An Assessment of Health Effects of Ambient Air Pollution in Latin America and the Caribbean

Area of Sustainable Development and Environmental Health
Pan American Health Organization
World Health Organization

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Regional Office of the World Health Organization

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PAHO HQ Library Cataloguing-in-Publication
Pan American Health Organization
An assessment of health effects of ambient air pollution in Latin America and the Caribbean.
Washington, D.C: PAHO, © 2005.

ISBN 92 75 12598 8

I. Title
1. AIR POLLUTION
2. AIR POLLUTANTS, ENVIRONMENTAL
3. ENVIRONMENTAL HEALTH
4. LATIN AMERICA
5. CARIBBEAN REGION

NLM WA 754

MESSAGE FROM THE DIRECTOR

The Pan American Health Organization, PAHO, was established in 1902 and works with all the countries of the Americas to improve the health and quality of life of their peoples. It also serves as the Regional Office for the Americas of the World Health Organization.

PAHO, in collaboration with numerous institutions throughout the Region, is committed to promoting and supporting the development of activities to identify and quantify the risks environmental degradation pose to human health.

Ambient air pollution is a form of environmental degradation ubiquitous in the Region. Economic and population growth, particularly in urban areas, are major drivers of atmospheric pollution. Therefore, social and economic development policies and practices need to take into account current and future impacts on health and the environment.

Sustainable development is not possible when there is a high prevalence of debilitating illness and poverty, and furthermore the health of a population cannot be sustained without a healthy environment and a responsive health system. Unhealthy lifestyles and consumption patterns, mismanagement of natural resources, and environmental degradation all impact health. Ill health hinders economic development and also hampers efforts to alleviate poverty.

The aim of this document is to set out the current state of knowledge on the links between ambient air pollution and adverse health effects, to inform the public, to guide in the allocation of resources, and the implementation actions.

Mirta A Roses
Director
Pan American Health Organization

PREFACE

In a rapidly changing and globalized world, environmental, occupational and consumer health risks, including violence and tobacco use, are not only increasing but also taking new forms. Public health policies and interventions to monitor, assess, communicate and control these risks deserve special attention as they impact on sustainable development. Realizing these challenges, the Pan American Health Organization (PAHO) recently created a unit to deal with the assessment and management of environmental, occupational and consumer health risks, to engage all sectors responsible for reducing the burden of disease, injury, disability, and premature death, attributed to these risks. As part of these efforts, PAHO conducted the following analyses to examine the impact of air pollution on human health in the Region under a cooperative agreement with the United States Environmental Protection Agency.

In many cities of Latin America and the Caribbean air pollution has become a major public health concern. Ambient concentrations of particles and other air pollutants exceed national air quality standards in many places. Exposure to the types and concentrations of air pollutants commonly found in urban areas has been linked to an increased risk of mortality and morbidity from a variety of conditions, including respiratory and cardiovascular diseases. Maternal exposure to air pollutants during pregnancy has also been linked to adverse effects on fetal growth.

Understanding associations between reported effects and exposure to air pollution includes the important steps of characterizing exposures to ambient air pollutants, defining the populations at risk and establishing at which levels specific exposures carry adverse health effects.

The first of two chapters in this book describes major social characteristics and environmental conditions of the Region in relation to potential exposures to ambient air pollution and their impact on human health. The following chapter presents a systematic search and review of research in the Region on the health effects of exposures to particulate matter. Quantitative summary estimates were generated and are reported. The evidence and what it means for the Region are later discussed. Although exposure to indoor tobacco smoke is a very important issue, we do not deal extensively with it in this publication. We hope to do it soon in a more specific document.

In addition to determining public health risks, this report provide a basis for establishing research and information requirements to assist in decision-making processes in the aim of improving air quality in the Region. In the last instance, we are certain that this report will help as well raising awareness and support for action on children and environmental issues included in the Healthy Environments for Children Alliance launched at the 2002 World Summit on Sustainable development. Action to reduce and eliminate the key environmental hazards to childhood and maternal health will ¨make every child and mother count¨.

Luis Galvao
Manager
Area of Sustainable Development and Environmental Health

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ABBREVIATIONS

AMI	Acute Myocardial Infarction
ARI	Acute Respiratory Infections
BIREME	Center for Latin American and Caribbean Health Sciences Data
ECLAC	Economic Commission for Latin America and the Caribbean
CI	Confidence Interval
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CVD	Cardiovascular Disease
ER	Emergency Rooms
ERV	Emergency Room Visits
GAM	Generalized Additive Models
ICD	International Classification of Disease
IHD	Ischemic Heart Disease
ISAAC	International Study of Asthma and Allergies in Childhood
LAC	Latin America and the Caribbean
LILACS	Latin America and the Caribbean Health Sciences Database
MEDCARIB	Caribbean Health and Medicine Database
NO_X	Nitrogen Oxides
NO_2	Nitrogen Dioxide
O_3	Ozone
PAHO	Pan American Health Organization
Pb	Lead
PEF	Peak Expiratory Flow
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter of 2.5 micrometers in diameter
PM_{10}	Particulate Matter of 10 micrometers in diameter
PPM	Parts Per Million
PPB	Parts Per Billion
REPIDISCA	Pan American Information Network on Environmental Health
RR	Relative Risk
RSI	Residential Sustainability Index
SE	Standard Errors
SCIELO	Scientific Electronic Library Online
SO_2	Sulfur Dioxide
TSP	Total Suspended Particles
$\mu g/m^3$	Micrograms per cubic meter
µm	Micrometer
UN	United Nations
WHO	World Health Organization

EXECUTIVE SUMMARY

In many cities of Latin America and the Caribbean (LAC) air pollution has become a major public health concern. Exposure to the types and concentrations of air pollutants commonly found in urban areas has been linked scientifically to an increased risk of mortality and morbidity from respiratory and cardiovascular diseases. Scientific reports also suggest that maternal exposure to air pollutants during pregnancy has an adverse effect on fetal growth.

The first chapter describes the main characteristics and conditions of the Region in relation to potential exposures to ambient air pollution and their impact on human health. The following chapter presents a systematic search and review of scientific evidence produced in the Region on the health effects of exposures to particulate matter. Quantitative summary estimates were generated and are reported. The evidence and what it means for the Region are discussed.

Ambient PM_{10} concentrations exceed national air quality standards in many LAC cities. Mobile sources are responsible for a large proportion of the air pollution in the Region's urban areas, since old buses and cars using outmoded technologies make up much of the total vehicle fleet. In many places across the Region the detrimental composition of diesel fuel exacerbates the situation. In some instances, problems are magnified by climate conditions and local topography, such as in the thermal inversions typically observed in Mexico City and Santiago, which cause episodes of reduced pollutant dispersion and raise the potential for exposure.

LAC is a highly urbanized Region. Several cities have more than five million inhabitants. Approximately 75% of the population lives in densely populated urban areas. Hence a large number of people are exposed to particles and other ambient air pollutants. In Mexico, alone, approximately 25 million people are affected by air pollution. Another 85 million live in other urban areas of LAC that also exceed ambient quality standards, such as Arequipa, Bogota, Fortaleza, Lima, Medellin, Santiago, and San Salvador. The total potentially exposed population in LAC is clearly under estimated, however, the information available is insufficient to determine what the true figure might be.

Much of the population in LAC faces a double environmental burden. In addition to recent hazards that have arisen over the past half-century, such as urban air pollution, many still face traditional hazards including lack of access to safe drinking water and inadequate waste disposal. Malnutrition, lack of access to health services and other ills related to poverty may render the population more susceptible to developing adverse health effects from air pollution. How far socioeconomic status modifies the effects of air pollution on health still warrants attention. In 2002, around 43% of Latin Americans lived in poverty.

Temporal variations in ambient PM_{10} concentrations have been associated with increased daily mortality. Scientific literature has shown a link between increases in air pollution and excess daily mortality at the elevated levels of air pollution observed in LAC. However, it is claimed that there is insufficient information currently to define a threshold below which effects of air pollution are not observable. Even at levels beneath existing air pollution standards in the Region, excess deaths should be discernable.

Systematic searches of the literature were performed to identify all of the studies associating air pollution and health effects conducted in LAC from 1994 to 2004. Searches were conducted in Spanish, English and Portuguese in the following bibliographic databases available in Internet:

The search revealed a total of 85 studies published in scientific periodicals between 1994 and August 2004 exploring the association between air pollution and health effects in the LAC Region. A full bibliography of the references is provided. The search results found the studies covered just six LAC countries: Brazil, Mexico, Chile, Peru, Cuba, and Venezuela. While a total of 25 cities were investigated in these six countries, closer inspection revealed even further concentration since more than half of the studies conducted in the Region were produced in Brazil and Mexico.

Further analysis of literature from the Region into the health effects of air pollution was limited to the assessment of results of the time-series studies conducted in LAC between 1994 and 2004 and that focused on particulate matter. Although studies using other designs were found in the search, the approach favored was the assessment of health effects considering temporal variations in air pollution levels (47 of the 85 studies cited). It was necessary to base our systematic review on one type of design to facilitate comparison of the results. Research using time-series provided the largest body of evidence with which to work. In addition, as systematic reviews of time-series studies have been conducted in Asia and Europe a review based on this type of design will enable us to compare the results from LAC with data from other parts of the world.

Overall, systematic analysis of LAC studies suggests that temporal variations in particulate matter do contribute to additional mortality and morbidity. A 10 $\mu g/m^3$ increase in ambient particle concentrations was linked to increases in daily mortality from all causes, all respiratory causes, and CVD. The same increment in ambient particle concentrations was also associated with increased hospital admissions from all respiratory causes.

Quantitative summary estimates were calculated to assess the percent increase in daily mortality associated to a 10 $\mu g/m^3$ increase in PM_{10} for some mortality causes. The quantitative summary estimate from the random effects model for mortality from all causes on the all-age group yielded a 0.61% increase in daily deaths (95%CI: 0.16,1.07). The quantitative summary estimate of the effect of exposure to an increase in air pollution levels in the health of the elderly population was greater than that observed for all causes in all ages. The random effects model provided an estimated increase of 0.86% in daily deaths (95%CI: 0.49, 1.24).

In general terms, the effects of air pollution observed in these studies are similar in magnitude to figures from other parts of the world. Caution should be taken when interpreting the results of this review. Summary estimates of effects were largely based on studies conducted in just three LAC cities. Hence they are not representative of the entire Region.

A rule was set that conclusions would only be drawn on the health effects of air pollution if there were at least three risk estimates for any one outcome per age group. Other age groups and outcomes could not be assessed. The Region lacks meaningful information about the effects of particle exposures on child mortality. While mortality from respiratory conditions in LAC is one of the main causes of death in children <5 few studies analyzed mortality from respiratory causes in children.

A number of studies did assess child mortality from all causes yet the information was not comparable because of differences in the age group definitions employed. The capacity to address this outcome was therefore limited. For the assessment of morbidity the issue of sparse data was particularly troublesome. The number of risk estimates for hospital admissions, emergency room, and outpatient visits yielded insufficient information to assess the influence of ambient particles on these outcomes.

In all likelihood, the summary estimates provided in this report are an underestimation of the true effect of air pollution on the populations of LAC, as the Region has a substantial population of children, a subgroup considered more vulnerable. Also, the average levels of air pollution found in LAC are substantially higher than those found currently in either Europe or the US. Finally, significant socioeconomic inequalities prevail in the Region and may amplify the impact air pollution has on health given the role of poverty as an effect modifier.

Although the body of evidence on which quantitative summary estimates were calculated could be improved the estimates do provide an approximation of the effect of air pollution in LAC populations. The estimates could, however, be used for policymaking purposes to help estimate the related cost of current levels of air pollution, and the benefits mitigation measures may bring.

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Alex Crawford

Chapter 1
An overview of health, economic, and environmental aspects of Latin America and the Caribbean

1.1 Introduction

Poor ambient air quality has become a major public health problem. Worldwide exposure to particulate matter (PM), a major component of air pollution, causes 800,000 premature deaths annually (Cohen, 2004). In Latin America and the Caribbean (LAC) air pollution is also of concern. Pressures from economic and population growth have been major determinants in the state of air quality. Arising from the need to meet increased demand for transport and power generation, combustion of fossil fuels is the main source of ambient air pollution that can reach unacceptable levels in urban areas. Moreover, the regional trend of increasing urbanization exposes more and more people to pollutants.

Air pollution in LAC is ubiquitous. More than 110 million people in LAC live in areas in breach of ambient air quality standards. Air pollution from combustion is associated with a higher incidence of acute and chronic health effects. Evidence from many studies conducted around the world links the types and concentrations of air pollutants commonly found in LAC urban areas to adverse health effects. Excess cardiovascular and respiratory mortality, lung cancer mortality, and mortality from acute respiratory infections in children are all health outcomes associated with pollutant levels exceeding ambient air quality standards (Cohen, 2004). The impact, on a variety of morbidity indicators, has also been reported (American Lung Association, 2001). Increased mortality and morbidity has direct and indirect implications for society ranging from an increased need of medical care to reductions in productivity and quality of life.

The aim and purpose behind the project was to assess current knowledge on the adverse health effects of air pollution on human health and the implications in the Region for society-at-large. This chapter explores the main characteristics and conditions of the Region in relation to potential exposures to ambient air pollution and their impact on human health.

LAC is a highly diverse Region encompassing 40 countries and a wide variety of geographies, economies, environments, and cultures. Whenever possible, data reporting has been organized by Subregion. When information proved insufficient, or key differences were identified between countries, disaggregated data was reported and discussed explicitly. Major aims of this chapter were to describe population and urbanization trends, the magnitude of air pollution problems in the Region and its sources, the rates of main health air pollution-related outcomes, and other characteristics that could alter exposure potentials and prompt the onset of adverse health effects.

1.2 Population and urbanization trends

In the year 2000, the population of LAC was approximately 518.9 million inhabitants or about 8.6% of the total world population (ECLAC, 2004a). Brazil and Mexico are the most populous nations in the Region. These two countries account for 51% of the total population while the remaining 49% of its peoples are distributed across 38 countries and territories. The Andean Area, comprising Bolivia, Colombia, Ecuador, Peru, and Venezuela is the most populated Subregion with 113 million inhabitants. The British Caribbean is the least populated sub region, yet it contains the greatest number of sovereign states or political units (Table 1-1).

Overall, population growth rates reveal a downward trend. For the Region, the average annual population growth rate has decreased to 1.3, from 2.1 per 100 over the past twenty years (PAHO, 2002b). In Central America, however, the growth rate is well above the Regional average (Table 1-2). In spite of the low current Regional growth rate by the year 2020 LAC will have an estimated population of 667 million representing an increase of 148 million people in 15 years (ECLAC, 2004a). So, many children will be affected from exposures to air pollutants in the years to come.

A decline in mortality from communicable diseases has proved a major contributor to increased life expectancy in the Region. By the year 2004, life expectancy at birth for Latin American and the Caribbean was 71 years; 74 years for females and 67 for males (PAHO, 2004). Average life expectancy in the various Subregions ranged from 75 years in the Southern cone to 67 in the Latin Caribbean (Table 1-2). Higher life expectancy will bring about a shift in the age distribution structure towards older age groups. By the year 2020 8.3% of the Region's population will be over 65 years of age, as op-

Table 1-1 Total estimated population in Latin America and the Caribbean 2000[a,b]

Country	Total Population	Country	Total Population
Brazil	170,693	Latin Caribbean	31,768
Mexico	98,881	Cuba	11,199
Andean Area	113,504	Dominican Republic	8,396
Colombia	42,321	Haiti	8,357
Peru	25,939	Puerto Rico	3,816
Venezuela	24,170	English Caribbean	6,612
Ecuador	12,646	Jamaica	2,580
Bolivia	8,428	Trinidad and Tobago	1,289
Southern Cone	61,076	Guyana	759
Argentina	37,032	Suriname	425
Chile	15,211	Bahamas	303
Paraguay	5,496	Barbados	267
Uruguay	3,337	Dutch Antilles	215
Central America	31,019	Saint Lucia	146
Guatemala	11,385	Saint Vincent and the Grenadines	118
Honduras	6,485	Virgin Islands (U.S.)	109
El Salvador	6,276	Aruba	93
Nicaragua	5,071	Grenada	81
Costa Rica	3,925	Dominica	78
Panama	2,948	Antigua and Barbuda	72
Belize	240	Saint Kitts and Nevis	42
		British Virgin Islands	20
		Anguilla	11
		Montserrat	4
		Total	518,864

a. Thousands of persons at mid-year
b. ECLAC, 2004a

posed to 5.4% in the year 2000 (ECLAC, 2004a).

LAC is among the most urbanized regions in the developing world. Currently 77% of the population lives urban areas (Table 1-2). The figure for LAC is higher than that of Europe and twice the current proportion of either Africa or Asia, although closer inspection reveals considerable Subregional variation (UN, 2003). For instance, in countries such as Argentina and Uruguay, as well as some of the Caribbean Islands, the urban population is reportedly over 90%. In contrast only around 50% of the population of Central America lives in urban areas (PAHO, 2004).

Seven cities in Latin America and the Caribbean had five million or more inhabitants in the year 2000. Four of these —Mexico City, Sao Paulo, Buenos Aires, and Rio de Janeiro— had populations over 10 million (Table 1-3). Mexico City and Sao Paulo are ranked as the second and third most populous cities of the world (UN, 2003). With the exception of Mexico City, all of the other mega cities are located in South America and two of them are in Brazil. Population projections indicate that Guatemala City and Belo Horizonte will have more than five million inhabitants by the year 2015 (PAHO, 2004). Poor air quality is common to almost all major metropolitan areas in the Region and the sheer numbers of people living in these areas alone puts a large proportion of the population of LAC at risk from exposures to ambient air pollutants.

Urbanization patterns in the Region typically involve a single very large city per country. Examples include Santiago, Buenos Aires, and Lima whose populations account for one third of each country's entire inhabitants (Table 1-3). In Peru, for instance, fewer than 700,000 people live in the second largest city, Arequipa. Urban populations will continue to grow faster than rural populations, but the highest growth rates will occur in smaller cities (UN, 1999).

Table 1-2 Demographic and socioeconomic indicators for Latin America and the Caribbean Subregions

Subregions and Countries	Annual population growth rate (%) 2004[a]	Life expectancy at birth (years) 2004[a]	Urban population 2004[a] (%)	Gross national income[a] 2002 (US$ per capita)
Latin America and the Caribbean	1.3	71.1	77.2	3,399
Brazil	1.2	68.7	83.6	2,830
Mexico	1.4	73.8	75.8	5,920
Andean Area[1]	1.6	71.7	76.1	2,251
Southern Cone[2]	1.2	74.8	86.7	3,949
Central America[3]	2.1	70.2	52.8	1,958
Latin Caribbean[4]	0.9	67.1	64.2	3,083
English Caribbean[5]	0.7	73.5	63.9	4,273

1. Bolivia, Colombia, Ecuador, Peru, and Venezuela.
2. Argentina, Chile, Paraguay, and Uruguay.
3. Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama.
4. Cuba, Haiti, Puerto Rico, and Dominican Republic.
5. Anguilla, Antigua and Barbuda, Dutch Antilles, Aruba, Bahamas, Barbados, Dominica, Grenada, Guadalupe, Guyana, Cayman Islands, British Virgin Islands, Virgin Islands of the United States, Jamaica, Martinique, Montserrat, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Saint Lucia, Suriname, Trinidad and Tobago, and Turks and Caicos Islands.

a. PAHO, 2004

1.3 Socioeconomic indicators

Over the past few years almost every country in the Region has experienced better economic performance. Growth has been steady and on a par with the world economy. The main motors behind economic development have been the expansion of markets and an increased demand for commodities. In 2004, the Region's economy is expected to increase by 4.5%. It is hoped that this increase will have a positive impact on employment and also contribute to reduce poverty (ECLAC, 2004b).

In 2002, around 43% of Latin Americans lived in poverty (UN Human settlements programme, 2004). A look at the 2002 figures for gross national income suggests that poverty is especially prevalent in Central America and the Andean Subregion (Table 1-2). In the past it was believed that poverty was essentially confined to rural areas, yet, many urban areas are deprived, too. Overall, in urban areas of the Region the percentage of households living in conditions of poverty (i.e.; those with incomes less than twice the cost of a basic food basket) is about 36%. This figure varies considerably, however. In Mexico City and Sao Paulo, for example, between 30% and 40% of the population live on or below the poverty line. Some countries report poverty levels of over 70%. (ECLAC, 2004a).

Deep inequalities are apparent in the Region's income distribution. The richest quintile in LAC earned approximately 45% of the total income, whereas the poorest quintile earned just 5% (PAHO, 2002b). Inequalities in the distribution of income in Latin America are the most extreme in the world. The Gini coefficients for all LAC countries were higher than the world average of 0.4 and countries such as Colombia, Chile, Paraguay, Bolivia, Honduras, Brazil and Nicaragua all reported values close to 0.6 (ECLAC, 2004a).

Poverty and unplanned urban growth has contributed to the development of slums. Poor urban dwellers that mostly live in substandard housing within informal

Table 1-3 Cities of Latin America and the Caribbean having five million inhabitants or more

City	Population (thousands) 2002[a]	Percentage of total country population 2000[b]
>10 millions		
Mexico city	18,259	18.2
Sao Paulo	18,182	10.1
Buenos Aires	12,819	32.3
Rio de Janeiro	10,756	6.1
5-9 millions		
Lima	7,740	29.1
Bogota	6,543	16.3
Santiago	5,709	36.0

a. United Nations, 2003
b. ECLAC, 2004a

settlements have limited or no access to basic services (UN, 1999). Central America has the highest prevalence of slums in the Region with its high urban growth rates and a large proportion of its population living in poverty (UN Human settlements program, 2004).

People living in poverty are probably more susceptible to air pollution. A study from Brazil found an inverse correlation between mortality due to air pollution and indicators of socioeconomic status. Higher mortality was linked with those living in areas where people receive poorer education, have lower levels of income and a higher percentage live in slums (Martins, 2004). Reasons for these associations may include: poor nutrition, lack of access to health services, lack of awareness of the adverse health effects of air pollution, inadequate housing for conferring protection as well as a potential exposure to high levels of indoor air pollution.

1.4 Sources of air pollution and ambient particle concentrations

1.4.1 Sources of air pollutants

Air pollutants are classified into primary and secondary pollutants. Primary pollutants are those directly emitted into the environment from a source while secondary pollutants are formed in ambient air through chemical and photochemical reactions of primary pollutants.

Several "natural" sources of air pollutants exist in LAC. Much of Central and South America is located on the so-called "Ring of Fire", home to most of the world's active and dormant volcanoes. In Central America alone there are over a 100 volcanoes including some active ones (Smithsonian Institution, 2004). Ash and gases are emitted in volcanic eruptions. Ash can travel long distances and affect both visibility and air quality in populated areas. Carbon dioxide and sulfur dioxide are typically released into the atmosphere during volcanic eruptions (OPS, 2000).

Forest clearing and stubble burning is common practice in the Region for converting rain forest into agricultural land and for further maintenance. During fires, ambient particles and carbon monoxide concentrations are high and invariably exceed air quality standards (Reinhardt, 2001; Arbex, 2004). The fires represent a significant source of air pollution, although they mostly occur in rural areas, where air quality problems arising from traffic or industry are less likely. Burning episodes tend to be fairly short, in comparison to emissions from other sources, however human populations living in the proximity are exposed to high concentrations of air pollutants. Such episodes are likely to become important regional sources of air pollution. Winds can carry particles hundreds of miles and so exacerbate air quality problems in polluted urban areas. Acute exposure may affect susceptible populations groups such as asthmatics and those with chronic conditions.

Another source of particle matter in the Region is from North African dust storms. Large quantities of dust are transported in the atmosphere from Africa into the Caribbean carrying dust particles as far as the Southeastern United States. Dust transport seems to be higher during the summer (June-August) and in certain years concentrations of dust over the Caribbean have been particularly high. Much of the transported dust mass is fine, in other words, consisting of particles under 2.5 µm in diameter (Prospero, 2003). Dust deposition affects air quality and may prove detrimental to health in susceptible populations as fine particles lodge deep in the lung.

Economic and population growth put further pressure on atmospheric pollution levels in the Region. Rapid industrialization and more vehicles in circulation have led to an increase in the combustion of fossil fuels to satisfy energy demands. Particulate matter (PM) is the main pollutant from the combustion of fossil fuels. In urban areas, primary PM mostly consists of carbon (soot) emitted from cars, trucks, and heavy equipment and crustal material from unpaved roads, stone crushing, construction sites and metallurgical operations. Secondary PM forms in the atmosphere from gases as fine particles and includes: sulfates, nitrates, and carbon (US EPA, 2004; Suh, 2000).

Particle pollution consists of a mixture of larger materials "coarse particles" and smaller material "fine particles". The two fractions have different origins and compositions. Coarse particles range in size from 2.5 micrometers (µm) in diameter to more than 40 µm. These are formed by mechanical crushing, grinding, or abrasion of surfaces and are suspended and dispersed by the wind and anthropogenic actions such as traffic and agricultural activities. Coarse particles are primarily composed of aluminosilicates and other oxides of crustal elements in soil and fugitive dust (US EPA, 2004; Suh, 2000).

Fine particles ($PM_{2.5}$) are less than or equal to 2.5 µm in diameter. They originate primarily from combustion sources (such as automobiles, power plants, and wood stoves), either through the condensation of volatilized materials (primary particulate matter), or from precursor gases reacting in the atmosphere to form secondary particles. The major components of fine particles often include sulfates, carbonaceous materials, nitrates, trace elements, and water. PM_{10} refers to all particles of less than 10 µm in diameter (US EPA, 2004).

Other primary pollutants emitted into the environment from the combustion of fossil fuels include sulfur dioxide (SO_2), nitrogen oxides (NO_x) and carbon monoxide (CO). Secondary pollutants, ozone and acid aerosols, are also commonly found in urban areas (Lippman, 2003).

Emissions inventories provide an estimate of the relative importance of different major emissions sources at a particular location. Data from emission inventories available for the cities of Bogota (CEPIS, 2005), Buenos Aires (Tarela and Peroné, 2002), Lima (CGIALLC, 2004), Mexico City (SMA, 2004), Santiago (CONAMA, 2004), and Sao Paulo (CETESB, 2002) gives information on the different sources of PM_{10}. Mobile sources contribute most to the atmospheric emissions in these cities, and account for one-third to two-thirds of all PM_{10} emissions (Table 1-4). Point sources, mainly heavy and light industry, are the second most important contributor, ranging from 4% in Buenos Aires to near 55% at Sao Paulo. Area sources, meanwhile, include commercial and residential activities and off road sources.

Emissions inventories from the Region are, however, limited. Figures for Buenos Aires, for example, suggest the way sources were classified had a significant bearing on the low percentage attributed to point sources. In addition, area sources were not reported for either Bogota or Sao Paulo and data from Lima appears to have been grossly underestimated.

Information is seldom reported on emissions from wind erosion and street dust since these are hard to quantify (Veranth et al, 2003). They are, nonetheless, important contributors to PM_{10}. Road sources include non-regulated construction and agriculture support equipment. Such machinery usually burns diesel or fuel oil, tends to be fairly old and many have faulty or poorly maintained engines. Consequently, PM_{10} figures are more than likely to be underestimated in current emission inventories (Clark et al, 2002).

Figures do indicate mobile sources are responsible for most of the air pollution in the Region's urban areas. Old cars and buses using outdated technologies and low-grade diesel comprise a large part of many LAC countries' vehicle fleets. In addition to particle pollution motor vehicles are also important sources of CO and NO_X.

Table 1-4 PM_{10} emission inventories for selected LAC countries

City	Percentage of PM_{10} emissions		
	Point	Area	Mobile
Bogota	66.6	0.0	33.3
Buenos Aires	4.0	32.4	63.6
Lima	33.0	0.7	66.3
Mexico City	32.7	5.9	61.4
Sao Paulo	55.2	0.0	44.8
Santiago	31.4	12.2	56.4

Note: Emissions for Sao Paulo correspond to TSP

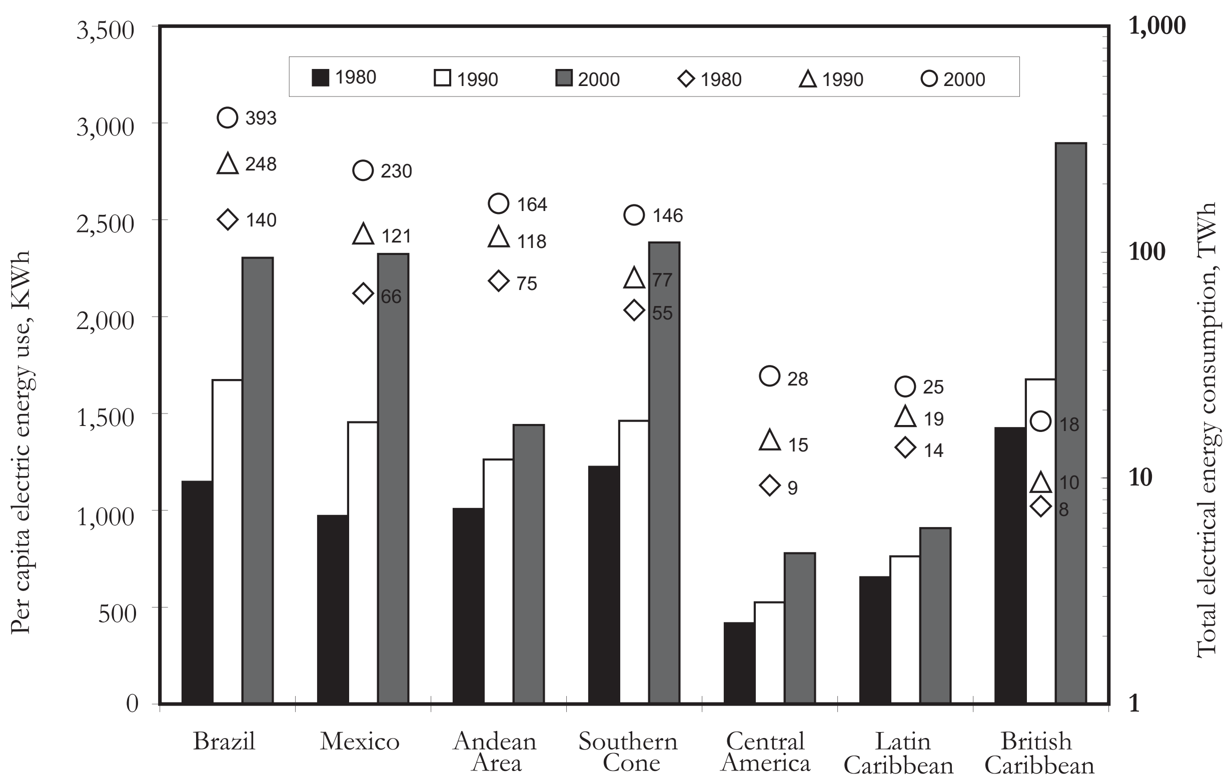
In parallel with urbanization patterns and improved economic development, transport in general has grown rapidly throughout LAC. From 1984 to 1993 the total vehicle fleets increased by 42.3% in Mexico, 37.1% in Brazil, and 13.6% in Chile (UN, 1996). Cars constituted between 70 to 90% of the national motor vehicle fleets in 1994 (World Bank, 1997). Since economic growth encourages vehicle ownership, such growth was likely.

At present motor vehicles are concentrated in the major cities. In 1994, the Metropolitan Area of Santiago contained 58% of all of the motor vehicles in Chile while in Argentina, 51% of the national fleet was in Greater Buenos Aires. In Brazil, the three largest metropolitan areas– Sao Paulo, Rio de Janeiro, and Belo Horizonte – collectively accounted for 45% of the national vehicle fleet. Road infrastructure has failed to keep pace up with rising transport activity in many places. Growth has resulted in severe traffic congestion leading to unproductive time delays and increased fuel consumption that, in turn, produces more emissions further deteriorating urban area ambient air quality (World Bank, 1997).

Other factors - besides infrastructure - that influence vehicle emissions in LAC are the age of the fleet, poor maintenance, and fuel quality. In many countries, the practice of importing inefficient used vehicles influences the fleet age. In Peru, where this is common practice, the fleet is old. Data from Lima reveal that 71% of the cars in the Peruvian capital are 10 or more years old. Motor vehicles older than 10 years made up 50% of the fleet in Argentina, 60 % in Ecuador and 64% in El Salvador (World Bank, 1997).

Diesel is used widely in LAC. Diesel engine exhaust is a source of fine particles into the environment. The sulfur content in diesel is critical in determining the level

Figure 1-1 Evolution of per capita electric energy consumption (bars) and total energy consumption (symbols and numbers) for the period 1980-2000.



of particles in its emissions: the higher the sulfur content, the higher are the emissions of particles (Clark et al, 2002; COPERT III, 2005).

Sulfur content of diesel in LAC varies from country to country, and even within countries. The following data are sulfur content ranges for some of these countries: Panama 0.50-1.50%, Venezuela 0.50%, Bolivia 0.35%, Uruguay 0.25%, Brazil 0.20%, Argentina 0.15%, Colombia 0.10-0.80%, and Peru 0.035-0.50%.

It is estimated that cutting the sulfur content from 0.5% to 0.035% would reduce diesel vehicle PM_{10} emissions by 75% (COPERT III, 2005). Hence, significant reductions in PM_{10} emissions from the introduction of cleaner fuels are possible and would be beneficial to public health. At current sulfur levels in diesel across LAC it is expected that transport sources will continue to be a major contributor to ambient particles throughout the region.

Power generation plants are point sources of particles into the atmosphere. In LAC, electrical energy consumption is higher in the more populous countries with the stronger economies. Over the past decade, the largest per capita increase in electric energy usage has occurred in the most economically dynamic countries or Subregions, such as Mexico, the Southern Cone, and the English Caribbean. Per capita, the English Caribbean uses most electricity in the Region, which is most likely due to tourism, as the many visitors to the island states each year consume large amounts of electricity (ECLAC, 2003).

Fewer people have access to electricity in Central America, the Latin Caribbean and the Andean Subregions. In fact, energy consumption has risen little over the past twenty years in the Latin Caribbean. A larger proportion of people living in these areas are more likely to use inefficient, polluting sources of energy than the people from other areas of the Region (Figure 1-1 constructed with data from ECLAC, 2003).

Specific technologies used in the fuel burning process and the quality of fuels determine the amount of pollutants such as PM_{10}, $PM_{2.5}$, NO_x, SO_2 and CO emitted from a given source. Biomass burning processes are inefficient, leading to higher pollutant emissions per unit of energy released. Therefore, in countries that are more

Table 1-5 National annual standard and ambient average concentrations of PM_{10} ($\mu g/m^3$)for some cities of Latin America and the Caribbean, 2000-2004

City	Annual standard ($\mu g/m^3$)	Annual ambient average concentrations of PM_{10} ($\mu g/m^3$)				
		2000	2001	2002	2003	2004
Arequipa[1]	50	111	91	102	100	90
Belo Horizonte[2]	50	13	21	26	-	-
Bogota[3]	65	58	64	66	66	66
Cochabamba[1]	-			98	104	64
Fortaleza[4]	50	84	74	81	-	-
Guatemala City[1]	-	-	54	-	-	-
Havana City[5]	-	-	75	60	54	
La Paz[1]	-	-	-	-	-	49
Medellin[3]	65	-	-	87	93	-
Mexico City[6]	50	71	60	65	64	54
Quito[7]	50	-	-	-	-	54
Rio de Janeiro[8]	50	-	39	40	53	-
San Salvador[1]	50	-	60	-	-	-
San Juan[9]	50	32	31	31	32	30
Santiago[10]	-	77	72	70	74	68
Sao Paulo[11]	50	52	49	51	48	41

1 SWISSCONTACT (Swiss Foundation for Technical Cooperation - Peru)
2 FEAM (Fundação Estadual de Meio Ambiente - Brazil)
3 Procuraduría General de Colombia (Delegada para Asuntos Ambientales y Agrarios)
4 SEMACE (Superintendência Estadual do Meio Ambiente - Brazil)
5 INHEM (Instituto Nacional de Higiene, Epidemiología y Microbiología - Cuba)
6 INE (Instituto Nacional de Ecología – Mexico)
7 REMMAQ (Red Metropolitana de Monitoreo Atmosférico de Quito – Ecuador)
8 FEEMA (Fundação Estadual de Engenharia de Meio Ambiente - Brazil)
9 US EPA (United States Environmental Protection Agency)
10SEREMI R.M (Secretaria Regional Ministerial de Salud, Región Metropolitana –Chile)
11CETESB (Companhia de Tecnologia de Engenharia Ambiental - Brazil)

dependent on biomass energy sources both indoor and regional air pollution levels would be expected to be higher (ECLAC/OLADE/GTZ, 2003).

Air quality problems are often heightened in certain geographic and climate conditions. Vehicle combustion processes are less efficient at high altitudes. This is a significant factor in the air pollution problems of many LAC cities including Arequipa, Bogota, Mexico City, and Quito. In Mexico City and Santiago thermal inversions cause frequent episodes of poor ventilation, trapping pollutants, deteriorating air quality and increasing the populations' potential exposure. Dispersion conditions can also be poor at times in Bogota, Quito, and Sao Paulo.

1.4.2 Ambient particle concentrations

Data was compiled on annual ambient average concentrations of PM_{10} in LAC cities from different sources for the period 2000-2004. Most data was obtained from public institutions responsible for national air quality programs. Other sources included international cooperation programs, formed to develop air-monitoring capacities in certain countries, and academic institutions (Table 1-5).

Not all countries have an annual standard for ambient PM_{10} in place. With the exception of Colombia that set its standard at 65 $\mu g/m^3$, elsewhere countries have adopted a 50 $\mu g/m^3$ standard. Significant inter-city differences exist regarding ambient particle concentration data collection. Some cities such as Mexico City, Santiago, and San Juan have a long history of monitoring air conditions. In other cities, few annual average concentration data points are available. For instance, in Quito, systematic ambient air monitoring was begun in 2003 so only one year of data was available when the request was made. Countries in Central America conducted short term monitoring campaigns through international cooperation programs. For Rio de Janeiro, the 2004 data is still being analyzed and not ready for publication.

In some cities, such as Lima and Arequipa, ambient PM_{10} concentrations are high. Annual concentrations of 117 and 118 μg/m^3 were reported. In other cities of the Region ambient PM_{10} concentrations are lower but many still do not meet national standards.

Temporal variations in ambient PM_{10} concentrations have been associated with increased daily mortality. At elevated levels of air pollution, as those observed in LAC (Table 1-5); scientific literature has shown a link between increases in air pollution and excess daily mortality. However, current literature claims there is insufficient information to define a threshold under which effects of air pollution are not observable (OMS, 2000). Even at levels below current air pollution standards in the Region, excess deaths should be observable.

As stated earlier, particle pollution consists of a mixture of coarse and fine particles. While PM_{10} measures the concentrations of both fine and coarse particles $PM_{2.5}$ measures the fraction of fine particles. Fine particles are small enough to be inhaled deeply into the lungs where they may persist. However, what is not clear is to what extent particles of different sizes and composition differ in their effects on health (HEI, 2003).

From the ambient PM_{10} concentrations reported for the Region, fine particle concentrations would probably also be high. In 2004, Mexico City reported an average concentration for annual ambient $PM_{2.5}$ of 24 μg/m^3. However, few LAC countries measure $PM_{2.5}$ concentrations on a regular basis or have developed regulations for fine particles.

1.4.3 Indoor Air Pollution

In developing countries, indoor air pollution is a public health problem deserving of attention. While the focus of this document is the assessment of effects related to outdoor air pollution, it was deemed important to give an overview of the situation of indoor air pollution in LAC including a description of main sources and exposures.

Households may use a combination of fuels such as electricity for lighting and wood for cooking and heating in urban and suburban areas. But poorly functioning stoves with inadequate venting are common. Studies conducted in Metropolitan Santiago to assess indoor particle concentrations reported elevated levels of particulate matter. These studies reported 24-hour average exposure levels in the range of 103-173 μg/m^3, which are actually higher than annual ambient air standards of many LAC countries (Rojas et al 2001; Cáceres et al 2001). Biomass fuels are cheaper than other types of fuels, and so continued use is favored amongst the poor. Besides economic motives certain cultural reasons also exist for favoring the use of biomass.

Residential sustainability index (RSI) estimates for 20 countries reveal large differences in the proportion of populations that rely on biomass fuels to meet their domestic energy needs (ECLAC, 2003). The index represents the ratio of wood use to consumption of petroleum derivates or secondary hydrocarbons (kerosene, diesel, liquefied petroleum gas) in residential settings. Households in Haiti, Paraguay, Honduras, Guatemala, Nicaragua, El Salvador, Peru, and Brazil rely heavily on wood for cooking and heating, and the RSI for these countries range from 75 to 100. In contrast, wood use for domestic energy purposes is lower in Mexico, Costa Rica, Argentina, and Venezuela where the RSI was under 25%. Wood use and crop wastes, such as sugar cane, seemed to be more common in Central American countries where the extent of urbanization is lower and poverty is higher. But in countries with high biomass consumption this is a common source of fuel in urban areas as well as in rural areas (ECLAC, 2003).

Biomass fuels are neither clean nor efficient. Smoke from biomass fuels contains a large number of pollutants that present dangers to health including small particles, carbon monoxide, and nitrogen dioxide. Dependence on biomass fuels for cooking and heating is commonplace in many countries of the Region. Air pollution inside households can be extremely high, and sometimes even exceed international reference standards for outdoor air pollution.

Exposure to indoor air pollution in the Region will vary depending on geographic factors. Households high in the Andes use the fuel for cooking and heating in open pit fires. Ventilation is poor, since such housing is built to withstand extremely cold weather, which leads to limited air replenishment and an accumulation of high concentrations of pollutants. Yet conditions are quite different in tropical areas of the Region. Here, the number of hours of exposure may be lower as no heating is required and house construction favors ventilation and air exchange to keep indoor temperatures cool. While biomass fuels are an important source of indoor air pollution in the Region, exposure patterns differ putting some populations at higher risk of developing adverse health effects.

Indoor air pollution from biomass has been linked to increases in the risk of acute lower respiratory infections in children and chronic obstructive lung disease in adults (WHO, 2002a). Women and children are more likely to be exposed; women are in charge of most of the household chores involving energy use and children often accompany their mothers doing housework.

Environmental tobacco smoke is an important source of indoor air pollution in the Region. A survey of secondhand smoke in public places of Latin America reported that vapor-phase nicotine was detected in most indoor places that were surveyed. High concentrations of nicotine were found in restaurants, bars, hospitals and government offices. Some schools also had high levels of nicotine. The survey also found that non-smoking areas did not effectively protect non-smokers from exposure to secondhand smoke (Navas-Acien et al, 2004).

In general, and particularly for hospitals and schools, concentrations of nicotine are higher in countries with higher prevalence of smoking (ACS, 2003) and with higher percentages of students reporting exposure to secondhand smoke in public places (CDC, 2005; GYTSCG, 2002). In LAC, at least 43% of students 13 to 15 years of age report breathing tobacco smoke involuntarily at home and 58% at public places (GTSSCG, 2005).

Exposure to secondhand smoke is a significant but avoidable cause of premature death and disease worldwide and in Latin America. These exposures have been related with the occurrence of asthma, bronchitis, pneumonia, and ear infections in children and lung cancer and heart disease in adults. Exposure to secondhand smoke also has an adverse impact on reproductive and perinatal health (WHO 2002b; CDC, 1986).

1.5 Health effects of air pollution

Studies conducted around the world have found positive associations between exposures to the ambient air pollutants typically found in urban areas and adverse health effects. Reported effects relate to pollutants from the combustion of fossil fuels, including particles, SO_2, NO_x, CO, and O_3. There are other outdoor pollutants present in urban air, such as volatile organic compounds and polycyclic aromatic hydrocarbons, but their impact on health has not been as well documented. Children, the elderly, and those with cardiac or respiratory diseases are among the most susceptible to the adverse health effects of air pollution.

Overall, reported health effects range from minor physiological disturbances to death. Cardiovascular and respiratory systems are affected by air pollution. Time-series studies conducted in different populations have reported excess cardiovascular and respiratory mortality. Hospital admissions as well as emergency department visits for cardiac and respiratory conditions are also increased in episodes of elevated air pollution levels. The mechanisms of action through which air pollution may have an impact on the respiratory and cardiovascular systems include decrement of pulmonary function, effects on heart rate variability, and inflammatory response (Cohen et al, 2004).

Table 1-6 Age-Adjusted Mortality Rates, 2000-2005 (100,000 pop)[a]

Subregions and countries	All causes		Diseases of the circulatory system		Malignant neoplasm		Communicable diseases	
	Men	Women	Men	Women	Men	Women	Men	Women
Latin America and the Caribbean	882	615	247	196	124	99	102	75
Brazil	1,031	676	324	247	138	100	114	77
Mexico	737	528	157	134	84	75	59	41
Andean Area[1]	860	634	220	185	114	110	109	85
Southern Cone[2]	768	511	241	170	157	109	69	51
Central America[3]	830	624	189	168	94	98	142	116
Latin Caribbean[4]	886	706	253	221	126	95	186	138
English Caribbean[5]	776	591	289	251	119	92	62	44

1. Bolivia, Colombia, Ecuador, Peru and Venezuela.
2. Argentina, Chile, Paraguay and Uruguay.
3. Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama.
4. Cuba, Haiti, Puerto Rico and Dominican Republic.
5. Anguilla, Antigua and Barbuda, Dutch Antilles, Aruba, Bahamas, Barbados, Dominica, Grenada, Guadalupe, Guyana, Cayman Islands, British Virgin Islands, Virgin Islands of the United States, Jamaica, Martinique, Montserrat, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Saint Lucia, Suriname, Trinidad and Tobago, and Turks and Caicos Islands.
a. PAHO, 2004

Table 1-7 Under-five mortality

Subregions and countries	Under five mortality[a,b]	Registered deaths due to ARI[a,c] (%)
Latin America and the Caribbean	39.8	9.3
Brazil	44.5	7.1
Mexico	33.8	9.5
Andean Area[1]	39.9	10.7
Southern Cone[2]	23.3	5.6
Central America[3]	44.7	20.5
Latin Caribbean[4]	45.8	6.7
English Caribbean[5]	28.4	6.4

1. Bolivia, Colombia, Ecuador, Peru, and Venezuela.
2. Argentina, Chile, Paraguay, and Uruguay.
3. Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama.
4. Cuba, Haiti, Puerto Rico, and Dominican Republic.
5. Anguilla, Antigua and Barbuda, Dutch Antilles, Aruba, Bahamas, Barbados, Dominica, Grenada, Guadalupe, Guyana, Cayman Islands, British Virgin Islands, Virgin Islands of the United States, Jamaica, Martinique, Montserrat, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Saint Lucia, Suriname, Trinidad and Tobago, and Turks and Caicos Islands.

a. PAHO, 2004
b. Rates per 1,000 life births.
c. Percentage of deaths from acute respiratory infections recorded in children under five.

Worldwide about 3% of deaths from cardiovascular disease could be attributed to particulate matter exposures. An estimated 31,000 annual deaths from this cause occur in the Region from these exposures (Cohen et al, 2004). Regional data shows that mortality from diseases of the circulatory system is an important cause of death for both males and females (Table 1-6). Age-adjusted mortality rates are elevated and much higher for this cause of death than rates for malignant neoplasm and communicable diseases. Adjusted mortality rates for Latin America and the Caribbean from this cause were 247 per 100,000 population in men and 196 in women. Brazil had the highest mortality rates from cardiovascular diseases in males and the second highest in women. Mortality rates were higher in females from the English Caribbean. Air pollution may be an important risk factor contributing to these rates, especially in urban areas, where a large number of people are exposed to elevated levels of particles and other air pollutants.

Diesel exhaust contains small carbonaceous particles and a large number of chemicals that are adsorbed onto these particles or present as vapors. The vapors and particles include mutagens, carcinogens, and lung irritants. Epidemiologic studies of workers in certain occupations suggest a weak association between exposure to diesel exhaust and lung cancer (HEI, 2003). Age-adjusted mortality rates from malignant neoplasm in LAC are elevated and it would prove constructive to assess the impact of air pollution on these rates.

Other effects of air pollution include exacerbated bouts of asthma and an increased occurrence of respiratory illnesses and symptoms. Asthmatics are more susceptible to the development of respiratory symptoms, including asthma attacks, and require medical attention during episodes of increased air pollution levels. Respiratory infections and symptoms, such as chest tightness, coughing, and wheezing, also occur in relation to increased air pollution levels (American Lung Association,

Table 1-8 Wheezing ever and asthma prevalence rates for selected cities of Latin America

City	Wheezing Ever[a] (%)		Asthma Diagnosis Ever[a] (%)	
	6 yrs	13 yrs	6 yrs	13 yrs
Cuernavaca	21.6	18.0	5.1	5.5
San Jose	48.8	18.0	26.9	18.5
Panama City	35.4	30.9	19.0	16.7
Lima	34.8	48.6	28.8	28.0
Asuncion	---	39.9	---	12.2
Montevideo	38.0	31.2	11.9	15.3
Buenos Aires	29.9	19.9	4.1	6.4
Rosario	33.2	24.0	6.5	7.6
Sao Paulo	49.2	45.4	6.1	10.0
Porto Alegre	46.8	46.9		21.9
Recife	44.4	39.0	20.7	21.0
Curitiba	41.9	40.4	6.6	8.6
Salvador	---	44.4	---	12.6
Santiago Center	41.1	32.3	10.0	12.4
Santiago South	36.5	27.8	10.5	11.5
Valdivia	40.4	22.8	16.5	11.9

a. Mallol, 2002

2001).

Overall, children are more vulnerable to environmental toxins than adults because of exposure patterns and physiologic immaturity. Children have higher breathing rates than adults and therefore a higher intake of air pollutants per unit body weight. By spending more time outdoors they increase their exposure potential too. The developing lung may have a limited metabolic capacity to address toxic insults. Since eighty percent of alveoli are formed postnatally, and changes in lung continue through adolescence, exposures to air pollutants pose a serious risk to this population group (The American Lung Association, 2001; American Academy of Pediatrics, 2004).

The death rate of children under five has decreased. Over the period between 1990 and 2000, mortality in this age group reduced by one third from approximately 53 to 38 deaths per 1,000 live births (PAHO, 2002a). Although Subregional estimates suggest similar rates, there are striking differences between countries (Table 1-7). The highest number of deaths occurs in Haiti, where a rate of 109 cases per 1000 birth was reported in 2004. In contrast, one of the lowest reported rates was from Cuba (9.5 x 1000), which happened to be within the same Subregion. In the Southern Cone death rates in Argentina, Chile and Uruguay are under the Subregional average yet the rate in Paraguay is above the Regional average (PAHO, 2004).

Acute respiratory infections (ARI) are an important cause of death in children. It is the leading cause of death in children 5-14 in the world and the second leading cause of death in children under 5 (UNEP, 2002). In LAC, the proportion of deaths due to ARI has decreased. It fell from 16.5% in 1980-1985 to 10.7% 1995-2000 (PAHO, 2002a). Rates, nevertheless, remain high and range from 6.7% in the Latin Caribbean to about 20% in Central America (Table 1-7). Worldwide, about 1% of deaths from acute respiratory infections in children could be attributed to particulate matter exposures (Cohen et al, 2004).

Asthma prevalence studies have been conducted in many countries of Latin America using the methodologies and questionnaire developed for the International Study of Asthma and Allergies in Children (ISAAC) (Table 1-8). The reported prevalence of wheezing ever in the Region is fairly elevated, ranging from 20 to 50%, and is more common in younger groups. Physician-diagnosed asthma is also high at almost 30% in some cities. The difference in the proportion of positive responses between the occurrence of symptoms and medical diagnosis suggests that asthma in LAC is under diagnosed (Mallol, 2004). Untreated asthma may lead to premature deaths in children exposed to environmental insults.

Several factors may contribute to the high rates of asthma in LAC. In countries with high levels of poverty, inadequate hygiene and sanitation practices may contribute to the occurrence of parasitic diseases and recurrent acute respiratory infections early in life rendering the child more susceptible to asthma morbidity and mortality. In addition, to outdoor air pollution, indoor air pollution from biomass burning and secondhand smoke are important risk factors for asthma attacks in LAC (Mallol, 2004; Schei et al, 2004). Genetic predisposition and how it modifies the impact of air pollution on children remains to be assessed. These factors may apply to other respiratory conditions as well.

1.6 Summary

Ambient PM_{10} concentrations exceed national air quality standards in many LAC cities. Mobile sources are responsible for a large proportion of the air pollution problem in the Region's urban areas, since old buses and cars using outmoded technologies make up much of the total vehicle fleet. The detrimental composition of diesel fuel across the Region exacerbates the situation. In some instances, this is magnified by climate conditions and local topography, such as in the thermal inversions typically observed in Mexico City and Santiago, which cause episodes of reduced pollutant dispersion and raise the potential for exposure.

LAC is a highly urbanized Region. Several cities have more than five million inhabitants. Approximately 75% of the population lives in densely populated urban areas. Hence, a large number of people are exposed to particles and other ambient air pollutants. In Mexico, alone, approximately 25 million people are affected by air pollution (National Institute of Ecology of Mexico, 2004). Another 85 million live in other urban areas of LAC that also exceed ambient quality standards, such as Arequipa, Bogota, Fortaleza, Lima, Medellin, Santiago, and San Salvador. The total potentially exposed population in LAC is clearly under estimated, however, insufficient information is available to determine what the true figure might be.

Widespread air pollution and the elevated population densities of many urban areas in the Region mean a large number of people are potentially exposed and at risk of developing adverse health effects. In LAC 35,000 deaths are attributed to air pollution annually (WHO, 2002b) yet the real number is likely to be higher. The elderly, children, and asthmatics are particularly susceptible populations. Children are of special interest. In the year 2000, children under 14 years of age accounted for 32% of the total population in LAC with 124 million living in urban areas. Children are more vulnerable to environmental insults because of exposure patterns and physiological immaturity.

Finally, a large proportion of the LAC population faces a double environmental burden. In addition to recent hazards that have arisen in the past half-century, such as urban air pollution, many still face traditional hazards including lack of access to safe drinking water and inadequate waste disposal. Malnutrition, lack of access to health services and other poverty-related conditions may render the population more susceptible to developing adverse health effects from air pollution. How far socioeconomic status modifies the effects of air pollution on health still warrants attention.

The circumstances recounted in this chapter emphasize the need to assess the magnitude of the effects of air pollution on health in LAC. A review of the Regional epidemiologic literature concerning the health effects of air pollution was conducted with this in mind.

Chapter 2
Systematic Literature Review on Health Effects of Air Pollution from Latin America and the Caribbean

This chapter details the search and review of epidemiologic literature produced in the Region to assess the effects of ambient air pollution, specifically particulate matter, on human health.

2.1 Literature search

2.1.1 Search strategy

Systematic searches of the literature were performed to identify all of the studies associating air pollution and health effects conducted in LAC from 1994 to 2004.

Searches were restricted to the period from January 1994 to August 2004 when structured searches of the literature took place. The goal was to establish the current state of research into the health effects of air pollution in the Region rather than to present a history of the topic. A key aim was to develop quantitative summary estimates, so it was preferable to focus on more recent studies that are likely to include better methodologies. A 'new wave' of epidemiologic studies, especially time-series, on the effects of air pollution on health began in the United States and Europe in the late 1980s. Preliminary searches of bibliographic databases revealed very few studies carried out on this subject in LAC prior to 1990.

Searches were conducted in Spanish, English and Portuguese in the following bibliographic databases available in Internet:

1. PubMed
(http://www.ncbi.nlm.nih.gov/entrez/query.fcgi)
2. US National Library of Medicine Gateway
(http://gateway.nlm.nih.gov/gw/Cmd)
3. Medline (http://medlineplus.gov/)
4. LILACS - Latin America and Caribbean Health Sciences
(http://bases.bireme.br/cgi-bin/wxis-lind.exe/iah/online/?IsisScript=iah/iah.is&base=LILACS&lang=p)

The searches were performed using the following terms or keywords:

1. PubMed:
   a. "(country), health, air pollution"
   b. "(country), morbidity, air pollution"
   c. "(country), mortality, air pollution"
   d. "(country), air pollution"
2. US National Lib Med Gateway:
   a. "(country)[mh], air pollution[mh], adverse effects [sh], epidemiology [sh]"
3. Medline:
   a. "(country), health, air pollution"
   b. "(country), morbidity, air pollution"
   c. "(country), mortality, air pollution"
4. LILACS
   a. "(country), health, air pollution"
   b. "(country), morbidity, air pollution"
   c. "(country), mortality, air pollution"
   d. "(country), air pollution"

The term (country) was replaced by Argentina, Belize, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Chile, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad and Tobago, Uruguay, Venezuela, Latin America and Caribbean.

Additional searches were performed at Embase (www.embase.com), at SCIELO (Scientific Electronic Library Online) an electronic library covering a selected collection of Latin American scientific journals, and at the Pan American Health Organization (PAHO) electronic library (http://www.bireme.br/bvs/I/ihome.htm). The PAHO library permits access to Caribbean Health Sciences Literature (MEDCARIB) and the Pan American Information Network's Environmental Health Database (REPIDISCA). These searches failed to produce any new studies however.

We also checked references cited in published papers to identify any studies not tracked down previously. The procedure returned a further three studies that were added to a general list.

Articles irrelevant to this study and duplicates were removed from the search results. This review does not include articles that solely reported animal experiments or effects in plants, those examining the effects of outdoor air pollution at the cellular level, those that only reported trends and levels of air pollution in specific locations without any associated health data, exposure assessment studies, and health studies with no relation to outdoor air pollution. Letters and conference abstracts were also excluded.

Published and non-published reports or academic theses outside the peer-reviewed literature covered by the databases we selected were overlooked.

A full reference and abstract for each article in the final list was downloaded from the bibliographic database into Reference Manager®. Articles were obtained from local libraries, from the PAHO library in Sao Paulo (BIREME), from web-based libraries and from journal websites.

2.2 State of knowledge

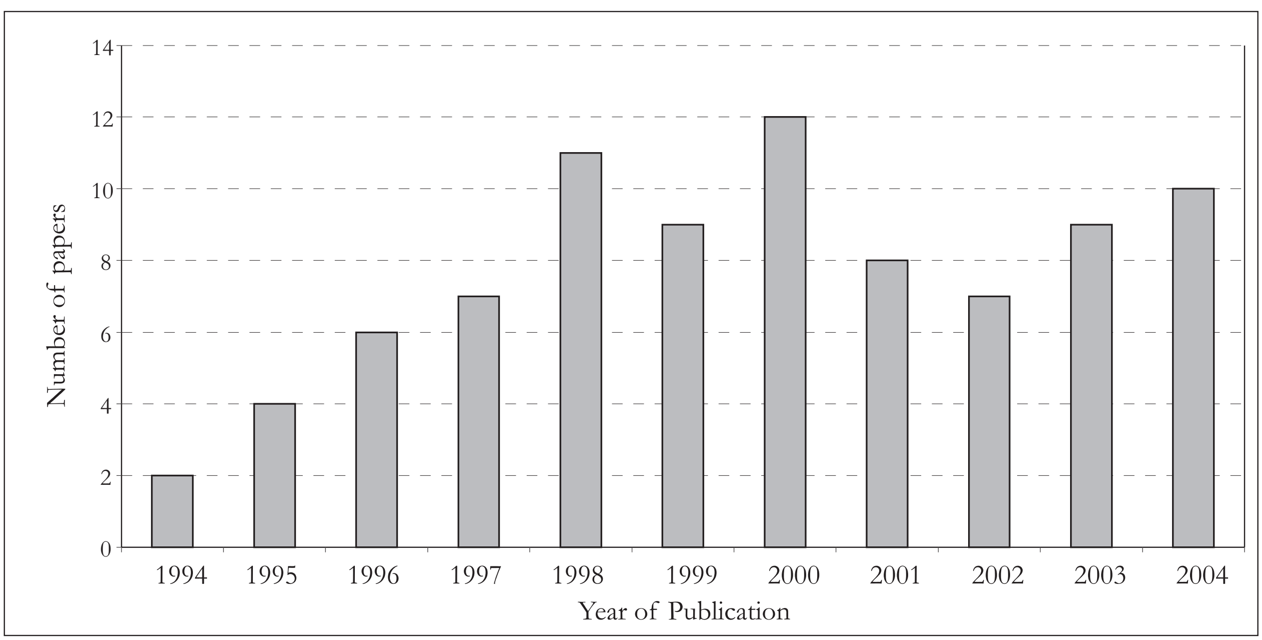
Our search revealed a total of 85 studies published in scientific periodicals between 1994 and August 2004 exploring the association between air pollution and health effects in the LAC Region. A full bibliography of the references is detailed in Appendix I while tables, grouped by principal health outcome, summarizing all of the studies are displayed in Appendix II.

Our search results found the studies covered just six LAC countries: Brazil, Mexico, Chile, Peru, Cuba, and Venezuela. And while a total of 25 cities were investigated in these six countries (Figure 2-1), closer inspection revealed even more concentration since more than half of the studies conducted in the Region were produced in Brazil and Mexico.

Figure 2-1 Epidemiologic studies of air pollution and health effects in Latin America and the Caribbean

Note: In the 85 studies, two examined several cities in different countries while four did not target any specific location. Figures in parentheses refer to the number of studies conducted in each location.

Figure 2-2 Number of epidemiologic studies of air pollution and health effects in Latin America and the Caribbean by year of publication, 1994 - 2004



Note: the year of 2004 is only through August.

In LAC there has been a marked increase over the past 10 years in the number of studies published on the health effects due to air pollution (Figure 2-2). Over seven scientific papers have been published on the subject every year since 1997. The reduction in 2001 and 2002 is probably just normal variation as the number of studies picks up again thereafter. The rising number of studies in the Region reflects the publication trend worldwide on the matter.

Most of the studies conducted in LAC over the period examined traditional pollutants from monitoring stations (particles, SO_2, NO_2, CO and O_3). One study (Fortoul, 1996) investigated airborne heavy metals such as cadmium, copper, cobalt, nickel, and lead. The few studies that did not specify the pollutants above instead compared areas of different levels of air pollution. Most studies examined both particles and gaseous pollutants. Articles predominantly assessed PM_{10} – particles up to 10 μm in diameter – but some studies also considered TSP, $PM_{2.5}$, and $PM_{10-2.5}$.

In LAC studies encountered in the published literature employed several different designs. Many studies adopt an ecological approach to assessing individual exposure, in which the exposure value used reflects exposure levels in the vicinity of an individual's home. Logistically personal exposure studies are more difficult and expensive and, therefore, have yet to be widely applied in this field of research. No studies using personal exposure were found in this review.

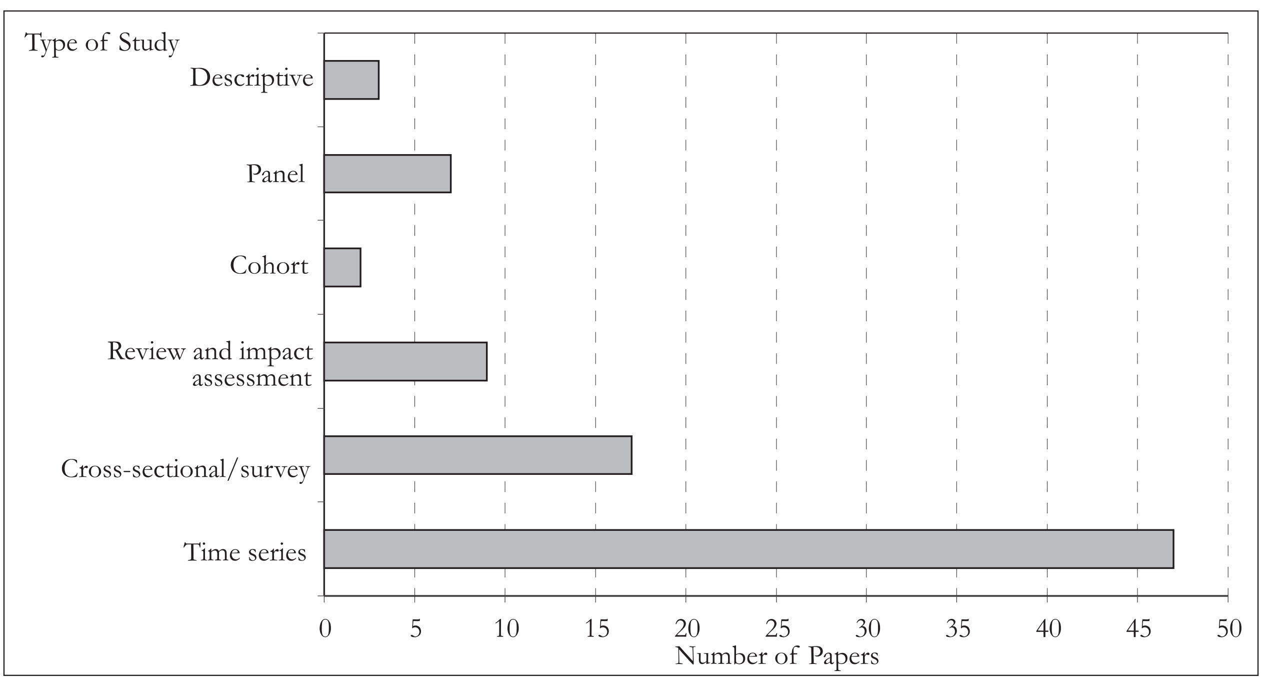
Ecological or correlation designs were most frequently used although cross-sectional and cohort studies were also employed. Nevertheless, authors preferred studies looking at the temporal variations in pollution levels and associated health effects, the so-called ecological time-series design (Figure 2-3). This type of design accounted for over half (47) of the articles reviewed.

New analytical approaches for time-series data along with increasing computational capacity have facilitated the development of analytical tools for time-series studies in air pollution epidemiology. This design offers certain advantages such as enabling acute effects of air pollution measured on a daily basis to be analyzed and provides the possibility of assessing different lag patterns from exposure to outcome. A critical, quantitative assessment of the daily time-series studies is presented in section 2.3.

Cross-sectional studies were the second most common epidemiologic design (17 publications). Most of these studies examined the prevalence of respiratory morbidities, signs, and symptoms in relation to levels of air pollution usually measured by air quality monitors.

A few other cross-sectional studies instead used

Figure 2-3 Designs used in epidemiologic studies of health effects of outdoor air pollution in Latin America and the Caribbean, 1994-2004



Sidebar 1- Effects of Air Pollution on Respiratory Function

Exposure to ambient air pollutants commonly found in most urban areas has been linked with impaired respiratory health and, in particular, pulmonary function. Exposure during childhood increases the risk of these children developing chronic lung diseases later in life. Set with this motive, investigators in LAC started to study the effects on pulmonary function of children exposed to air pollution.

In the past decade, research has been conducted on the subject in Mexico City (Castillejos, 1995; Romieu, 1996; Romieu, 1997b; Gold, 1999; Calderon-Garciduenas, 2003), in Havana, Cuba (Alfonso-Valiente, 1996) and in Puchuncavi, Chile (Sanchez, 1999).

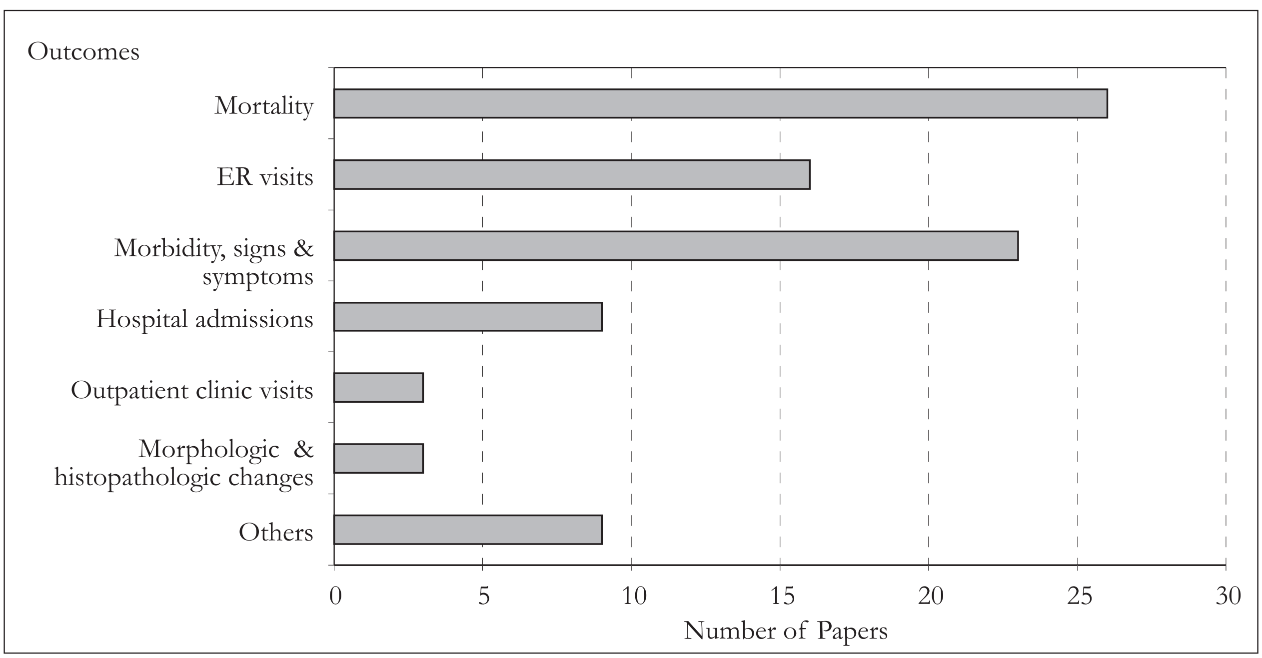
In relation to the effects of air pollution on pulmonary function, Gold et al (1999) found that an increase of 17 $\mu g/m^3$ in $PM_{2.5}$ and 25 ppb in O_3 was associated with a 7.1% reduction in morning peak expiratory flow (PEF) of schoolchildren. Asthmatic children also exhibited reductions of PEF associated to ambient levels of particles (Romieu, 1996) and O_3 (Romieu, 1997b).

Not all studies examined specific levels of air pollution. For example, Calderon-Garciduenas (2003) and Alfonso-Valiente (1996) compared children living in highly polluted areas to others considered non-exposed. Both authors found decreases in pulmonary function among children living in more polluted areas.

In addition, studies also examined a range of respiratory symptoms such as coughing, phlegm production, wheezing and breathing difficulties. All of these studies found an increased incidence of symptoms associated with higher levels of ambient air pollution.

crude indicators of pollution levels, such as "high and low". For example, Petrella (2001) examined rates of hospital admissions for respiratory diseases between areas of low and high pollution in three small Brazilian cities. Using a similar approach and with the help of Geographic Information Systems, Peinado (2002) also compared numbers of asthma crisis and hospitalizations in relation to areas with or without factories in Lima, Peru. In both cases, higher rates of disease were observed in "more polluted" areas.

Figure 2-4 Health outcomes examined in epidemiologic studies of outdoor air pollution in Latin America and the Caribbean, 1994 - 2004



Note: 4 papers evaluated more than one outcome and were included more than once.

Three other cross-sectional studies examined morphologic or histopathologic changes in autopsy lungs in Mexico City (Brauer, 2001 and Fortoul, 1996) and Brazil (Souza, 1998). They all found higher concentrations of particles or metals in the lungs of people from areas of higher pollution.

Eight of the published studies our search returned were literature reviews and are summarized in tables in Appendix I. Such articles typically assess the effects of air pollution on the respiratory system in regard to urban air pollutants, particles from biomass combustion or particles alone.

Other designs such as cohort or panel studies were less common perhaps due to their inherent logistical difficulties. Panel studies were mostly conducted to evaluate the effects of air pollution on respiratory signs and symptoms and pulmonary function of children. A summary of the results of the panel studies is displayed in Sidebar-1.

The two cohort studies (Vargas-Catalan, 1994 and Alfonso-Valiente, 1996) were follow-ups of children attending day care centers and primary school, respectively, to explore differences in respiratory morbidities from air pollution in different areas. While Alfonso-Valiente, 1996 found that schoolchildren living in areas of high pollution presented higher rates of lower respiratory infection than those in low pollution areas in Havana, Vargas-Catalan, 1994 found exactly the opposite for children attending day care centers in Chile.

The three descriptive studies (Peitier, 1998; Martinez-Ordaz, 2000; and Brilhante, 2002) were very simple in design and merely described characteristics of air pollution and health effects in selected areas.

Mortality (26 studies) was the outcome of greatest interest in relation to air pollution (Figure 2-4). Research looked at mortality from all causes or from specific causes such as respiratory conditions, for which a biological air pollution link is most plausible, and cardio-

Sidebar 2- Very Early Effects of Air Pollution on Health

Worldwide, evidence is mounting that the effects of ambient air pollution are higher for more vulnerable sub-groups such as the elderly and children. Few studies, however, have investigated the effect of air pollution on prenatal and neonatal mortality. Cities in LAC tend to have large, young populations and so afford the possibility of exploring such effects.

Studies conducted in the Region over the past 10 years have explored the effects of air pollution at different stages of early childhood from prenatal up to one-year. Loomis et al (1999) found an association between excess infant mortality (<1yr) and levels of fine particles in the days prior to death in Mexico City. For a 10μg/m^3 increase in $PM_{2.5}$ they observed a 6.9% increase in infant deaths (95%CI: 2.5-11.3%).

In Sao Paulo, Brazil, Nishioka et al (2000) and Lin et al (2004) found a link between ambient levels of PM_{10} and other pollutants and neonatal mortality (0-28 days). Lin estimated that an interquartile increase in PM_{10} (23.3 μg/m^3) brought about a 4% (95%CI: 2.0-6.0%) increase in neonatal mortality.

Pereira et al (1998) and Nishioka et al (2000) examined late fetal losses (28 weeks or more into gestation) in relation to air pollution in Sao Paulo and found an association between levels of NO_2 and O_3, and to a lesser extent to SO_2 and CO, and intrauterine mortality. Pereira also encountered a correlation between umbilical cord blood levels of carboxyhaemoglobin and ambient levels of carbon monoxide (CO) casting evidence of fetal exposure to outdoor levels of air pollution.

If air pollution can affect the health of very young children and even unborn babies it seems reasonable to suggest that it may also have an effect on intrauterine growth. With this in mind, Gouveia et al (2004) examined the association between exposure to outdoor air pollution during pregnancy and birth weight in Sao Paulo. Effects of exposure to PM_{10} and CO in the first trimester were observed, although the effects from CO appeared more robust. It was estimated that average birth weight decreased by 23g for a 1-ppm increase in mean exposure to CO during the first trimester.

These findings illustrate the implications elevated air pollution may have on children's health in LAC. In urban areas poverty, malnutrition and poor sanitation are prevalent. This heightens exposure to pollutants as well as susceptibility to the effects of air pollution. Around 75% of the population of LAC resides in urban settings and, therefore, many of the Region's children are vulnerable to the consequences air pollution may have on health.

vascular diseases. The elderly was the most studied age group, although several papers also examined mortality among children and some mortality in general without specifying age. Most of these were time-series studies and are reviewed quantitatively below. Studies assessing the effects of air pollution on the very young are summarized in Sidebar-2.

On the whole, studies into the relationship between air pollution and mortality found statistically significant associations between levels of air pollution and mortality for all causes as well as for specific causes in children, the elderly and the total population.

The second most investigated outcome in relation to air pollution in LAC was morbidity (Appendix I). Morbidity is a useful indicator in health studies since it is usually more sensitive than mortality at expressing variations in the health of the population and therefore provides useful information for health policy and planning. Most studies in this section focused on respiratory morbidity. Some, however, examined the effect of air pollution on birth weight, on heart frequency and rhythm, or on nasal cancer and used cross-sectional, time series or panel study designs. All reported statistically significant positive associations with outdoor air pollution.

Emergency room visits (16 studies), hospital admissions (9 studies), and visits to outpatient clinics (3 studies) were also investigated in the Region in relation to air pollution (Appendix I). In the assessment of morbidity, studies of daily emergency room visits or admissions to hospitals have the advantage of being based on relatively easily accessible existing data. This, in turn, makes it possible to explore relationships with daily variations in air pollution. Studies of children (<15 years old) and of respiratory diseases predominate. Most of these studies report estimates of increased risk or prevalence associated with air pollution for a wide variety of adverse health outcomes.

2.3 Analysis of time-series studies

Further analysis of literature from the Region on the health effects of air pollution was limited to the assessment of results of the time-series studies that were conducted in LAC and focused on particulate matter between 1994 and 2004. Although studies using other designs were found in the search, the approach favored was the assessment of health effects considering temporal variations in air pollution levels (47 of the 85 studies cited). It was necessary to base our systematic review on one type of design to facilitate comparison of the results. Research using time-series provided the largest body of evidence with which to work. In addition, as systematic reviews of time-series studies have been conducted in Asia and Europe a review based on this type of design will enable us to compare the results from LAC with data from other parts of the world.

Each study was examined to determine content and evaluate whether it met with the selection criteria. The purpose of developing these criteria was to make sure that any conclusions drawn were based on the best set of data available. The type of statistical analysis performed was a key consideration when accepting studies. The following set of criteria was established to address this point:

- Poisson regression analysis was used and information to obtain the regression coefficients was provided.
- adjustments for important confounders, especially meteorological, seasonal and temporal factors was carried out
- provide information on some measure of the uncertainty of the result presented (confidence intervals [CI], standard errors [SE], or t statistics)

After defining which studies remained in the systematic review it was necessary to select the risk estimates from the individual studies that best described the impact of particle exposures on mortality and morbidity. Only effects from single pollutant models were considered for this review. There was a possibility some studies reported results that were not adjusted by other pollutants. In addition, adjustment of other pollutants most likely varied between studies, potentially leading to multiple combinations per outcome category and insufficient data to make valid inferences on the effect.

An initial assessment of the studies showed that various parameters of ambient particle concentrations were used to assess health effects. Parameters used in the studies were: PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$, TSP, smoke, and sediment particles. Risk estimates for associations with smoke and sediment particles were not considered in this review.

It was also found that several studies reported risk estimates of the same outcome for more than one parameter of ambient particle concentrations. When this occurred, only the risk estimate reported for PM_{10} was considered for the review. In the event PM_{10} was not assessed, the risk estimate for $PM_{2.5}$ was considered instead.

Often, in studies for any one outcome, risk estimates were provided for different exposure periods using lags or moving averages of daily pollutant concentrations.

With regard to defining the critical window of time when exposure exerts most effect, current knowledge of the biological mechanisms is limited as to how particle exposures have an effect on the study outcomes. For this reason the selection of the risk estimate that best predicted the effect was based on statistical considerations. The following selection criteria were established:

- the lag or moving average that the author described as the best fit
- the more statistically significant lag or moving average

The type of risk estimates generated and reported by the studies varied. Some studies reported the RR for a given change in pollutant concentration, usually along its CI. Others presented the percent change in the mean number of daily events of the study outcome, which is the RR expressed as a percentage, accompanied by its CI. Other studies reported regression coefficients (β), which were accompanied by their SE. In addition, the risk estimates were generated for different unit increases in exposure levels across studies so several exposure parameters were used to assess effects of particles.

To set a common base from which to make inferences about the meaning of the results from individual studies, and eventually generate quantitative summary estimates, risk estimates were transformed. The unit into which individual risk estimates were transformed was the percentage change in the mean number of daily events for a 10ug/m^3 increase in pollutant concentration. Along the same lines a decision was made to transform results for TSP or $PM_{2.5}$ into its PM_{10} equivalent. This would provide greater comparability of the available data. The ratio used for the transformation has been used previously; that is $PM_{10} \approx TSP x0.55$ (Stieb et al, 2002) and $PM_{2.5} \approx PM_{10} x0.60$. The latter conversion factor was obtained from studies that assessed both metrics of particulate matter.

Risk estimates from individual studies were combined into categories of outcome by age group. Frequency tables were constructed to describe data in each category. Further evaluation of the evidence was conducted when a category had at least three risk estimates.

Quantitative summary estimates of the pooled results were calculated to identify the overall magnitude of the effect of air pollution. These were calculated for the percent change in daily mortality and their 95% CI by pooling all the estimates available for the category using a fixed effects (with inverse variance weighting) and random-effects models (DerSimonian and Laird, 1986).

Quantitative summary estimates were calculated under the following conditions. The first was that risk estimates were available for at least three cities. Often several studies were conducted in the same city and some were conducted during similar or identical time periods. Whenever studies reported results for the same time period, results using PM_{10} as the exposure metric were preferred. If more than one used PM_{10}, then preference was given to the study analyzing the longer time frame. If coincidence persisted then the most recent risk estimate was taken for calculating the summary estimate. The latter approach was adopted in a recent review of Asian time-series studies (HEI, 2004) and is based on the assumption that a risk estimate from a recent study is more likely to have been calculated using the latest statistical techniques.

2.3.1 Main findings

Our thorough search of the bibliographic databases returned a total of 47 time-series studies that were conducted between 1994-2004 to assess the influence of temporal variations in ambient particles concentrations on mortality or morbidity. Twenty-one of the 47 studies were excluded from the analysis (Table 2-1). The chief reason for excluding studies was that the statistical methods employed did not meet selection criteria (11 studies). Additional problems encountered were not employing Poisson regression, not controlling for time trends or weather, or not providing some measure of uncertainty. Another reason for excluding studies had to do with the exposure parameter (5 studies). Some studies did not assess effects of particles, one assessed effects but results were not reported, and another used sediment particles as the exposure parameter. A further reason involved stratification of results by season or place of death (3 studies). Finally two studies were excluded because their results were reported in another article that was included.

The outcomes assessed by the 26 remaining studies were: mortality (16), emergency room visits (5), hospital admissions (3), and outpatient visits (1). One study reported results for effects on both mortality and hospital admissions.

2.3.1.1 Methodological aspects of the studies

All time series studies employed Poisson regression to model the daily counts of health events (mortality, hospital admissions, or ER visits). While all of the studies made adjustments for temporal and meteorological factors, adjustment procedures varied considerably.

For example, some studies used indicator variables for month and/or season to control for temporal factors, while others used harmonic waves. The majority of studies though employed smoothing factors in generalized additive models (GAM) for these adjustments. Poisson GAM regression has been introduced more recently to air pollution epidemiology studies and is considered more flexible and appropriate for modeling the effects of air pollution while controlling for covariates. Its use was first documented in LAC studies in 1996 (Ostro, 1996; Loomis, 1996) and has since become the norm in the Region for time-series using Poisson regression.

Much the same applies in the screening of meteorological data; nowadays most studies use smoothing functions in GAM models to control for temperature and humidity. Nevertheless, the selection of meteorological parameters (mean, maximum or minimum temperature, for example) and the specification of models for these adjustments varied substantially among studies. Therefore, while most studies provide some evidence that meteorological parameters have been dealt with appropriately (for example, through analysis of residuals) it is not possible to assess the extent to which these adjustments were responsible for differences in the results presented in studies carried out in cities with a large diversity of weather patterns.

2.3.1.2 Mortality

Seventeen studies remained for analyzing the effects of particles on mortality. These were conducted in Sao Paulo (7 studies), Mexico City (5), Santiago (3), and Rio de Janeiro (1). One study reported results for two locations, Sao Paulo and Rio de Janeiro. Overall, PM_{10} was the exposure parameter of choice to assess the effects of particles on mortality with 13 studies reporting results for this parameter. Other studies used either $PM_{2.5}$ or TSP as the exposure parameter.

Individual results from these studies were further combined for analyses into categories of cause of deaths by age group (Table 2-2). Overall, eight different causes of death were assessed in the studies. These were: all causes, all respiratory causes, pneumonia, chronic obstructive pulmonary disease (COPD) and asthma, car-

Table 2-1 Time-series studies excluded from systematic literature review

Reference	Location	Reason for exclusion
Arbex, 2000	Araraquara	Exposure parameter used was sediment particles
Avendaño, 1999	Santiago	Statistical techniques did not match the selection criteria
Avendaño, 2003	Santiago	Statistical techniques did not match the selection criteria
Bedolla Barajas, 1999	Guadalajara	Statistical techniques did not match the selection criteria
Borja Aburto, 1997	Mexico City	Results already reported in Loomis 1996
Botter, 2002	Sao Paulo	Statistical techniques did not match the selection criteria
Calderon Garciduenas, 2000	Mexico City and Monterrey	Statistical techniques did not match the selection criteria
Gouveia, 2002	Rio de Janeiro and Sao Paulo	Reported preliminary results. Final results reported in Gouveia, 2003
Hernandez Garduño 1997	Mexico City	No assessment of particle effects
Ilabaca, 1999	Santiago	Results stratified by season
Kishi, 1998	Sao Paulo	Statistical techniques did not match the selection criteria
Martins, 2002b	Sao Paulo	Statistical techniques did not match the selection criteria
O'Neill, 2004a	Mexico City	No assessment of particle effects
Romieu, 1995	Mexico City	Results for particles effects not reported
Rosas, 1998	Mexico City	Results stratified by season
Saldiva, 1994	Sao Paulo	Statistical techniques did not match the selection criteria
Salinas, 1995	Santiago	Statistical techniques did not match the selection criteria
Solé, 1998	Sao Paulo	Statistical techniques did not match the selection criteria
Tellez Rojo, 1997	Mexico City	No assessment of particle effects
Tellez Rojo, 2000	Mexico City	Results stratified by place of death
Zamorano, 2003	Santiago	Statistical techniques did not match the selection criteria

Table 2-2 Distribution of risk estimates by cause of death and age group

Cause of death	Age group		
	All	Elderly	Children
All causes	7	7	4
All respiratory	4	5	2
Pneumonia		1	1
COPD+asthma		1	1
CVD	4	4	
Stroke		1	
Conduction disorders +arrhythmia		1	
AMI		1	

diovascular disease (CVD), stroke, conduction disorders and arrhythmia, and acute myocardial infarction (AMI).

Based on the age ranges of the study populations, three groups were formed: all ages, elderly, and children. The elderly group comprised the results of studies whose population was 65+ years of age. The only study targeting the elderly not to employ this definition used 60+ years. In contrast, age ranges in studies of children varied greatly. Results were reported for four different ages: <5 years (4 studies), <28 days (2 studies), > 28 weeks of pregnancy (1 study), and <1 year (1 study).

When individual results were broken down into categories of cause of death by age group the number of results available for any one combination diminished limiting the strength of conclusions that may be drawn from the data (Table 2-2).

a. Deaths from all causes

An assessment of individual results suggests an adverse impact of temporal variations of particles on populations residing in urban areas of LAC. In five out of the seven studies that analyzed mortality for the all cause-all age category a rise in daily mortality was associated with a 10 µg/m^3 increase in PM_{10}. Excess daily mortality ranged from 0.04% to 1.83% (Table 2-3).

In the assessment of results for mortality from all causes we found two studies from Mexico City, Borja-Aburto, 1998 and Castillejos, 2000, had been conducted over the same period thus representing the same study population. Nonetheless, they reported results for different exposure parameters. In the first study, effects were assessed using $PM_{2.5}$ as the exposure parameter while the latter added analysis of PM_{10}. Something similar occurred in the two studies from Santiago (Ostro, 1996 and Cifuentes, 2000). Cifuentes expanded the exposure period originally assessed by Ostro for the same population and analyzed effects of $PM_{2.5}$ instead. Even when using the same population and time period, effects reported from these studies were not necessarily the same. Some sources of variation are the use of different exposure parameters, modeling techniques and covariates used for adjustment.

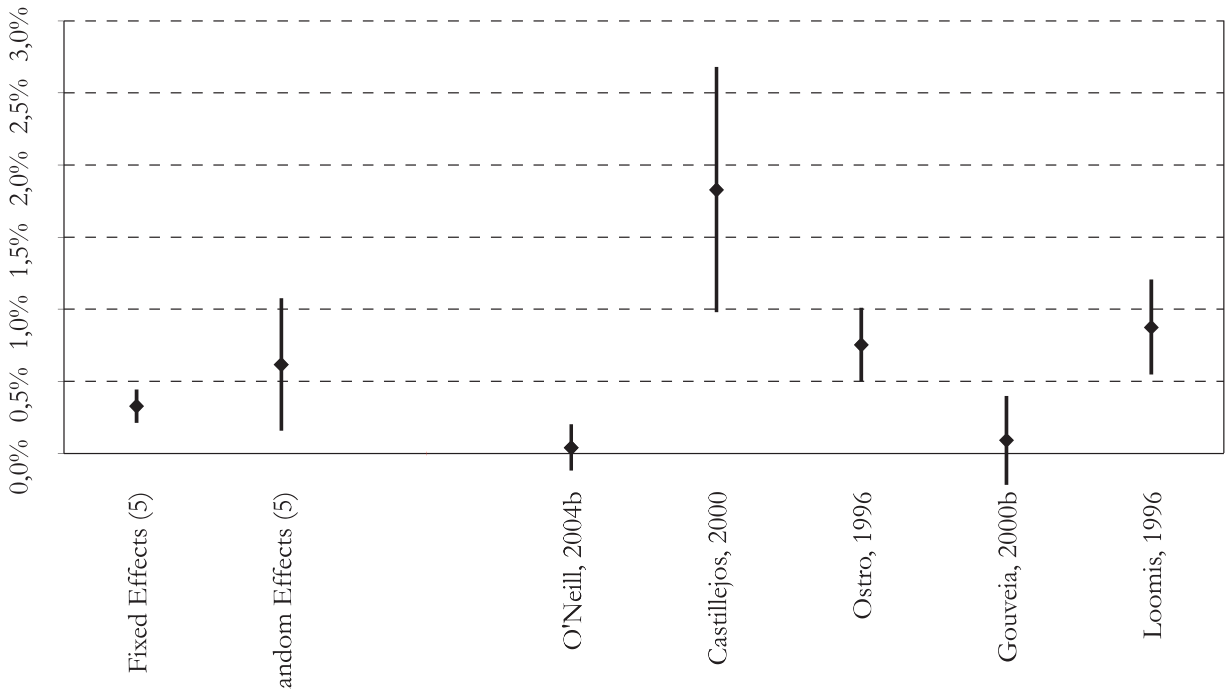
The quantitative summary estimate from the random effects model for mortality from all causes on the all-age group yielded a 0.61% increase in daily deaths (95%CI: 0.16,1.07) for a 10 µg/m^3 increase in PM_{10}. A 0.33% (95%CI: 0.21, 0.44) increase in daily deaths was obtained from the fixed model (Figure 2.5). Significant heterogeneity was observed among individual estimates.

Overall, results from LAC studies suggest that the impact of temporal variations on particle concentrations is stronger on the elderly. All seven studies reported a

Table 2-3 Percent change in daily mortality for a 10 µg/m^3 increase a PM_{10} reported in individual studies for "All Causes, All Ages"

Location	Study period	Original pollutant assessed	% change (CI)	Reference
Mexico City	90-92	TSP	0.87 (0.55, 1.20)	Loomis, 1996
Mexico City	93-95	$PM_{2.5}$	0.81 (0.10, 1.50)	Borja Aburto, 1998
Mexico City	93-95	PM_{10}	1.83 (0.98, 2.68)	Castillejos, 2000
Mexico City	96-98	PM_{10}	0.04 (-0.12, 0.20)	O'Neill, 2004b
Santiago	88-96	$PM_{2.5}$	0.44 (0.31, 0.57)	Cifuentes, 2000
Santiago	89-91	PM_{10}	0.75 (0.50, 1.01)	Ostro, 1996
Sao Paulo	91-93	PM_{10}	0.09 (-0.22, 0.40)	Gouveia 2000b

Figure 2-5 Random and fixed effects summary estimates for mortality from all causes in the all ages group for a 10 µg/m³ increase a PM_{10}



statistically significant association between the percentage change in daily mortality from all causes on the elderly and a 10 µg/m³ increase in PM_{10}. Increases in daily mortality ranged from 0.50% to 2.01% (Table 2-4).

Study duplication was also found in the analysis of mortality from all causes among the elderly. Some studies reported results for more than one outcome and the Borja Aburto, 1998 and Castillejos, 2000 overlap is repeated here, too. Overlap also occurred in two studies from Santiago, where Sanhueza, 1998 expanded the exposure period originally assessed by Ostro, 1996.

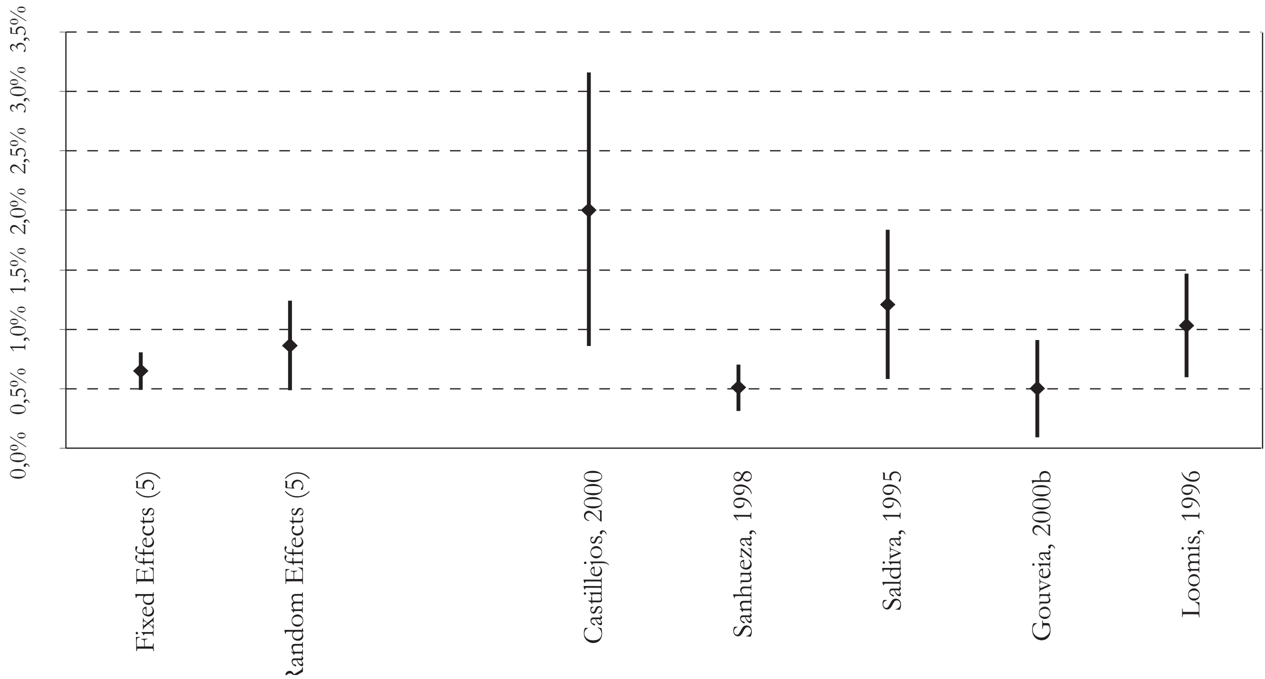
The quantitative summary estimate of the effect of exposure to an increase in air pollution levels in the health of the elderly population was greater than that observed for all causes in all ages. The fixed effects model provided an estimate of a 0.65% increase in daily mortality in the elderly (95%CI: 0.49, 0.81) for a 10 µg/m³ increase in PM_{10}. Again, there was evidence of heterogeneity among primary estimates and the random effects model, which estimated an increase of 0.86% in daily deaths (95%CI: 0.49, 1.24), provided a higher estimate than the fixed model. (Fig 2.6)

Children were also affected by temporal variations in particle concentrations, but the number of studies

Table 2-4 Percent change in daily mortality for a 10 µg/m³ increase in PM_{10} reported in individual studies for "All Causes, Elderly"

Location	Study period	Original pollutant assessed	% change (CI)	Reference
Mexico City	90-92	TSP	1.03 (0.60,1.47)	Loomis, 1996
Mexico City	93-95	$PM_{2.5}$	0.94 (0.02,0.86)	Borja-Aburto, 1998
Mexico City	93-95	PM_{10}	2.01 (0.86,3.16)	Castillejos, 2000
Santiago	88-93	PM_{10}	0.51 (0.32,0.71)	Sanhueza, 1998
Santiago	89-91	PM_{10}	0.91 (0.58,1.25)	Ostro, 1996
Sao Paulo	90-91	PM_{10}	1.21 (0.58,1.84)	Saldiva, 1995
Sao Paulo	91-93	PM_{10}	0.50 (0.09,0.91)	Gouveia 2000b

Figure 2-6 Random and fixed effects summary estimates for mortality from all causes in the elderly for a 10 μg/m³ increase in particle exposure



assessing the effects of particles on mortality from all causes among children was smaller than those available for the other age groups. Only four studies were available yet all four reported associations between daily mortality and a 10 μg/m³ increase in PM_{10}. Changes in daily mortality varied from 0.80 to 4.01% (Table 2-5).

Study duplication was identified here as well. Nishioka, 2000 and Lin, 2004 reported results for the same study group and period. Studies assessing mortality from all causes in children analyzed different age groups. Two studies looked at neonates, one at infants, while another study group assessed was late fetal deaths.

b. Deaths from all respiratory causes

Fewer studies evaluated the impact of ambient particle concentrations on mortality from all respiratory causes in comparison to mortality from all causes. Only four studies assessed these effects for the all-age group. Three of the four studies reported associations between a rise in particle concentrations and excess daily mortality for the all-age group. Excess daily mortality ranged from 0.59 to 3.85% (Table 2-6).

For this outcome individual risk estimates were available for only two locations. In addition, studies at each location analyzed data for the same time period.

Table 2-5 Percent change in daily mortality for a 10 μg/m³ increase in reported in PM_{10} individual studies for "All Causes, Children"

Location	Study period	Original pollutant assessed	Age group (years)	% change (CI)	Reference
Mexico City	93-95	$PM_{2.5}$	<1 year	4.01 (1.48,6.61)	Loomis, 1999
Sao Paulo	91-92	PM_{10}	>28 weeks of pregnancy	0.80 (0.71,1.91)	Pereira, 1998
Sao Paulo	98	PM_{10}	<28 days	3.87 (1.46,6.35)	Nishioka, 2000
Sao Paulo	98-00	PM_{10}	<28 days	1.71 (0.13,3.32)	Lin, 2004

Table 2-6 Percent change in daily mortality for a 10 μg/m³ increase in reported in PM_{10} individual studies for "All Respiratory Causes, All Ages"

Location	Study period	Original pollutant assessed	% change (CI)	Reference
Mexico City	93-95	$PM_{2.5}$	1.45 (-0.67,3.62)	Borja-Aburto, 1998
Mexico City	93-95	PM_{10}	3.85 (1.16,6.55)	Castillejos, 2000
Santiago	88-93	PM_{10}	0.59 (0.17,1.01)	Sanhueza, 1998
Santiago	89-91	PM_{10}	1.28 (0.64,1.92)	Ostro, 1996

Three studies reported a link between excess daily mortality from all respiratory causes on the elderly and ambient particle concentrations. Daily mortality differences varied from 0.14% to 5.4% (Table 2-7).

Table 2-7 Percent change in daily mortality for a 10 μg/m³ increase in reported in PM_{10} reported in individual studies for "All Respiratory Causes, Elderly"

Location	Study period	Original pollutant assessed	% change (CI)	Reference
Rio de Janeiro	91-93	TSP	1.64 (-0.55,3.89)	Gouveia 2003
Rio de Janeiro	91-93	TSP	1.65 (-0.50,3.85)	Daumas, 2004
Sao Paulo	91-93	PM_{10}	0.91 (0.08,1.75)	Gouveia, 2000b
Sao Paulo	96-00	PM_{10}	0.14 (0.08,0.20)	Gouveia, 2003
Sao Paulo	97-99	PM_{10}	5.40 (2.30,8.60)	Martins, 2004

Two sets of studies were conducted for the same city and study period. One set was Gouveia, 2003 and Daumas, 2004. In fact, results reported in these studies were identical. The other set was that of Gouveia, 2003 and Martins, 2004. Martins's study period, is a subset of the period assessed in an earlier study conducted by Gouveia (2003). In Martins' work, the study population lived within a two-kilometer radius from the air monitoring stations, while Gouveia used the entire population of Sao Paulo. The former might be a more precise measure of exposure leading to a reduction in exposure misclassification. This may, in part, explain the strong

Table 2-8 Percent change in daily mortality for a 10 μg/m³ increase in reported in PM_{10} reported in individual studies for the "All CVD Causes, All Ages" category

Location	Study period	Original pollutant assessed	% change (CI)	Reference
Mexico City	93-95	$PM_{2.5}$	1.29 (-0.01,2.61)	Borja-Aburto, 1998
Mexico city	93-95	PM_{10}	2.00 (0.39,3.60)	Ostro, 1996
Santiago	88-93	PM_{10}	0.25 (0.05,0.45)	Castillejos, 2000
Santiago	89-91	PM_{10}	0.76 (0.33,1.20)	Sanhueza, 1998

Table 2-9 Percent change in daily mortality for a 10 μg/m^3 increase in reported in PM_{10} reported in individual studies for "All CVD Causes, Elderly"

Location	Study period	Original pollutant assessed	% change (CI)	Reference
Rio de Janeiro	91-93	TSP	0.73 (-0.73,2.21)	Gouveia, 2003
Rio de Janeiro	91-93	TSP	0.73 (-0.70,2.18)	Daumas, 2004
Sao Paulo	91-93	PM_{10}	0.58 (0.02,1.15)	Gouveia, 2000b
Sao Paulo	96-00	PM_{10}	0.30 (-0.30,0.91)	Gouveia, 2003

effect observed in this study when compared to Gouveia 2003 and to all others.

Only two studies addressed the possible link between air pollution and respiratory mortality in children, so there is insufficient data for further remarks.

c. Deaths from CVD causes

For the assessment of mortality from CVD in all ages there are few studies from which to make inferences on the impact of ambient particle concentrations. Three of the four studies assessing CVD deaths reported a statistically significant association. Excess daily mortality ranged from 0.25% to 2.0% (Table 2-8).

As observed previously results are available for just two cities (Santiago and Mexico City) and cover similar time periods.

The assessment of mortality from all causes of CVD was also conducted separately on the elderly age group. Only one study reported an association between particle exposures and this outcome. Other results are not indicative of any adverse effect (Table 2-9).

As in earlier observations, the studies of Gouveia, 2003 and Daumas, 2004, conducted on the same population and study period, reported similar results.

2.3.1.3 Hospital admissions

Four studies, all from Brazil, reported on how temporal variations in ambient particle concentrations influence hospital admission numbers. Three of the studies were conducted in Sao Paulo while the other reported results for both Sao Paulo and Rio de Janeiro. PM_{10} was selected to describe ambient particle concentrations in all four studies.

Individual results from these studies were categorized for analyses by cause of hospital admissions and by age group (Table 2-10). Six different causes were assessed in the studies: all respiratory causes, pneumonia, asthma, COPD and asthma, CVD, and ischemic heart disease (IHD).

In these studies the elderly age group just involved populations of 65 years of age or over. In a similar fashion to the mortality data, age ranges of the groups of children varied considerably from study to study. One analyzed data for five different age groupings: ≤2, 3-5, 6-13, 14-19, and 0-19. Other studies reported effects for the <5 (2 studies), <1 (1 study), and <13 (1 study) age groups.

Table 2-10 Distribution of risk estimates by cause of hospital admission and age group

Cause of hospital Admission	Age Group	
	Elderly	Children
All respiratory	2	9
Pneumonia	1	3
Asthma		1
COPD+asthma	1	
CVD	1	
IHD	1	

When disaggregated, except for the category "all respiratory causes in children", few estimates were available by cause of hospital admission per age group. In addition, results were reported from just two cities. This limits the scope for drawing conclusions from the data.

Table 2-11 Percent change in daily hospital admissions for a 10 μg/m³ increase in reported in PM_{10} reported in individual studies for "All Respiratory Causes, Children"

Location	Study period	Original pollutant assessed	Age group (years)	% change (CI)	Reference
Rio de Janeiro	00-01	PM_{10}	<5	1.84 (0.40,3,30)	Gouveia, 2003
Sao Paulo	92-93	PM_{10}	<13	1.61 (0.80,2.43)	Braga, 1999
Sao Paulo	92-94	PM_{10}	<5	0.40 (-0.15,0.97)	Gouveia, 2000a
Sao Paulo	93-97	PM_{10}	≤2	5.27 (4.44,6.09)	Braga, 2001
Sao Paulo	93-97	PM_{10}	3-5	1.85 (0.11,3.61)	Braga, 2001
Sao Paulo	93-97	PM_{10}	6-13	0.53 (-0.34,1.40)	Braga, 2001
Sao Paulo	93-97	PM_{10}	14-19	1.39 (0.09,2.71)	Braga, 2001
Sao Paulo	93-97	PM_{10}	0-19	1.94 (1.60,2.28)	Braga, 2001
Sao Paulo	96-00	PM_{10}	<5	6.73 (4.90,8.60)	Gouveia, 2003

d. Admissions for all respiratory causes

Overall the data suggests that temporal variations in ambient particle concentrations do influence the incidence of respiratory conditions in children that consequently required hospitalization. Studies reported excess daily hospital admissions ranging from 0.40% to 6.73% (Table 2-11).

Behind the large number of risk estimates available for this outcome is one study that reported estimates for five different age groups (Braga et al, 2001). The aim of this study was to assess variations in the magnitude of effects across different age groups. Data clearly showed the ≤2 age group exhibited the strongest effects and indicates that the youngest children are at higher risk of developing air pollution-related health effects.

A subsequent study, also conducted in Sao Paulo (Gouveia, 2003), on the <5 age group reported similar results. Gouveia encountered a much larger effect with the same age group in the 2003 study than an earlier analysis by the same author (Gouveia, 2000a). The methodologies used can explain much of the difference in the results. In the first study harmonic waves were used to control for temporal and seasonal trends, while Gouveia 2003 employed GAM Poisson regression smoothing functions. Hence, differences in statistical methodology can account for some variation in results from the same city.

e. Admissions from pneumonia

Three risk estimates were reported on the relationship between particle concentrations and hospital admissions from pneumonia. One study reported an association of this outcome for two different age groups: <5 and <1 year. The two studies reporting these results were carried out in the city of Sao Paulo and found increases in daily admissions for pneumonia ranging from 1.84% (0.40,3.30) to 2.30% (-5.97,11.29) for children under 5 years old. For infants (< 1 year) the percentage increase was slightly smaller 1.61% (0.80, 2.43) (Table 2-12).

Table 2-12 Percent change in daily hospital admissions for a 10 μg/m³ increase in reported in PM_{10} reported in individual studies for "Pneumonia, Children"

Location	Study period	Age group (years)	% change (CI)	Reference
Sao Paulo	92-94	<5	1.84 (0.40,3.30)	Gouveia, 2000a
Sao Paulo	92-94	<1	1.61 (0.80,2.43)	Gouveia, 2000a
Sao Paulo	96-00	<5	2.30 (-5.97,11.29)	Gouveia, 2003

2.3.1.4 Emergency room visits

Five studies assessed the influence of daily variations of particle concentrations on emergency room visits (ERV). These were conducted in Sao Paulo (3 studies), Havana (1), and Ciudad Juarez (1). PM_{10} was the parameter used to describe ambient particle concentrations in all 5 studies. Most studies assessed respiratory-related ERV. One study reported effects of air pollution on ERV for angina and acute myocardial infarction (AMI).

Respiratory effects were reported for eleven different causes and two age groups; children and the elderly (Table 2-13). Studies assessing the effects on children looked at a similar age range. Results were reported for the following age definitions: <13 years (1 study), <14 years (1 study), <15 years (1 study). The elderly age group comprised results from studies where the population was 65 years of age (2 studies).

Several of these studies reported significant increases in daily ERV with increases in ambient particle concentrations. However, it was not possible to combine risk estimates from individual studies into categories of ERV causes. Since some studies did not provide ICD codes it is not clear what group of diagnoses ERV causes belonged to in the results reported. In addition, the data is sparse and, even assuming causes were similar, yield insufficient information to assess the influence of ambient particle concentrations on ERV.

2.4 Discussion

Overall, systematic analysis of LAC studies suggests that temporal variations in particulate matter do contribute to additional mortality and morbidity. A 10 μg/m³ increase in ambient particle concentrations was linked to increases in daily mortality from all causes, all respiratory causes, and CVD. The same increment in ambient particle concentrations was also associated with increased hospital admissions from all respiratory causes.

Table 2-13 Distribution of risk estimates by cause of emergency room visit and age group

Cause of emergency room visit	Age Group	
	Elderly	Children
All respiratory		1
Wheezing		1
Asthma		1
Acute bronchial asthma crisis		1
Acute respiratory diseases		1
Acute respiratory infections		1
Upper respiratory diseases		1
Upper respiratory infections		1
Lower respiratory diseases		1
Chronic lower respiratory disease	1	
Angina + AMI	1	

Table 2-14 Quantitative summary estimate for the percent change in all cause mortality for a 10 μg/m³ increase in reported in PM_{10} for other regions of the world, by age group

Location	% change (CI)	Reference
All causes, all ages		
Asia	0.49 (0.23,0.76)	HEI, 2004
Europe	0.60 (0.40,0.80)	Katsouyanni, 2001
Latin America	0.61 (0.16,1.07)	PAHO
United States	0.21 (0.09,0.33)	Dominici, 2003
Worldwide	0.65 (0.51,0.76)	Stieb, 2002
All causes, elderly		
Europe	0.70 (0.50,1.00)	Katsouyanni, 2001
Latin America	0.86 (0.49,1.24)	PAHO
Worldwide	0.86 (0.61,1.11)	Stieb, 2002

The quantitative summary estimate calculated in this study for the effects of PM_{10} on all cause-all age mortality was compared to data from similar studies conducted in other parts of the world. Overall, the summary estimate calculated with data representing three Latin American cities was similar to figures reported in other studies. The same pattern emerged comparing the summary estimate calculated in this study for the effects of PM_{10} in the all cause-elderly group (Table 2-14).

Associations reported in many LAC studies are consistent with current assessments of the effects of air pollution on human health. Even so, the body of evidence assembled by pooling results from individual studies may still be insufficient to draw strong conclusions concerning the impact of particle exposures in the Region. Several reasons explain this matter.

Although most of the body of work produced in the Region was conducted to assess effects on mortality, when stratified by individual causes of death data was sparse. A rule was set that conclusions would be drawn on the health effects of air pollution only if there were at least three risk estimates for any one outcome per age group. After pooling the data from all studies it was observed that the amount of evidence for any one outcome was small and few did comply with the rule. For instance, the largest concentration of results was available for the outcome of all causes and only for two of the three age groups: all ages and the elderly.

Other age groups and outcomes could not be assessed. The Region lacks meaningful information about the effects of particle exposures on child mortality. While mortality from respiratory conditions in LAC is one of the main causes of death in children <5 few studies analyzed mortality from respiratory causes in children. Some studies did assess child mortality from all causes; yet, this information was not comparable because of differences in the age group definitions employed. The capacity to address this outcome was therefore limited. For the assessment of morbidity the issue of sparse data was particularly troublesome. The number of risk estimates for hospital admissions, emergency room, and outpatient visits yielded insufficient information to assess the influence of ambient particles on these outcomes.

Finally, the calculation of quantitative summary estimates was only possible for two outcomes. Summary estimates are particularly useful when devising policy because they provide an exposure-response function from which the number of deaths or diseases (attributable risk) may be estimated.

Some other limitations can be expected to affect this systematic review of the LAC literature on the health effects associated with exposure to ambient air pollution. One possibility is that the searches performed in the bibliographic databases might have failed to find work from the Region. However, considerable effort was made to find all published studies. Literature searches were conducted in three languages and several regional bibliographic databases were researched using a structured algorithm. Upon implementing these strategies, it is unlikely further published studies exist.

This does not, however, rule out the possibility of publication bias, i.e. the possibility that negative results were not included in this review because they were never published. This is a problem for any systematic review of the literature. In this review it was difficult to measure the extent of any such bias since we have too few studies for a robust analysis, especially when aggregating the studies by age group and outcome.

When performing the calculations of the summary estimates we encountered evidence of heterogeneity among the primary results. While heterogeneity might indicate real differences in the effect estimates, important dissimilarities among the studies included in this review should be considered. For example, analytical approaches to deal with confounding factors such as temporal trends, seasonality and meteorology varied considerably among studies. Differences were observed in the selection of parameters to be included as well as in the specifications of the models. Such factors might account for much of the variability among the studies.

Another point for discussion is the issue identified with convergence criteria when using S-Plus® GAM routines (Dominici et al, 2002). S-Plus is a statistical package that has been widely used in the time-series analyses reviewed in this report. When there is more than one nonparametric smoothing function in the GAM in S-Plus, and the parameter to be estimated is small, the default settings for the iterative estimation procedure in the GAM function of this software package do not ensure convergence and can provide biased estimates of regression coefficients and standard errors. Dominici et al (2002) found this problem was responsible for an overestimation of the effects of air pollution on mortality in the US.

In the time series studies in LAC that applied Poisson GAM in S-Plus, very few authors reported this problem and they did not provide analysis with stringent convergence criteria for comparison. Some papers, however, presented results with different modeling strategies stressing that results were similar to those obtained through GAM. Again, it is difficult to assess the extent of possible bias due to this problem in the estimates presented in the LAC studies. Nevertheless, considering that few smoothing functions were used in most of the studies that employed GAM models in LAC, the estimation bias ought to be small.

Discrepancies in data quality between cities may be another source of heterogeneity in these studies. With respect to health data, potential differences in diagnosis, recording, and reporting of health outcome data may have introduced heterogeneity. This analysis focused primarily on mortality outcomes that are usually more reliable than morbidity or hospital discharge data. Nevertheless, some degree of variability may still remain in the mortality data.

With respect to air quality data, most of the studies used data from regularly certified official monitoring networks. Data from these networks have been used routinely in health effects studies with no apparent problem. Yet methods of measuring ambient particles might differ among the cities and practices are not always reported. This difference in methodology can influence the estimates obtained in time-series studies

(O'Neal, 2004b).

In addition, the sources, the levels and the composition of the ambient air pollution as well as some exposure determinant factors, such as population mobility and daily activity patterns may vary greatly from city to city. However, the possibility of assessing such differences is beyond the scope of this review.

This study contributes to understanding the magnitude of the effects of air pollution in LAC by summarizing the state of knowledge and developing quantitative summary estimates for specific outcomes when feasible. From the standpoint of the policy making processes regarding the control of air pollution levels quantitative assessments are essential. They provide useful indicators since quantitative measures of the impacts of air pollution allow policy-makers to assess and quantify the probable benefits of pollution control measures and compare them to the costs of implementation.

Our literature review contained a single documented attempt to assess the health impact of ambient air pollution in the Region (Cifuentes, 2001). The study estimated the health benefits of air pollution reductions for three cities, Santiago, Mexico City and Sao Paulo, those for the most detailed information exist. For some important effects associated with air pollution, however, it had to rely on concentration-response functions (C-R) based on epidemiologic studies conducted outside the Region, principally in the US.

Ideally, quantification should be based on local studies since importing the C-R functions from elsewhere and applying them within LAC has several limitations. Studies conducted in developed countries provide estimates based on pollutant compositions and levels unlike those in developing countries. In addition, health-impact estimates refer to populations of different socioeconomic levels exhibit distinct patterns of morbidity, mortality and vulnerability (Cifuentes, 2001; Stieb, 2002).

Using locally derived indicators would reduce the uncertainty involved in risk assessment and offer constructive information for estimating the impact of the pollution control programs adopted and action on public health. Once this information is available for the Region and for specific countries and cities it will allow policy-makers to start or to continue planning and formulating policies to control levels of ambient air pollution and bring with it enormous benefits to the entire population of the Region.

3. Conclusions

This report reiterates that levels of air pollution in many urban areas of the LAC are high and often exceed international air quality standards. Patterns of increasing urbanization in the Region, the elevated population densities in many urban areas and the number of people in the most vulnerable groups are ingredients for a potentially significant impact of air pollution exposure on human health.

A large and diverse body of scientific studies was uncovered upon reviewing the LAC literature on the health effects associated with exposure to air pollution. In certain aspects, literature produced in LAC seems similar to the broader international epidemiological texts on the topic. For example, most of the studies identified used the time-series design, a trend also observed elsewhere.

Critical review of the LAC literature found that particle exposures are associated with different health endpoints ranging from mortality for all causes and ages to morbidity for respiratory and cardiovascular diseases in specific age groups. Nevertheless, the strongest body of evidence was constructed for the effects on mortality on the general population and in the elderly. Unfortunately, information on the effects of air pollution on other outcomes and population groups important to the Region, such as young children, is sparse and non-uniform and thus remains to be explored further.

In general terms, the effects of air pollution observed in these studies are similar in magnitude to figures from other parts of the world. The apparent consistency with international findings may be misleading - caution should be taken when interpreting the results of this review. Summary estimates of effects were largely based on studies conducted in just three LAC cities. Hence they are not representative of the entire Region. A lack of ambient air monitoring data limits the potential for assessing the effects of ambient air pollution on human health elsewhere.

In addition, it is most likely that the summary estimates provided in this report are an underestimation of the true effect of air pollution on the populations of LAC. This is because the Region has a substantial population of children, a subgroup considered more vulnerable. Also, the average levels of air pollution found in LAC are substantially higher than currently found in either Europe or the US. Finally, significant socioeconomic inequalities prevail in the Region and may amplify the impact air pollution has on health given the role of poverty as an effect modifier.

While the body of evidence on which quantitative summary estimates were calculated could be improved these estimates provide an approximation of the effect of air pollution in LAC populations. The estimates could, however, be used for policymaking purposes to help estimate the related cost of current levels of air pollution, and the benefits mitigation measures may bring.

APPENDIX

APPENDIX I - Summary information of the studies

Table 1 – Summaries of epidemiologic studies of air quality and mortality in Latin America and the Caribbean, 1994-2004

Reference	Location	Period	Study design	Age group	Cause of death	Pollutants
Botter, 2002	Brazil[1]	1991 -1993	Time series	≥65	All causes	TSP, O_3, SO_2, CO, NO_2
Conceicao, 2001	Brazil[1]	1994 - 1997	Time series	<5	Respiratory diseases	PM_{10}, O_3, SO_2,CO
Daumas, 2004	Brazil[2]	1990 - 1993	Time series	≥65	Respiratory diseases, CVD	TSP
Gouveia, 2000b	Brazil[1]	1991 - 1993	Time series	all, ≥65, <5	All causes, respiratory and CVD	PM_{10}, O_3, SO_2, CO, NO_2
*Gouveia, 2002	Brazil[1,2]	1996 - 2000[1] 1990 -1993[2]	Time series	≥65, <5	Preliminary results on respiratory and CVD. Final results published in Gouveia, 2003	PM_{10}, TSP[1], O_3, SO_2, CO, NO_2
*Gouveia, 2003	Brazil[1,2]	1996 - 2000[1] 1990 - 1993[2]	Time series	≥65, <5	Respiratory diseases, pneumonia, COPD, CVD, stroke, conduction disorders, arrhythmia and AMI	PM_{10}, TSP[1], O_3, SO_2, NO_2, CO
Lin, 2004	Brazil[1]	1998 - 2000	Time series	<28 days	All causes	PM_{10}, O_3, SO_2, CO, NO_2
Martins, 2004	Brazil[1]	1997 - 1999	Time series	>60	Respiratory causes	PM_{10}
Nishioka, 2000	Brazil[1]	1998	Time series	<28 days, fetuses >28 weeks	Intrauterine	PM_{10}, O_3, SO_2, CO, NO_2
Pereira, 1998	Brazil[1]	1991 - 1992	Time series	fetuses >28 weeks	Intrauterine	PM_{10}, O_3, SO_2, CO, NO_2
Saldiva, 1994	Brazil[1]	1990 - 1991	Time series	<5	Respiratory diseases	PM_{10}, O_3, SO_2, CO, NO_x
Saldiva, 1995	Brazil[1]	1990 - 1991	Time series	≥65	All causes	PM_{10},O_3, SO_2, CO, NO_x
Solé, 1998	Brazil[1]	1984 -1994	Time series	5-34	Respiratory causes and asthma	PM_{10}, TSP, O_3, SO_2, NO_2
Cifuentes, 2000	Chile[3]	1988 -1996	Time series	all	All causes	$PM_{10-2.5}$, $PM_{2.5}$, O_3, SO_2, CO, NO_2
Ostro, 1996	Chile[3]	1989 -1991	Time series	all, >65 by sex	All causes, respiratory and CVD	PM_{10}, O_3, SO_2, NO_2
Salinas, 1995	Chile[3]	1988 -1991	Time series	all	All causes	$PM_{2.5}$, $PM_{10-2.5}$, O_3, SO_2, CO
Sanhueza, 1998	Chile[3]	1988 -1993	Time series	all, ≥65	All causes, respiratory and CVD	PM_{10}, $PM_{2.5}$, O_3, SO_2

Table continues next page

Table 1 – Summaries of epidemiologic studies of air quality and mortality in Latin America and the Caribbean, 1994-2004

Reference	Location	Period	Study design	Age group	Cause of death	Pollutants
Borja-Aburto, 1997	Mexico[4]	1990 -1992	Time series	all, ≥65, <5	Respiratory and CVD	TSP, O_3, SO_2, CO, NO_2
Borja-Aburto, 1998	Mexico[5]	1993 -1995	Time series	all, ≥65	All causes, respiratory and CVD	$PM_{2.5}$, O_3, SO_2, NO_2
Castillejos, 2000	Mexico[6]	1993 -1995	Time series	all, >65	All causes, respiratory and CVD	PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$, O_3, SO_2, NO_2
Loomis, 1996	Mexico[5]	1990 -1992	Time series	all, ≥65, <5	All causes, respiratory and CVD	O_3, TSP, SO_2
Loomis, 1999	Mexico[5]	1993 -1995	Time series	<1	All causes	$PM_{2.5}$, O_3, SO_2, NO_2
O'Neill, 2004a	Mexico[5]	1996 - 1998	Time series	all, ≥65	All causes	O_3
O'Neill, 2004b	Mexico[5]	1994 -1998	Time series	all	All causes	PM_{10}
Tellez-Rojo, 2000	Mexico[5]	1994	Time series	≥65	Respiratory diseases, COPD	PM_{10}, O_3, SO_2, NO_2

* This article also evaluates hospitalizations and it is quoted again in Table 4
1 Sao Paulo, 2 Rio de Janeiro
3 Santiago
4 Mexico Federal District, 5 Mexico City, 6 Southwest Mexico City

Table 2 – Summaries of epidemiologic studies of air quality and morbidity, signs and symptoms in Latin America and the Caribbean, 1994-2004

Reference	Location	Period	Study design	Age group	Outcome	Pollutants
Gouveia, 2004	Brazil[1]	1997	Cross-sectional	birth >37 weeks	Low birth weight	PM_{10}, O_3, SO_2, CO, NO_2
Ribeiro, 2003	Brazil[1,2,3]	1986 and 1998	Cross-sectional	11-13	Respiratory symptoms	PM_{10}, SO_2
Rios, 2004	Brazil[4,5]	1998 - 2000	Cross-sectional	13-14	Asthma prevalence	PM_{10}
Pertuze, 1997	Chile[6,7]	1994 and 1995	Cross-sectional	15-65	Respiratory symptoms and coughing reflex	PM_{10}, O_3, SO_2
Sanchez, 1999	Chile[8]	1996	Panel	6-12	Maximum expiratory flow and respiratory symptoms	PM_{10}, SO_2
Vargas Catalan, 1994	Chile[6,7,9]	1991 and 1992	Cohort	2 -18 months	Respiratory morbidities	Comparison of high and low pollution areas
Zamorano, 2003	Chile[6]	2001	Time series	< 1	Acute bronchiolitis	PM_{10}, $PM_{2.5}$
Alfonso Valiente, 1996	Cuba[10]	Unquoted	Cohort	forth and fifth graders	Allergic manifestations, pulmonary functions and respiratory morbidities	Comparison of high and low pollution areas
Pita Rodriguez, 2001	Cuba[10]	1991	Cross-sectional	7-12	Respiratory symptoms and immunoglobulin levels	Comparison of high and low pollution areas
Calderon-Garciduenas, 2000a	Mexico[11,12]	1976 -1997 and 1993 -1998	Time series	all	Nasal and paranasal cancer	SO_2, CO, NO_x, NO_2
Calderon-Garciduenas, 2000c	Mexico[11]	Not stated	Cross-sectional	children	Upper and lower respiratory symptoms and lung hyperinflation	Comparison of high and low pollution areas
Calderon-Garciduenas, 2003	Mexico[11]	1999 - 2000	Cross-sectional	5-17	Respiratory system damages and pulmonary function	PM_{10}, O_3
Castillejos, 1995	Mexico[11]	1990 - 1991	Panel	71/2 to 11	Respiratory symptoms and pulmonary function	PM_{10}, $PM_{2.5}$, O_3

Table continues next page

Table 2 – Summaries of epidemiologic studies of air quality and morbidity, signs and symptoms in Latin America and the Caribbean, 1994-2004

Reference	Location	Period	Study design	Age group	Outcome	Pollutants
Fajardo Arias, 1997	Mexico[11,13]	1992	Cross-sectional	< 5	Respiratory diseases and other symptoms	TSP, PM_{10}, O_3, SO_2, CO, NO_2, Pb
Gold, 1999	Mexico[11]	1991	Panel	8-11	Peak flow and respiratory symptoms	PM_{10}, $PM_{2,5}$, O_3
Holguin, 2003	Mexico[11]	2000	Panel	60- 96	Cardiac variance and frequency	$PM_{2.5}$ indoor, $PM_{2.5}$ ambient, O_3, SO_2, CO, NO_2
Martinez, 2000	Mexico[14]	1992 - 1996	Descriptive	-	Asthma	PM_{10}, TSP, SO_2, NO_2
Meneses Gonzalez, 1996	Mexico[11]	1991 and 1991 - 1992	Panel	5-13	Pulmonary function	PM_{10}, O_3, SO_2, NO_2
Romieu, 1996	Mexico[11]	1991 and 1991 - 1992	Panel	5-13	Respiratory symptoms and peak flow	PM_{10}, $PM_{2.5}$, O_3, SO_2, NO_2
Romieu, 1997b	Mexico[11]	1991 and 1991 - 1992	Panel	5-13	Pulmonary function	PM_{10}, O_3, SO_2, NO_2
Sanchez-Carrillo, 2003	Mexico[11]	1996 -1997	Cross-sectional	All	Respiratory and ophthalmologic symptoms	PM_{10}, O_3, SO_2, NO_2
Santos Burgoa, 1998	Mexico[11]	Not stated	Cross-sectional	9-80	Respiratory symptoms	PM_{10}
Villareal-Calderon, 2002	Mexico[11]	Not stated	Cross-sectional	9-16	Anthropometric indices	PM_{10}, O_3
Rojas, 2001	Venezuela[15]	1999	Cross-sectional	adults	Signs and symptoms related to CO and serum carboxihemoglobin concentration	CO

1 Sao Paulo, 2 Osasco, 3 Juquitiba, 4 Duque de Caxias, 5 Seropèdica
6 Santiago, 7 San Felipe, 8 Puchuncavi, 9 Los Andes
10 Havana City
11 Mexico City, 12 Monterrey, 13 Pachuca, 14 Comarca Lagunera
15 Valencia

Table 3 – Summaries of epidemiologic studies of air quality and emergency room visits in Latin America and the Caribbean, 1994-2004

Reference	Location	Period	Study design	Age group	Outcome	Pollutants
Arbex, 2000	Brazil[1]	1995	Time series	all	Inhalations	Particulate sedimentation
Brilhante, 2002	Brazil[2]	Pollution data: 1980-1995. Outcome data: 1991	Descriptive	all	Respiratory diseases	TSP
Lin, 1999	Brazil[3]	1991 - 1993	Time series	<13	Respiratory diseases, upper and lower respiratory diseases, and wheezing	PM_{10}, O_3, SO_2, CO, NO_2
Lin, 2003	Brazil[3]	1994 - 1995	Time series	45- 80	Angina and AMI	PM_{10}, O_3, SO_2, CO
Martins, 2002a	Brazil[3]	1996 - 1998	Time series	≥65	Chronic lower respiratory diseases	PM_{10}, O_3, SO_2, CO, NO_2
Martins, 2002b	Brazil[3]	1996 - 1998	Time series	≥65	Pneumonia and influenza	PM_{10}, O_3, SO_2, CO, NO_2
*Avendaño, 1999	Chile[4]	1998	Time series	0-15	Lower respiratory infection	PM_{10}
*Avendaño, 2003	Chile[4]	2002	Time series	0-15	Lower respiratory infection	PM_{10}
Ilabaca, 1999	Chile[4]	1996 - 1998	Time series	<15	Respiratory disease, upper and lower respiratory diseases and pneumonia	PM_{10}, $PM_{2.5}$, O_3, SO_2, NO_2
Romero-Placeres,2004	Cuba[5]	1996 - 1998	Time series	<14	Acute respiratory diseases, acute respiratory infections, asthma,	PM_{10}, smoke and SO_2
Bedolla Barajas, 1999	Mexico[6]	1994	Time series	all	Asthma	PM_{10}, O_3, SO_2, CO, NO_2
Hernandez-Cadena, 2000	Mexico[7]	1997 - 1998	Time series	<15	Upper respiratory infections, asthma	PM_{10}, O_3
Romieu, 1995	Mexico[8]	1990	Time series	<16	All causes, asthma and respiratory diseases	TSP, O_3, SO_2, NO_2
Rosas, 1998	Mexico[8]	1991	Time series	≤15, 16-59, >59	Asthma	PM_{10}, O_3, SO_2, NO_2

Table continues next page

Table 3 – Summaries of epidemiologic studies of air quality and emergency room visits in Latin America and the Caribbean, 1994-2004

Reference	Location	Period	Study design	Age group	Outcome	Pollutants
*Tellez-Rojo, 1997	Mexico[8]	1993	Time series	0-4, 5-14	Upper and lower respiratory infections	O_3, SO_2, NO_2
Peinado, 2002	Peru[9]	1997 - 1998	Cross-sectional	<14	Asthma	Comparison of high and low pollution areas

* Articles that also evaluated other outcomes and are, therefore, quoted in other summary tables
1 Araraquara, 2 Rio de Janeiro, 3 Sao Paulo
4 Santiago
5 Havana City
6 Guadalajara, 7 Juarez City, 8 Mexico City
9 Lima

Table 4 - Summaries of epidemiologic studies of air quality and hospital admissions in Latin America and the Caribbean, 1994-2004

Reference	Location	Period	Study design	Age group	Outcome	Pollutants
Braga, 1999	Brazil[1]	1992 -1993	Time series	<13	Respiratory diseases	PM_{10}, O_3, SO_2, CO, NO_2
Braga, 2001	Brazil[1]	1993 -1997	Time series	≤2, 3-5, 6-13, 14-19, 0-19	Respiratory diseases	PM_{10}, O_3, SO_2, CO, NO_2
Gouveia, 2000a	Brazil[1]	1992 -1994	Time series	<5, <1	Respiratory diseases, pneumonia, asthma	PM_{10}, O_3, SO_2, CO, NO_2
*Gouveia, 2002	Brazil[1,2]	1996 -2000[1] 1990 -1993[2]	Time series	≥65, <5	Preliminary results on respiratory and CVD. Final results published in Gouveia, 2003	PM_{10}, TSP[1], O_3, SO_2, CO, NO_2
*Gouveia, 2003	Brazil[1,2]	1996 - 2000[1] 2000 - 2001[2]	Time series	≥65, <5	Respiratory diseases, pneumonia, COPD, CVD, IHD	PM_{10}, O_3, SO_2, CO, NO_2
Kishi, 1998	Brazil[1]	1992 -1993	Time series	<5	Respiratory diseases	PM_{10}, O_3, SO_2, CO, NO_2
Petrela, 2001	Brazil[3,4,5]	1997	Cross-sectional	all ages	Respiratory diseases	Comparison of high and low pollution areas
*Avendaño, 1999	Chile[6]	1998	Time series	0-15	Lower respiratory infections	PM_{10}
*Avendaño, 2003	Chile[6]	2002	Time series	0-15	Lower respiratory infections	PM_{10}

* Articles that also evaluated other outcomes and are quoted in other summary Tables
1 Sao Paulo, 2 Rio de Janeiro, 3 Ouro Preto, 4 Diamantina, 5 Viçosa
6 Santiago

Table 5 - Summaries of epidemiologic studies of air quality and outpatient clinic visits in Latin America and the Caribbean, 1994-2004

Reference	Location	Period	Study design	Age group	Outcome	Pollutants
Ostro, 1999	Chile[1]	1992 - 1993	Time series	<2, 3-15	Upper and lower respiratory diseases	PM_{10}, O_3
Hernández-Garduno, 1997	Mexico[2]	1992 - 1993	Time series	all	Respiratory infections	O_3, NO_2
*Tellez-Rojo, 1997	Mexico[2]	1993	Time series	0-4, 5-14	Upper and lower respiratory infections	O_3, NO_2

* Article that also evaluated other outcomes and are quoted in other summary Tables
1 Santiago
2 Mexico City

Table 6 - Summaries of review studies of outdoor air pollution and health effects in Latin America and the Caribbean, 1994-2004

Reference	Location	Age group	Outcome	Pollutants
Arbex, 2004	Brazil	Children	Diseases of the respiratory system	Particles from biomass burning
Oyarzún, 1998	Chile[1]	All	Effects on respiratory system	Urban air pollutants
Romieu, 1997a	LAC countries and elsewhere	All	Mortality	Particles
Rosales-Castillo, 2001	LAC countries and elsewhere	All	Mortality and morbidity	PM_{10}, O_3
Calderon-Garciduenas, 2000b	Mexico[2]	Children	Cytokine imbalance	Urban air pollutants
Vallejo, 2003	Mexico[2]	All	Several health effects	Particles, O_3, SO_2, NO_2, CO, Pb
Oyarzún, 2004	Worldwide	All	Asthma	Smoke, NO_2, CO, CO_2, indoor air pollutants
Rizzo, 1998	Worldwide	All	Diseases of the respiratory system	O_3, SO_2, NO_2, CO and indoor air pollutants

1 Santiago
2 Mexico City

Table 7 - Summaries of studies of outdoor air pollution and health effects in Latin America and the Caribbean for other outcomes, 1994-2004

Reference	Location	Period	Study design	Age group	Outcome	Pollutants
Peiter, 1998	Brazil[1]	1995 - 1997	Descriptive	all	Health conditions	SO_2
Souza, 1998	Brazil[2,3,4]	1992 - 1995	Cross-sectional	all	Histopathologic and morphologic alterations in lung	comparison of high and low pollution areas
Cifuentes, 2001	Brazil[5], Mexico[6], Chile[7] and US[8]	2000 - 2020	Health impact assessment	all	Mortality, hospital admissions, outpatient clinic visits, ERV, school absenteeism, days lost at work, etc.	PM_{10}, O_3
Brauer, 2001	Mexico[6]	1999 - 2000	Cross-sectional	>60	Particles in the lung	$PM_{2.5}$
Fortoul, 1996	Mexico[6]	1950 and 1980	Cross-sectional	adults	Histhopatologic changes in lungs	Air metals

1 Volta Redonda, 2 Guarulhos, 3 Ribeirao Preto, 4 Ourinho, 5 Sao Paulo
6 Mexico City
7 Santiago
8 New York

APPENDIX II - References

(Bold face indicates the time-series studies analyzed)

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