Adaptation to the Health Impacts of Air Pollution and Climate Extremes in Latin American Cities

SECOND YEAR REPORT

Prepared for:

Inter-American Institute for Global Change Research

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1. Introduction

The overall objective of this IAI-funded study is to investigate a crucial and not fully explored problem, not in Latin America: the independent and combined effects of exposure to weather-related stresses and air pollution and human vulnerability to urban health in Buenos Aires, Bogotá, Mexico City and Santiago. We expect that the results of this project will be scientifically sound and relevant for both environmental and public health authorities. The project aims at answering three research questions a) what are the independent and combined effects of exposure to heat-cold stress and air pollution and human vulnerability to urban health in the four Latin American cities? b) how do patterns in mortality/morbidity and vulnerability vary spatially and what human and natural factors account for this differential distribution within the seemingly homogenous boundaries of the cities? And c) what are unique and common adaptive capacities and adaptation strategies in four Latin American cities? This report presents the progress achieved during the second year - i.e., June 2009- July 2010.

2. Research activities

The ADAPTE team gathered, validated and analyzed data on temperature, air pollution and vulnerability including: a) an exploratory time series analysis to identify main patterns of the health, weather, and air pollution data; b) a generalized linear model (GLM) with Poisson log-linear distribution to measure changes in the Relative Risk (RR) of health outcomes such as mortality due to changes in temperature and air pollution; c) a geospatial assessment of differential patterns of vulnerability within the urban centers. Presently, the team is running multivariate regression analyses to quantify the combined impacts of weather, air pollution and vulnerability on health. The following sections describe in more detail three main components of this effort.

Besides focusing on the city-level efforts, each city team collaborated with the coordinating team at NCAR, and helped them understand the development context of each city in such issues as climate and weather, medical data, governance structures, air quality concerns, and vulnerable and resilient areas. Both the students of each city and the NCAR team (especially Mercy Borbor) held conference calls at least once a week through Skype and other internet communication tools. This activity proved to be very useful for both the NCAR team and us.

2.1 Air quality

Bogotá's team coordinated the arrangement of air quality data from the air quality monitoring networks operating in each city. After this, all research efforts were guided towards getting to know the behavior of air pollution in time and space using the information provided by each city's team. Bogotá's team designed the template for data collection by the city teams, collated these data and formed a master database with one time resolution (1-hour) for the years available. After compiling the master database, the team got a general overview of the air quality problems and calculated the number of times in which the levels of air pollution exceeded the World Health Organization standards for criteria pollutants. The team also reviewed reports by the local environmental agencies to corroborate their findings.

2.2 Weather

Both the NCAR and Buenos Aires' teams coordinated this effort. Each city team collected daily temperature data classified as maximum, mean, and minimum temperature and relative humidity measures from the meteorological stations mostly located at the regional airport of the cities. Daily temperature and relative humidity readings were made by automatic-recording instruments.

2.3 Putting the pieces together exposure, vulnerability and health

The NCAR team was responsible for designing and applying the statistical tools to explore and quantify the independent and combined effects of exposure to heat-cold stress and air pollution and human vulnerability to urban health. The NCAR team undertook the following steps for that purpose.

Weather data: the NCAR team with support from the city-teams transformed the temperature and humidity data by using a centered moving average (CMA) smoother as a common method to reduce the noise within the raw data set. Different CMA ranges (daily, 3, 7, 15, 30, 182 days) were explored whereas a 15 days smoother was found to fit the data. In addition, the NCAR team explored the impact of lags (daily, 3, 7, 15 days) on the statistical model.

Air quality data: missing data points that occasionally occurred in the PM_{10} time series were estimated using a multiple linear regression function in SPSS (version 16.0). For the air pollution data lag times (L) of 0, 1, 3, and 7 days were used. It was assumed that a unit of increase in air pollution on a given day displays its related health impact only after L days in the future. Applying different CMA smoothing ranges (3, 7, 15 days) for the PM_{10} and ozone data set had no substantial effect on the results.

Health data: All city teams gathered and validated health data and sent them to the NCAR team. With the advice from Patricia Matus, our health expert from Chile, the NCAR team conducted an exploratory statistical analysis by using a time-series approach to explore how climatic factors, air pollution, and mortality co-vary over time. The time-series was decomposed into separate components in order to control for the confounding impact of seasonality on the predictor - mortality relationship. A binary approach for analyzing the relevant data was used. In the first step, a linear regression was utilized to explore correlations and interrelations among the variables. In the second step, a generalized linear model (GLM) with Poisson log-linear distribution was used to assign relative risk (RR) estimates.

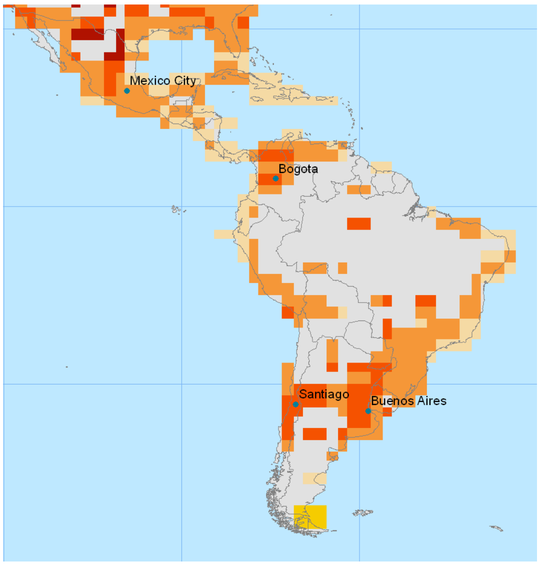
2.4 Vulnerability

After receiving and validating the vulnerability indicators created by the city teams, the NCAR team used a four step approach to explore the impact of indicators of socioeconomic-vulnerability (SEV) on the relationship between climatic factors, air-pollution and mortality. First they conducted a *Principal Component Analysis* (PCA) to eliminate vulnerability factors with a weak or non-existent statistical relation to mortality. Using a Pearson correlation matrix based on Eigen-values and a rotated (Varimax) component plot not significant ($\rho > 0.05$) factors were eliminated. Then a linear regression was utilized to explore correlations and interrelations among both the selected vulnerability and mortality variables. Third, multiple regression models were used to determine the most significant SEV indicators. Last but not least, the NCAR team is in the process of using the results of the regression to select the most vulnerable locations.

3. Research findings

Cities and climate are coevolving in a manner that could place more populations at risk from exposure to extreme temperature and air pollution. As can be seen in Figure 1, key urban areas of Latin America are projected to be increasingly affected by heat-waves, yet, we don't know how vulnerable to those health impacts urban populations currently are, i.e., what their current - baseline - vulnerability is. To answer this question ADAPTE seeks to understand the independent and combined effects of heat/cold stress, air pollution and social vulnerability on the health of populations in the cities.

Figure 1: Projected increased severity of the worst annual heat events by 2030. CCSM-3 simulations A2 scenario

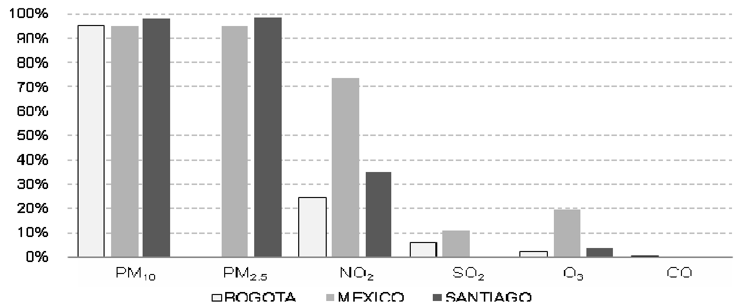


Source: GIS-NCAR (2009)

As supported by the research findings of other scholars, the team has found that temperature and air pollution pose interacting threats to the health of the populations we studied. For instance, after organizing the air quality data for Mexico, Santiago and

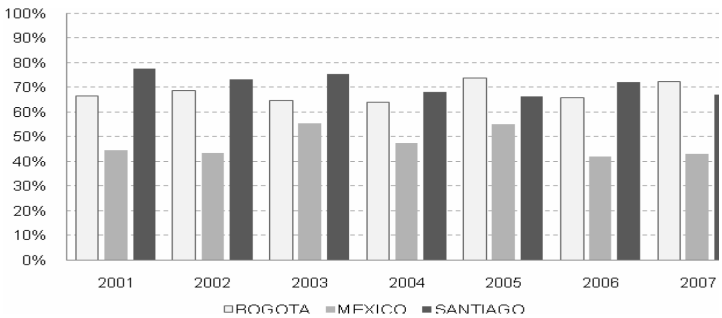
Bogotá,[1] and comparing them with the World Health Organization recommendations for air quality (WHO, 2005), we confirmed that the main air pollution problem in all three cities is related to particulate matter (PM) in their coarse and fine fractions (Figure 2). In general, for all criteria pollutants, Mexico City is still the most polluted city. However, PM temporal trends show that the number of times that this city's records overpass international standards is lower than that of Santiago and Bogotá (Figure 3).

Figure 2: Non-attainment levels by pollutant, based on WHO annual recommendations (20 µg m^{-3})



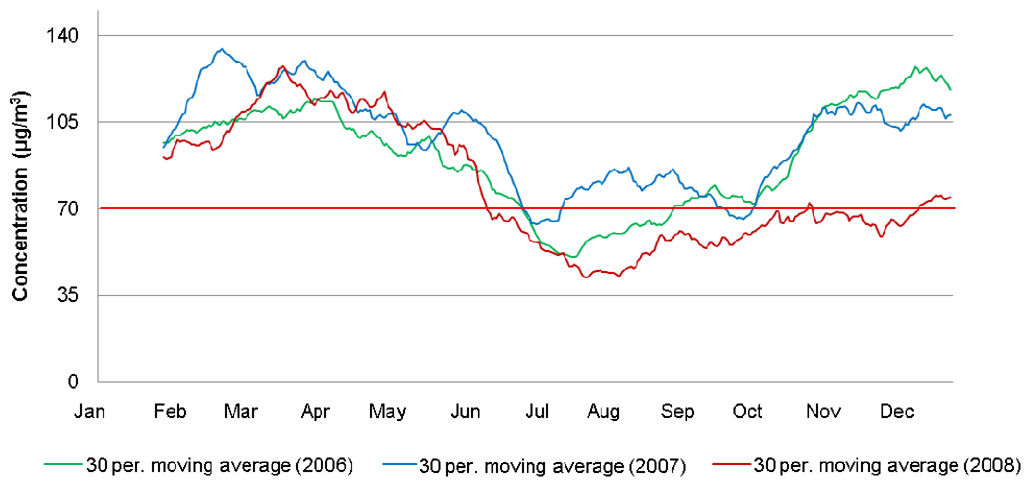
[1] We didn't include Buenos Aires in the analysis air quality because air pollution data in Buenos Aires are scarce. There is only one monitoring station that has been working for two decades, and there are two recently installed in the City Area. Nevertheless there are some other data collected by the scientific sector which allows us to conclude: 1) the CO, SO_2 and PM_{10} levels are in general lower than the standards, 2) NO_X levels frequently exceed WHO standards, 3) there is not sufficient information about $PM_{2.5}$, but from some campaigns is possible to conclude that there are few cases of values higher than WHO standards, and 4) there are not enough measurements of O_3 to make a diagnostic.

Figure 3: Non-attainment levels for PM_{10}, based on WHO daily recommendation (50 µg m^{-3})



Regulation about sulfur content in fuels was a strategy introduced several years ago in Mexico and Santiago to diminish PM emissions by both mobile and stationary sources. This process started in Bogotá in July, 2008. The air quality station located in the industrial zone, where traffic is dominated by diesel trucks, showed a reduction in PM levels right after the lower-sulfur diesel was introduced (Figure 4).

Figure 4: Moving averages (p = 30) of PM_{10} in one station located at the industrial zone of Bogotá



As fully documented in previous research, meteorology plays a vital role in air quality dynamics. The four cities are located in different climate zones, with different climate regimes regarding rainfall, wind and temperature. There is a positive correlation between mortality and pollution levels in both the cities up north (Mexico and Bogotá) and in Santiago. Furthermore, there is evidence of more frequent high pollution episodes in cities with more defined climatic seasons (e.g. Santiago and Mexico City).

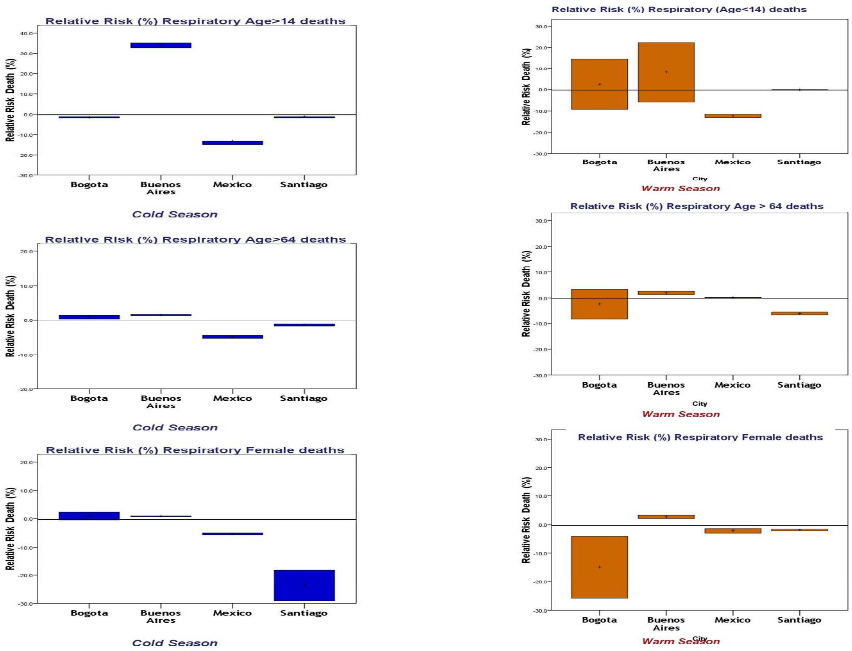
Decision makers want to have a measure of the implications of air pollution and weather on the health of urban populations. Therefore the team quantified urban populations' likelihood or relative risk (RR) of dying from the exposure to

a) Heat/cold stress impacts. During the warm season the highest RR of respiratory mortality was found in Buenos Aires (RR: 1.032), followed by Mexico City (RR: 1.003). In Bogotá, children showed a higher RR during the cold season (RR: 1.2). Regarding cardiovascular mortality, during the warm season the highest RR was found in Mexico City (RR: 1.015), followed by Buenos Aires (RR: 1.013). In Bogotá, there was a higher RR during warm season for elderly populations.

b) Atmospheric pollutants. The highest RR was found in Santiago (RR: 1.03), followed by Mexico City (RR: 1). In the two cities, a daily 10 $\mu g/m^3$ increase in the levels of PM_{10} has the potential to increase cardiovascular (CVD) mortality risk by of 3% and 0.3% respectively. Mexico City (RR: 1.2) and Santiago (RR: 1.02) also have the highest risk of total respiratory deaths.

The team therefore found that not all demographic segments of the urban populations are equally affected by the heat/cold stress, air pollution and other hazards climate change is predicted to aggravate. Socioeconomic characteristics of the population such as age, income and levels of education also explain variances in mortality within the cities. For example, Figure 5 shows the different weight of age and gender in respiratory mortality during both the cold and warm season.

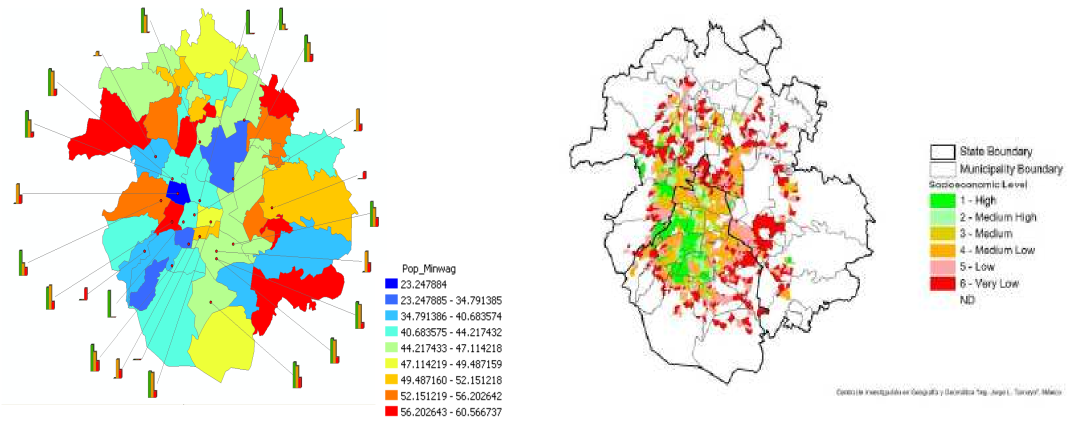
Figure 5: Relative risk by age and gender



We found that some of the most important socioeconomic factors associated to both cardiovascular and respiratory mortality were: a) number of people with less than higher education, b) number of persons with disabilities, and c) number of households with more than 7 members. Results of the Multi Regression Model show that the levels of education were highly associated to cardiovascular (CV) and respiratory (R) mortality in Buenos Aires (R^2: 77% for CV, 84% for R) and Mexico City (R^2: 89% for CV, 95% for R), while the percentage of persons with disabilities was the strongest indicator of vulnerability in Bogotá (R^2: 94% for CV, 95% for R) and Santiago (R^2: 36% for CV, 47% for R). The level of education is highly correlated with overcrowding. This indicates not only a strong association between low levels of education and poverty in Buenos Aires and Mexico City, but also between these indicators and higher mortality-risks. It seems that in Bogotá and Santiago education is not the most important determinant of mortality risk. Moreover, in the case of Santiago de Chile, the factors used in the model just explained 36% (47%) of the mortality variance suggesting there are other indicators of vulnerability that should be considering in the analysis.

Aggregate analysis can't capture finer spatial differentiations in socioeconomic status and vulnerability. For instance, data on income at the municipal level in Mexico City can hide finer spatial differentiations (Figure 6). People living in Santa Fe, one of Bogotá's most vulnerable districts, experienced a relative risk increase RR 1.208 for a temperature increase of 1°C whereas people living in Teusaquillo, one of the least vulnerable districts, experienced a much lower risk (RR 0.771). This relation was observed for both seasons whereas the difference was most pronounced during the cold season.

Figure 6: Mexico City: socioeconomic differentiation at municipal and AGEB* levels (left and right respectively)



Notes: red denotes low levels of income. * In Spanish AGEB stands for geo-statistic basic unit of analysis

4. Challenges and Difficulties

The main challenge facing the group is the lack of data covering long periods of time and at a finer spatial scale (e.g. municipality, comuna), especially in Buenos Aires. After several months of collecting and validating information, we were faced with the challenge of selecting data at the time and space scales that best fit our research goals. When possible, we used statistical tools to make up for missing data. The sharing of databases among city- and theme-teams has been solved in quite an easy way, using internet web pages specialized in this matter. As said before, internet-based communication proved to be very useful to interchange ideas and understand each city's situation regarding our object of study.

Regarding the analysis of exposure to weather and air pollution a challenge was the missing values of some data and the difficulty to complete them by statistical methods due to extended period of missing data. Therefore, we applied the analysis for the time period with the best series of data. The Generalized Linear Model for inner spatial units in each city wasn't always possible because we had few cases leading to statistical no significance. Therefore, the analysis is focusing on those spatial units (e.g., municipalities) with enough information and air pollution data availability.

4. Future activities

1. Continue the comparative analysis of air quality in the cities

2. Finish the multivariate regression analyses (MRA) to quantify the combined impacts of weather, air pollution and vulnerability on health

3. Combine the MRA with a GIS-based analysis to explore the differentiation, within cities, of such determinants of vulnerability as income, access to education, and access to infrastructures

4. Present ADAPTE's research-findings in international and regional conferences, workshops and seminars

5. Turn ADAPTE's research-findings into seven publications. We are drafting

    a. three comparative papers, one at the city level that includes the four cities, one highlighting geospatial differences in vulnerability within cities that only includes Bogotá, Santiago and Mexico City, and one highlighting air quality issues in the three cities;

    b. in depth and detailed papers for each city (i.e. four papers)

6. Contribute to a chapter on air pollution and health in Latin American cities led by Laura Gallardo, PI of SAECM

7. Continue making sure that students
    a. participate in training programs and activities on the most important concepts regarding air pollution, environmental health, GIS and vulnerability studies;

    b. develop their scientific skills and are capable of designing, planning, and conducting research projects in the referred areas of scientific research

5. Contribution of Principal Investigator

To organize the different components of the ADAPTE Project we named leaders responsible for each of the main themes and cities: Eduardo Behrentz for air pollution and Bogotá; Laura Dawidowski for weather and Buenos Aires; Alejandro Leon and Paulina Andulce for Santiago; Patricia Matus for health; Mercy Borbor for statistical design and application; Olga Wilhelmi for GIS and vulnerability; and Patricia Romero Lankao for Mexico City, vulnerability and overall coordination of the project.

Eduardo Behrentz: Coordinated the collecting and validating of air quality data by students from the four cities. Data were processed in the time resolution and format each team leader required for the health and vulnerability analysis. The Bogotá team also followed the procedures set by the coordinating team to prepare data for those analyses. In regards of Bogotá's analysis, we discussed the preliminary results that other teams achieved in order to contextualize and explain them. We also suggested time periods of study, to explore seasonalities that are particular to our city.

Laura Dawidowski: coordinated the collecting and validating of weather data by students from the four cities. She helped the students validate and organize the data. The Buenos Aires Team was in charge of processing data for the city, with help of the other theme leaders regarding pollution, health and vulnerability. We processed the whole data to obtain a matrix that we used to carry the statistical analysis. We applied the statistical procedures to run models of analysis that allowed us to obtain results on correlation between the analyzed variables.

Mercy Borbor Cordova: developed and coordinated the methodology for exposure risk assessment of cardiovascular and respiratory Mortality to weather variables and air pollution; designed a general framework, using Generalized Linear Model, for a relative risk seasonal analysis by sex and age groups. She is choosing and testing the Linear Multi regression Analysis that better fits the analysis of the socio-economic and vulnerability indicators within the cities.

Olga Wilhelmi: as co-coordinator of the vulnerability analysis got the weather, air pollution and vulnerability data from the four cities and transformed them in GIS data. She coordinated the GIS analysis of exposure and vulnerability.

Patricia Matus: has led and advised the health analysis for Santiago and Buenos Aires respectively. She has provided insights to the NCAR team not only on health issues but also on the development context of Santiago.

Paulina Andulce: coordinated the collecting of vulnerability indicators for Santiago, and has provided advice on the development context for adaptation in this city.

Patricia Romero Lankao: coordinated the gathering, organization and validating of vulnerability data and of all the information from Mexico City. She coordinated the reviews of literature on air pollution, health, and vulnerability by two students (Griselda Gunther and Raphael Nawirotzki). She has been responsible for coordinating the efforts of all theme and city leaders and is currently drafting the outlines of some of the comparative and city papers.

6. Presentations, publications, capacity building

Workshop

The team held a workshop on November 17-19, 2008, at NCAR (Boulder CO) with a three-fold goal: a) to assess the work done, i.e. the quality and comparability of data bases and; b) to define a road map to accomplish the main goals of the project (e.g. to agree on theoretical frameworks, and methodologies to analyze and integrate the three components of the project), and c) to build capacity, i.e. train students in the use of GIS, epidemiological statistics and other tools.

Papers, theses

- Caneo, K., et al (2009) "Asociación entre la contaminación del aire y condiciones meteorológicas con la morbilidad y mortalidad por causas respiratorias y cardiovasculares en la población del Gran Santiago, período 2001 – 2005" (unpublished manuscript to be submitted)

- Nawrotzki, R., (2009), "Exploring the influence of seasonality and demographic characteristics on the relation between weather, air pollution and mortality in Bogotá, Colombia, ***Project submitted to obtain the degree of Masters*** of Science in Administration, Community and International Development, Andrews University, 38pp.

- Parra, D., Gaitan, M., Behrentz, E., (2009), "Air quality analysis in three Latin American cities", (unpublished manuscript to be submitted).

Presentations

- Leon, A., Matus, P., and Caneo, K., (2009) "Emissions, Climate, Wealth and Health in a Highly Polluted Latin American Capital City", IHDP 2009 Open Meeting, Bonn Germany

- Romero Lankao, P., et al (see footnote 1) (2009) "Adaptation to the health impacts of air pollution and climate extremes in Latin American cities (ADAPTE) Research Findings", IHDP 2009 Open Meeting, Bonn Germany

- Romero Lankao, P., et al (see footnote 1) (2009) "Adaptation to the health impacts of air pollution and climate extremes in Latin American cities (ADAPTE) Research Findings", Human Security in an Era of Global Change GECHS Synthesis Conference, Oslo

Posters

- Dawidowski, L. and Abrutzky, R., **"**Contaminación atmosférica por monóxido de carbono y mortalidad en la Ciudad Autónoma de Buenos Aires"**.** *International Conference: "Air Quality and Urban Climate in Buenos Aires*. Buenos Aires, Argentina, 27-28 November 2008

- Parra, D., Gaitan, M., and Behrentz, E., (2009), "Air quality analysis in three Latin American cities", II Congreso Colombiano y *Conferencia*. Internacional de Calidad *del Aire* y Salud Pública, Cartagena Colombia

The Colombian team is comprised of one tenure-track professor (Dr. Eduardo Behrentz) and two chemical engineering graduate students (Natalia E. Muñoz and Daniela M.E. Parra). Ms. Parra's master's program is being funded by the ADAPTE project whereas Ms. Muñoz received funding from an in-kind contributor to this project. During this reporting period, Ms. Muñoz was awarded her master's degree, for which she presented a graduate project on medical databases management in the city of Bogotá. Ms. Parra finished the first part of her graduate project, performing a comparative analysis among Bogotá, Mexico City and Santiago based on air quality data. The second part of this project will include a component of estimation of exposure in the city due to background concentrations (i.e. ambient air), and an analysis of redundancy in the number of stations in Bogotá.

Ms. Parra and Dr. Behrentz attended the ADAPTE Workshop in Boulder (CO), in November 2008, where the analysis until that point achieved was shared. They also participated in the II Colombian Congress and International Conference on Air Quality and Public Health held in Cartagena, in July 2009, where a poster was presented. As part of this event, the SAEMC international team had one of its annual meetings with an active participation of the students from all cities. The ADAPTE team also had a meeting to agree on the work to be done in the following months.

The Buenos Aires team is comprised by Laura Dawidowski as senior researcher and Rosana Abrutzky as student researcher. The Epidemiological aspect of the work is directed by Patricia Matus of the University of Chile., who also led the health analysis for Santiago. Rosana is a sociologist. She is doing a Master on Environmental Management in the National San Martín University, funded by the ADAPTE project. In this framework she is completing her second year of courses and drafting her Master Thesis. She also participated of two scientific meetings: 1) ADAPTE workshop, held by the ADAPTE tem in Boulder, CO, during November 2008, and 2) Conferencia Internacional Calidad del Aire y Clima Urbano en Buenos Aires, November 27-28, 2008. The Buenos Aires ADAPTE team presented a poster: “Impacto en la salud de las temperaturas extremas y la contaminación atmosférica en Buenos Aires”.

The Mexican team is composed of one Social Scientist Patricia Romero Lankao, and assistant, a student and an adviser on health issues. Magali Hurtado has provided advice on health analysis and data. Angelica Rosas Huerta has a master on Public Policies and is doing her Ph.D. on transportation and climate change policies in Mexico City at the Metropolitan Autonomous University Xochimilco where she got a position as professor last year. Maria Griselda Guenther finished her major on water policies in Mexico and Argentina at the UNAM. Angelica and Griselda attended the Boulder workshop in November 2008.

Last but not least, two students more students have done their master theses as part of their participation in ADAPTE:

a) Karla Caneo who works as student assistant for the Santiago team and is writing a master thesis on the independent and combined effects, on mortality and morbidity of the exposure to air pollution and temperature in Santiago.

b) Raphael Nawirotski who made an intense internship at NCAR (May 1 to July 30, 2009), worked as student assistant in ADAPTE and wrote a report to obtain his masters degree of Science in Administration, Community and International Development, Andrews University,