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Commentary

Respiratory disease and particulate air pollution in Santiago Chile: Contribution of erosion particles from fine sediments

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ABSTRACT

Air pollution in Santiago is a serious problem every winter, causing thousands of cases of breathing problems within the population. With more than 6 million people and almost two million vehicles, this large city receives rainfall only during winters. Depending on the frequency of storms, statistics show that every time it rains, air quality improves for a couple of days, followed by extreme levels of air pollution. Current regulations focus mostly on PM10 and PM2.5, due to its strong influence on respiratory diseases. Though more than 50% of the ambient PM10s in Santiago is represented by soil particles, most of the efforts have been focused on the remaining 50%, i.e. particulate material originating from fossil and wood fuel combustion, among others. This document emphasizes the need for the creation of erosion/sediment control regulations in Chile, to decrease respiratory diseases on Chilean polluted cities.

1. Introduction

Santiago, Chile, one of the cities with the most serious air pollution problems in the world is geographically located surrounded by mountain ranges, leaving the country's capital with no proper air drainage (Rutllant and Garreaud, 1995). As most Chilean cities, Santiago has thermal inversions during winter months (April–August) that make atmospheric conditions highly vulnerable, preventing polluting particles in the air to be dispersed (Garreaud et al., 2002).

Among the most relevant air pollution sources on Chilean cities are vehicles, manufacturing industries, and residential wood combustion. All of them increase their contribution to air pollution, depending on the amount of fuel consumption (Romero et al., 2010). However, fugitive emissions of coarse particulate material are mainly produced due to suspended dust from eroded areas and fields and stream alluvial deposits (Mena-Carrasco et al., 2012; Feng et al., 2011; Garcia-Chevesich, 2008).

Particles in the air disperse or decrease significantly only when precipitation occurs or fronts bring in relatively clear cold air masses, temporally improving air quality. However, this situation continues for a couple of days and air pollution then comes back to pre-rain levels, or even worse. When such phenomena reaches critical levels necessitating environmental alerts, pre-emergencies, or emergencies, hospitals often become overloaded with the increase of respiratory problems among the local population. According to the Chilean Environmental National Commission (Conama) (Comision Nacional del Medio Ambiente (CONAMA), 2009), an average of 20,000 people suffer air pollution-related problems each year in Santiago, causing more than 700 deaths during winter seasons (O'Ryan and Larraguibel, 2000; Jorquera and Barraza, 2012).

According to the country's Environmental Report (Informe País) and many other studies around the world, the most relevant air polluting variable in terms of the population health is PM10s, i.e. particulate material smaller than 10 μ in diameter (Universidad de Chile, 2008; Samet et al., 2000). This important parameter has been documented on an hourly base and at different locations within and around the Santiago basin since the year 1998 due to increasing

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fossil fuel and wood combustion. On the other hand, worldwide research suggests that wind erosion of soils and sediments is another source that generates particulate material harmful for human health (Hagen, 2004). In fact, fugitive dust is an actual concern in the United States, since PM10s and PM2.5s are regulated by the Environmental Protection Agency (EPA) and are considered important air pollutants (Samet et al., 2000; Feng et al., 2011). Furthermore, wind erosion of soils and sediments, and fugitive dust emissions contribute not only to desertification and loss of soil productivity, but also to the worsening of air quality and visibility (Feng et al., 2011).

2. Santiago's current problems

Despite the situation mentioned above, the Atmospheric Decontamination and Prevention Plan (ADPP) for Santiago, created in 1998, has incorporated countless regulations and norms to decrease air pollution in the capital. Table 1 shows the main efforts generated by the ADPP. The focus of the ADPP has not significantly changed since its creation, considering the fact that the Government continues to focus on improving vehicle and industry emissions. However, little has been done to decrease the major component of PM10: soil (sediment) particles (O'Ryan and Larraguibel, 2000; Universidad de Chile, 2008; Sharratt and Edgar, 2011). In fact, even though Jorquera and Barraza (Jorquera and Barraza, 2012) measured smaller quantities of soil in PM2.5 samples, O'Ryan and Larraguibel (O'Ryan and Larraguibel, 2000) reported that more than 50% of PM10s are represented by soil particles.

Fine sediment: Small diameter soil particles are detached from their origins (i.e. construction sites, agricultural fields, and dirt roads, among others) and transported by water and wind during storm events, to the paved streets of Santiago. Later on, a few days after the rain, when sediments are completely dry, air turbulence produced by vehicles and wind lift again the sediment particles into the air, dangerously increasing PM10 concentrations making the city's air quality worse. This process might also explain why air quality improves when rainfall occurs frequently, since this way sediments remain humid and, as a consequence, wind erosion is not possible. Additionally, it is important to add that soil particles are bipolar, i.e. they have the capacity to transport other chemical compounds, such as SOx, CO, pesticide residues, and fungal spores etc., commonly found on PM10s (Garcia-Chevesich, 2008).

Table 1
High-impact activities to decrease Santiago's air pollution levels, by the year 2001 (Source: Informe País 2008).

Source focus	Main activities
Buses	Removal of 2700 buses with inappropriate air pollution technology
	Incorporation of 1000 buses with low emissions
	Post-treatment systems
Large trucks	Removal of trucks with inappropriate air pollution technology
	Norms EURO III and EPA98
	Post-treatment systems
Inappropriate vehicles	Norms TIER I and EURO III
Dust control	Street vacuuming
	Road pavement
Fuel improvements	Diesel quality 300 and 50 μg m^3
	Better home-use fuel qualities
Fire management	Prescribed burn restrictions
New industry regulations	CO emission norms
	SOx emission norms
	Program to reduce SOx in major emissions
Compensation and emission permits	Industry's NOx emission limit
	PM10 emission limits for industrial processes
	Emission compensation for industry and transportation

Fungal Spores: The pathogenic role of invasive fungal infections (IFIs) related to dust exposure has increased during the past two decades. The most important include Coccidioidomycosis, Histoplasmosis, Paracoccidioidomycosis, and a variety of Opportunistic Mycoses (Colombo et al., 2011; Sifuentes-Osornio et al., 2012). Although endemic mycoses are a frequent health problem in Latin American countries, clinical and epidemiological data remain scarce and fragmentary. Medical scientists have begun to investigate more deeply into the mechanisms of these diseases and their relationship with susceptible populations. Working habits (e.g. agriculture, livestock activities, construction, urban dust sources, etc.) and leisure activities have been the focus of attention by public health officials along with individuals with immunosuppression, as a number of outbreaks of endemic mycoses have been traced to exposure to microorganisms in their natural habitat, soil and dust.

Coccidioidomycosis is an endemic IFI caused by species of Coccidioides. This disease is probably the best understood of the IFIs since it has been well-studied in the USA. It is highly prevalent in arid and semi-arid regions ($<$600 mm of annual rainfall) with high temperatures. The deserts of the Southwest USA is a type region for Coccidioides species. The natural habitat of the species is 5 cm–30 cm below the surface of alkaline soils. Weather conditions are usually extreme, ranging between 0 °C and 45 °C. The two distinct species are endemic in different regions: *C. immitis* in the San Joaquin Valley in California and *C. posadasii* in Arizona, Texas, Mexico, Central America, and South America. Endemic areas in Latin America include the Sonoran and Chihuahuan deserts of northern Mexico, the Motagua River valley in Guatemala, the Comaya valley in Honduras, the Sierras Pampeanas in Argentina, the Magdalena, Guajira, and Cesar provinces in Colombia, the area of the Great Chaco in Paraguay, and several regions in Venezuela and Brazil.

Increased incidence has recently been reported in Argentina and the United States, mainly owing to migration and new residential construction in high-risk areas. Pulmonary outbreaks usually have been associated with earthquakes, military encampments, agriculture, construction sites, and archeologic excavations The role of urban dusts originating from erosion is poorly documented. In Catamarca, Argentina, the incidence rates grew by 350% from 2006 to 2009. Most cases in the United States and Mexico occur in individuals younger than 5 or older than 55 years while the higher occurrences in South America involve those 25–35 years of age.

Despite knowledge of the above processes, the only activities to reduce soil particles (50% of PM10s) in Santiago have been street vacuuming and street paving (Table 1). Nothing has been done in terms of attacking the problem from its origin, i.e. to control sediment production on sites where vegetation has been removed.

3. International experience

Many countries have implemented the incorporation of sediments among their measurable parameters to control fugitive dust emissions, in order to protect the public health. This fact has improved the efficiency of air quality standards of a number of countries. According to the World's Health Organization (World Health Organization, 2005), an organization involved with environmental regulations of more than 200 countries, the recommended standard for PM10 concentrations is 50 μg m (Romero et al., 2010). However, most countries establish their own limits on air quality, mainly because PM10 and its composition might be a function of local climates, (i.e. annual precipitation, which determines natural plant cover) and natural sediment yields from watersheds. According to Langbein and Schumm (Langbein and

Schumm, 1958), there is a relationship between annual precipitation and sediment leaving drainage areas (Fig. 1). Assuming a constant area and considering Chile's geographical distribution of precipitations, at the Atacama Desert, the driest place on Earth, there is no sediment yield because no precipitation occurs and there is no resulting streamflow. However, the Atacama is prone to wind transport of fine soil particles. As one advances south, more annual precipitation takes place and, hence more sediment production. This trend continues until about 300 mm yr^{-1} (below this point, there is not enough precipitation to sustain plant cover all year round). However, beyond 300 mm yr^{-1} sediment yield decreases as precipitation increases, simply because more plant cover can get established, protecting the soil surface against the release of soil particles. For instance, 300 mm yr^{-1} represents the inflection point where maximum amounts of sediment yield is expected, and Santiago's annual precipitation is around 338 mm yr^{-1}. This explains why sediment yield in the extreme south, where mean annual precipitation overpasses 4 m, is negligible.

Thus, the proportion of soil particles in PM10s should be larger in cities located under dryer climates, such as arid, semiarid, and Mediterranean, the latter corresponding to Santiago.

The USA Clean Water Act was created by the US EPA in 1972, where the law clearly prohibited the release any type of contaminant into the USA's water bodies. Sediment was incorporated into the list of contaminants in 1998, because sediment is considered the main pollutant of the world's rivers and lakes. As a consequence, erosion and sediment control is mandatory in the USA ever since, leading to the appearance of a whole industry of products destined for such purpose and giving origin to the International Erosion Control Association, a key organization for education and commercial networking of the industry. At the same time, the US Federal Government, universities, and even the private sector have invested in countless studies to determine the economic efficiency of erosion and sediment control. Thus, since 1998, air quality (PM10 concentrations) have significantly improved in the main US cities (Fig. 2), attributing such improvement to the incorporation of erosion and sediment control, because sediment release affects air quality, as previously mentioned. In fact, sediment control is currently part of the National Ambient Air Quality Standards (NAAQS) to regulate particulate material in the USA, mostly due to its high composition of PM10 pollutants (similar to the case of Santiago, as observed by O'Ryan and Larraguibel (O'Ryan and Larraguibel, 2000)). Furthermore, there is currently a strict regulatory and monitoring system in cities with air pollution problems, such as Los Angeles (325 mm $year^{-1}$ of annual precipitation), where fines for not controlling sediment production can reach up to US$10,000 per day of violation, partly due to the dramatic effects of soil particles on the city's air quality and PM10s, i.e. people's health. Different from Santiago, where environmental alerts begin at 150 μg m (Romero et al., 2010) of PM10 in 24 h, many USA cities have set environmental alert levels at 65 μg m (Romero et al., 2010). Despite the above, the US EPA is currently re-evaluating the NAAQS to modify the PM10 standard (Sharratt and Edgar, 2011).

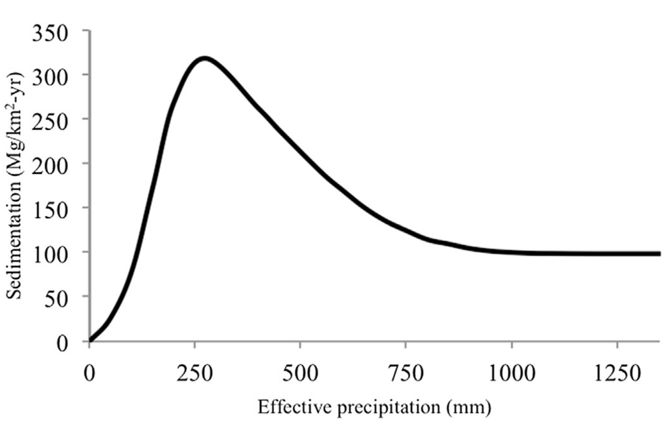

Fig. 1. Relationship between mean annual precipitation and sediment yield. Source: Langbein and Schumm (1958), cited by Garcia-Chevesich (2008).

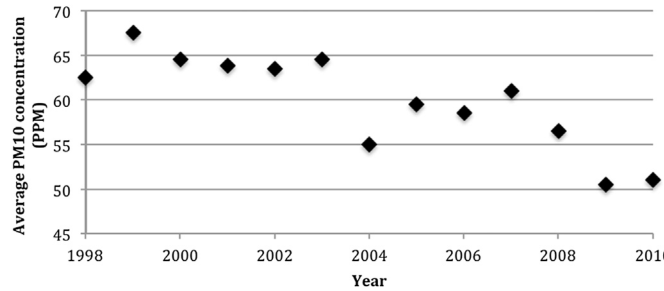

Fig. 2. Evolution of average PM10 concentration in the United States, considering 279 cities. Source: EPA public data.

4. Conclusions and recommendations

The need to reduce the detachment and transport of soil particles, and their deposition on the streets of Santiago, in order to improve air quality is unquestionable. To date, the main efforts to decrease PM10's soil particle concentrations have been focused in the wrong area of the process. Instead of keeping soil particles in their origin (construction sites, agricultural fields, dirt roads, etc.), i.e. the most economic and efficient option, resources have been invested mainly on street vacuuming after fine sediment deposition.

The city of Santiago has increased in size nearly 1000 ha yr^{-1} during the past few decades. Such expansion has occupied thousands of hectares of agricultural fields (Platt, 2006). For instance, it is crucial to follow environmental politics similar to the USA Clean Water Act, where the presence of regulations created to minimize sediment production from disturbed sites (fine sediment origin) have resulted in better air quality and better public health in cities subject to sediment deposition.

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