Risk Factors for Asthma Emergency Care (continued)

Source of Threat	***Strategies***	***Methods***	***Data***	***Statistical***
LEVEL OF ANALYSIS				
7. Study year is retrospective, variable measures must be consistent with study year. 8. Data at the individual level is in custody of different sources, not always complete, and at times conflicting.	Obtain study year data archived in government agencies & other sources. Rely on primary sources of data where possible.	Many sources exist for archival data although data availability changes with time. Use different sources of data when needed for clarification.	Data research through a variety of sources including, central depositories (e.g., city planning, library), FOIL requests, etc. Arrive at default criteria for accepting and rejecting data, cross-reference, or combine multiple sources of data.	Create new composite variables where there are insufficient hits on individual level to improve fit model fit.
9. Buildings and segments with AKA addresses will result in double counts of some measures when total asthma ED counts are obtained.	Obtain total number of Asthma ED visits for a building without double counting values.	Code buildings and segments as being north-south or east-west routes.	Counts data sources only once.	Create separate models for north-south and east-west buildings, segments, and combined building and segment models for the same direction.

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