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WHITE PAPER

Chile Confronts its Environmental Health Future After 25 Years of Accelerated Growth

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Abstract

BACKGROUND Chile has recently been reclassified by the World Bank from an upper-middle-income country to a high-income country. There has been great progress in the last 20 to 30 years in relation to air and water pollution in Chile. Yet after 25 years of unrestrained growth, there remain clear challenges posed by air and water pollution, as well as climate change.

OBJECTIVE The aim of this study was to review environmental health in Chile.

METHODS In late 2013, a 3-day workshop on environmental health was held in Santiago, Chile, bringing together researchers and government policymakers. As a follow-up to that workshop, here we review the progress made in environmental health in the past 20 to 30 years and discuss the challenges of the future. We focus on air and water pollution and climate change, which we believe are among the most important areas of environmental health in Chile.

RESULTS Air pollution in some cities remains among the highest in the continent. Potable water is generally available, but weak state supervision has led to serious outbreaks of infectious disease and ongoing issues with arsenic exposure in some regions. Climate change modeling in Chile is quite sophisticated, and a number of the impacts of climate change can be reasonably predicted in terms of which areas of the country are most likely to be affected by increased temperature and decreased availability of water, as well as expansion of vector territory. Some health effects, including changes in vector-borne diseases and excess heat mortality, can be predicted. However, there has yet to be an integration of such research with government planning.

CONCLUSIONS Although great progress has been made, currently there are a number of problems. We suspect that the Chilean experience in environmental health may be of some use for other Latin American countries with rapid economic development.

KEY WORDS air pollution, Chile, climate change, water pollution, policy

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INTRODUCTION

In 2013, the World Bank reclassified Chile from an upper-middle-income country to a high-income country, based on its having a per capita gross national product exceeding $12,600. The World Bank does not take economic inequality into account in determining a country's status; Chile's 2011 Gini index (an index of inequality with higher scores indicating more inequality) rating was 51, among the highest in Latin America and 10 points higher than the Gini index for the United States in 2010.[1] In 2010, Chile became a member of the Organization for Economic Cooperation and Development (OECD), a grouping of 36 developed countries; among these countries, which include Turkey and Mexico, Chile has the highest Gini index.

Although a good indicator of overall disparity, the Gini index does not reflect inequalities within regions. In terms of economic activity, the north is dominated by mining. The center (the capital city of Santiago, main ports and agrarian valleys) concentrates political and financial power, as well as agricultural and industrial activity. Cattle, forestry, and fishing occur mainly in the south. Population and production are both concentrated in Santiago (49.3% GDP) and Antofagasta, the main mining region in the north (10.4% of GDP), respectively.[2] Poverty (defined as <$7085/y income for a family of 4), varies among regions from 4% in Antofagasta, up to 28% in the IX Region of Araucanía, where the population of Mapuche ethnic origin is mostly settled (Fig. 1). Furthermore, inequality varies distinctly within the country; data from 2003 indicated that county-level Gini coefficients (then 55 for the whole country) varied widely across the country, ranging from 41 to 62.[3]

Compared with most countries in Latin America, Chile had a long history of democracy before the military coup in 1973. The period since 1939 laid the foundations for a successful industrial development under the state patronage, so that by mid-century the state owned or had interests in more than 100 strategic enterprises, such as transport, energy, and water. Later, the exacerbation of historical political struggles for more structural changes ended in the 1973 military coup, which interrupted the democratic trail and drastically changed the state-oriented policy to an extreme open market–oriented system.[4] Though the military regime was characterized by strong business development, it sharpened the extreme poverty and vulnerability of the poor. The return to democracy in 1990 began with 42% of the population under poverty and with public social protection systems dismantled.[5]

Between 1990 and 2015, Chile experienced unprecedented growth and managed to lower poverty to 14.4% (2013)[6]; however, this growth was mostly based on raw materials. The OECD, in a 2009 report, highlighted the impact of the accelerated growth on natural resources and the environmental burden generated by mining, agricultural and forest overexploitation, as well as overcrowding in Santiago, which was pointed to as among the most polluted the cities in the world.[7]

Here we describe the state of environmental health in Chile, which may be seen as a model for the future of other Latin American countries as they become more developed. After the re-establishment of democracy and a period of rapid economic growth, during which environmental concerns were somewhat on the back burner, now is a good time to assess the overall picture of environmental health in Chile and consider how to move forward. We focus on air and water pollution and on climate change, which are among the most important environmental issues in Chile.

This article reflects the findings of a workshop held in Santiago, Chile, in October 2013, called "Planning for a Global Environmental Health Hub Based in Chile," which brought together researchers from around the country, as well as government personnel working in environmental health. The workshop was funded by the US National Institutes of Health Fogarty International Program, as part of a new initiative to support a multinational network of regional hubs for Global Environmental and Occupational Health Sciences (GeoHealth).[8] For details of the workshop, see http://geohealthchile.blogspot.com/p/environmental-and-occupational-health.html. Chile, with a strong group of environmental health researchers and a nucleus of technicians in government agencies devoted to environmental health, was considered as a possible area for a future GeoHealth Hub; our team was awarded a Fogarty Planning Grant for a GeoHealth Hub in Chile. However, when Chile was reclassified as a rich country in 2013, it became ineligible for Fogarty funding. We now plan that Chile will play an important role in south-south collaboration in environmental health training for a new GeoHealth Hub to be centered in Peru.

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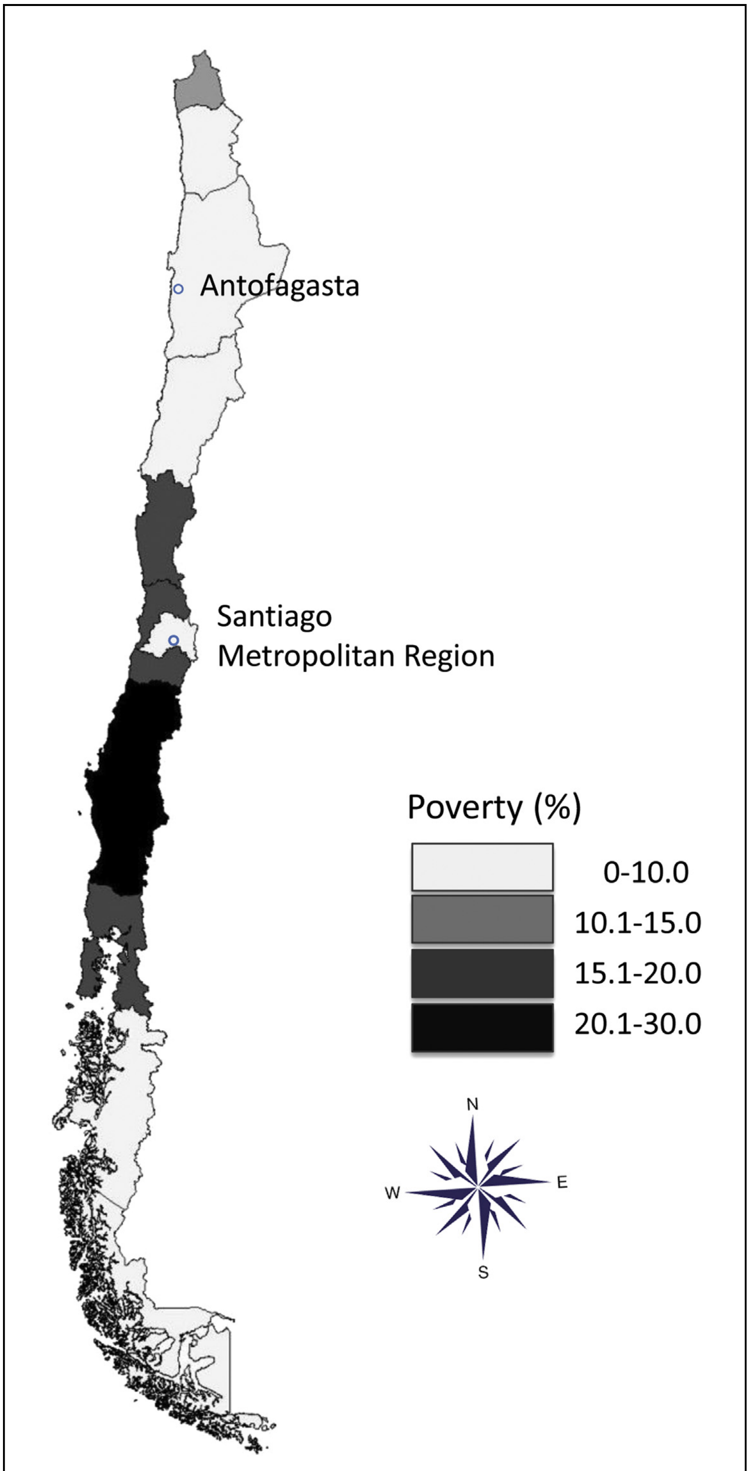

Figure 1. Regions of Chile by percentage of people under the poverty line (USD $7085/y for families of 4 members) in 2013. (Data from Chilean Ministry of Social Development.[129])

AIR POLLUTION: PAST AND CHALLENGES

In the past 40 years, air quality in Chile has become an issue of high concern given the growing proportion of population exposed to high levels. Santiago, the capital city with almost 7 million inhabitants (40% of the country's population), is located in a valley surrounded by mountains from the coastal and Andean ranges. Every winter this topography, along with an inverse temperature layer, limited rains, and minimal airstream, results in a low dispersion rate, insufficient to cope with the progressively higher concentration of pollutants emitted.[9]

As noted earlier, the country has undergone a period of accelerated economic and industrial growth, with cities occupying land previously used in agriculture.[10,11] By the early 1990s Santiago had levels of air pollution comparable to megacities such as Sao Paulo and Mexico City, despite having barely one third of the population of these cities.[12]

Air quality monitoring in the metropolitan area of Santiago was initiated as early as 1974 and standards for criteria pollutants were established in 1978. However, regulatory plans began only in 1990, after the military dictatorship lost power. Key interventions of those plans aimed at reducing overall emissions or were directed at specific pollutants such as leaded gasoline and sulfur in diesel fuel. Particulate matter (eg, PM_{10} and $PM_{2.5}$) data, which were regularly collected only starting in 1989, indicated significant reductions of pollutants in Santiago in the early years after emissions-reducing policies were enacted (Fig. 2). However, current $PM_{2.5}$ levels in Santiago still surpass the 20 $\mu g/m^3$ Chilean standard for $PM_{2.5}$ established in 2012,[13] as well as the World Health Organization's (WHO's) 10 $\mu g/m^3$ annual standard.

The interventions to reduce air pollution in Santiago, although significant, were not sufficient to offset the growth of the city, particularly the increase of mobile sources and the increased use of wood for heating (because of its lower cost compared with gas or electric energy). The public and private vehicular fleet in Santiago has doubled since 2001, reaching the current 1,700,000 vehicles and accounting for 40% of the country's fleet.[14] After decades of monitoring and decontamination plans, Santiago in 2011 was still among the top 5 capitals in Latin

America with the highest annual mean $PM_{2.5}$ (Lima, 38 μg/m^3; Guatemala city, 33 μg/m^3; Tegucigalpa, 32 μg/m^3; Bogota, 27 μg/m^3; and Santiago, 26 μg/m^3).[15]

In 2004, air monitoring expanded to other regions of the country, mainly because of the mandatory monitoring required for potentially polluting private companies. Currently the network of air quality monitoring has 130 private and 58 public stations nationwide that monitor PM_{10}, $PM_{2.5}$, carbon monoxide, sulfur dioxide, nitrogen oxide, and ozone.[16] Five percent of the monitors are in Santiago.[16]

There are 3 air pollution areas of concern in Chile: (1): a north-central zone, with mining and thermal power production that generate particulate matter,[17,18] as well as heavy metals and sulfur dioxide[19,20]; (2) a highly populated urban area (including Santiago) of industrial development and large vehicle fleets emitting particulate matter, carbon monoxide, sulfur dioxide, and ozone; (3) and a cold-weather central-south area with heavy use of wood for domestic use. As stated in the introduction, the southern area has the largest proportions of poor families, determining their higher vulnerability.[3]

There are very high levels of contaminants in some areas outside of Santiago. Four Chilean cities have been reported by WHO as being among the top 5 Latin American cities with highest $PM_{2.5}$ levels in 2011 (Rancagua, 54 μg/m^3; Chillán, 53 μg/m^3; Temuco, 48 μg/m^3; and Talca, 44 μg/m^3),[15] although these rankings may partly reflect the more extensive regional air sampling in Chile compared with other countries. In the southern city of Coyhaique, daily air PM_{10} surpasses 350 μg/m^3 in wintertime, far exceeding the Chilean daily standards for PM_{10} (150 μg/m^3).[16] This and other southern cities, where burning wood is common for heating, register more than 30 "emergency" days (daily values for PM_{10} higher than 330 μg/m^3). This finding has forced the environmental authority to declare decontamination plans for these areas, which, over 10 years, should bring the 3-year moving average level of the specific contaminant to below the annual standard.[22]

Research on the health effects of air pollution is still relatively sparse. Most of this research has been time series studies on registered emergency visits,[23-27] hospitalization[28-30] and mortality associated with air pollutants.[31-39] In the exposure sphere, some studies have measured personal exposure to particulate matter[40]; others have proposed models

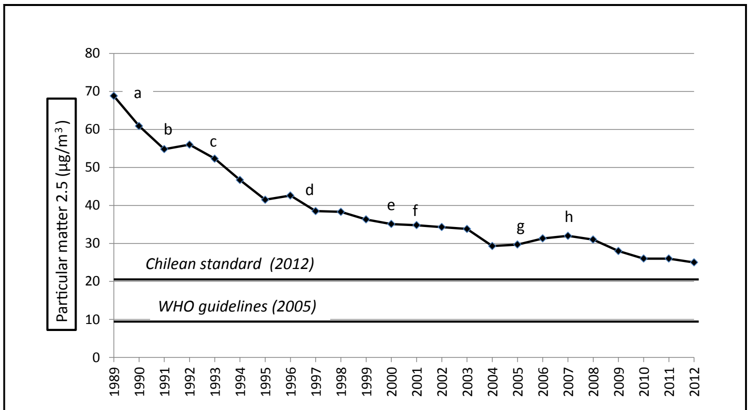

Figure 2. Evolution of annual mean $PM_{2.5}$ in Santiago, 1989–2012. Interventions: a, 1990, removal of 3000 buses; b, 1991, arrival catalytic vehicles; c, 1993, sulfur reduction in diesel 5000-3000 ppm; d, 1997, sulfur reduction in diesel from 3000 to 1500 ppm; e, 2000, sulfur reduction in diesel 1500 to 1000 ppm; f, 2001, removal of lead; g, 2005, removal of 2200 buses; h, 2007, new system of public transport. (Source: Ministry of the Environment.[16,21])

to predict the levels of pollutants[41] or have identified the source apportionment of outdoor particulate matter.[42] Only a few publications have aimed at evaluating the economic significance of contaminants reduction,[43] and there are only a few publications dealing with indoor air pollution and its health effects.[44,45] As expected, studies concentrate primarily on the Santiago Metropolitan Region,[23-27,33,34,44] with a some notable exceptions.[35,37,45,46]

These studies have reported relative risks (RRs) of 1.05–1.10 for each 100 μg/m^3 PM_{10} in Santiago for respiratory mortality in the elderly,[47] whereas in Temuco the RRs were higher, which led the authors to suggest that particles could be more dangerous because of chemical composition.[35] In terms of morbidity, increases of 100 μg/m^3 of PM_{10} were associated with elevated risks of acute respiratory infection (RR 1.16, 95% CI 1.14–1.18) and hospital admissions (RR 1.14, 95% CI 1.09–1.18) in those >65 years of age.[37] Another study conducted in Temuco between August 2009 and June 2011 assessed the daily concentration of ultrafine particles (particles smaller than 100nm) and its relationship to daily outpatient visits for respiratory causes in health centers. The authors reported ultrafine particle values between 1.62 and 25.81 μg/m^3 and significant risk in people older than 65 years for each 4.73 μg/m^3 (interquartile range) increase (RR = 1.15; 95% CI 1.06–1.25).[46] Chemical speciation of fine particles has been studied, finding that $PM_{2.5}$ with high content of zinc, chromium, copper, sodium, and sulfur was more strongly associated with mortality than $PM_{2.5}$ mass.[48] Overall, these reported RRs are

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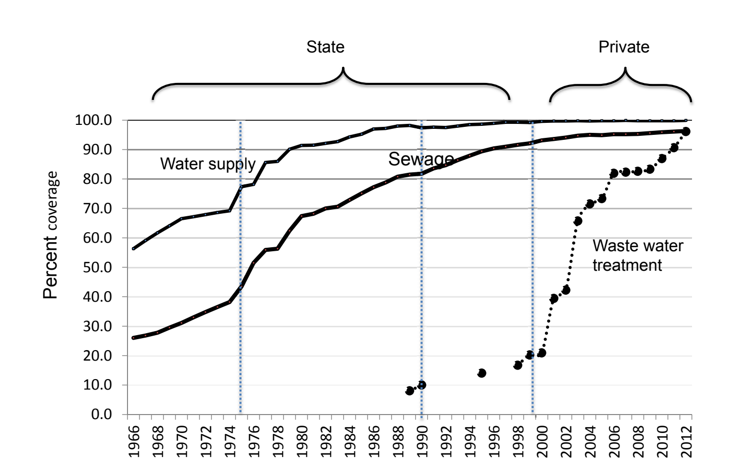

Figure 3. Historical coverage of urban sanitation in Chile, 1966–2012. (Data source: Superintendence of Sanitary Services [SISS].[62])

consistent with those found in developed industrialized countries, but it has been important to document these effects in Chile in terms of influencing public policy.

Future studies of air pollution effects need to be considered in conjunction with climate change, because sources such as burning fossil fuels and biomass are common to both.[49-51] For example, a recent study (done outside of Chile) found that the effect of low or high temperature on mortality is modified by air pollution and suggests that the reduction in the emission of particulate matter is closely related to a decrease in mortality in extreme temperatures.[50]

WATER: PAST AND CHALLENGES

In a short time span, water provision and treatment in Chile has changed substantially, from state management with widely subsidized prices to private sector management. Private companies were granted water rights, and now provide water, sewage, and waste treatment, with an allowed profit of 7% by law.

By the early 1970s, concurrent with the high rates of urban expansion, Chilean cities reached 75% coverage of potable water and 40% coverage of sanitation. Thereafter, under the military dictatorship (1973–1990), urban coverage of potable water reached more than 95%. Yet, it should be noted that the official figures did not consider the high degree of disconnection of users for nonpayment, which was estimated at 30%, given the low wages and unemployment at the time. This situation led to a system of targeted subsidies for the poor.[52]

With the return to democracy in 1990, the water sector was modernized.[53] By the end of the decade, the drinking water system, still under state management, had achieved high efficiency but with significantly higher tariffs for consumers. This happened in a context of unprecedented economic growth but with high socioeconomic inequality[54] (those in the top 10% of income had 45% of national income in 2000),[55] thus requiring increased subsidies to the poorest.[56]

After proposals from international agencies, the government sold water and infrastructure rights to private enterprises in the late 1990s. The justification, still under debate,[57,58] focused on the inability of the state to make investments in wastewater treatment, which at the time was virtually nonexistent.[59] The cholera epidemic at the beginning of the 1990s was a potent warning, perhaps more for its impact on exports than for its health significance,[60] because the epidemic was promptly stopped with focused interventions.[61]

Figure 3 shows the evolution of urban coverage of supply, sewerage, and wastewater treatment. At the beginning of the 1990s only 2.8% of the urban population lacked access to potable water, but a significant number had no access to sewerage and there was virtually no wastewater treatment. Wastewater treatment was implemented and reached the current coverage of close to 98%, but only after users funded the cost.[52,62]

The high availability of potable water and adequate sanitation in urban areas, coupled with targeted interventions in children's health, helped lower infant mortality from 119.5 per 1000 live births (one of the highest in Latin America) in the 1960s to 16.0 in the 1990s and 7.4 in 2012, one of the lowest rates in the continent.[63] Typhoid fever and hepatitis rates, 2 indicators of improved sanitation, fell sharply in the wake of targeted interventions to curb the epidemic of cholera in the country in the early 1990s (Fig. 4).[64] Although there was 1 peak of hepatitis in 2002–2003, there has since been a steady decline. The hepatitis A vaccine, although available for the wealthy under the private health system (covering 13% of the population in 2011), has not been available to a wider public except for a few targeted campaigns, so it is unlikely that the large fall in hepatitis rates was due to vaccination.

Another challenge has been the long-standing problem of arsenic in water, which has affected communities in northern Chile, especially the city of Antofagasta, located in the desert. Between 1958 and 1971, this city had very high water arsenic levels, averaging 0.86 mg/L.[65] Strong complaints forced the installation of a first abatement plant in 1970, resulting in a lowering to 0.12 mg/L, still high compared with the WHO 1963 standard of 0.05 mg/L.[66] The current Chilean standard was set at 0.01 mg/L in 2005, although allowing temporary levels as high as up to 0.03 for 10 years.[67] Health effects of arsenic in the highly exposed populations in the north of Chile have been widely documented, with excesses of lung cancer,[68] bladder cancer,[69] and heart disease, which decreased as arsenic concentrations decreased.[70]

Overall, Chile appears to have been successful with regard to its water treatment. However, water coverage is still limited in some rural areas. Rural water is supplied through cooperatives, which register 99% coverage in more populated areas but only 7% in semipopulated and 2% in low-populated areas.[71] In addition, some rural communities also lack sewerage,[72] and in specific northern regions, rural areas are also still exposed to high arsenic content in water.[73]

The state role remains relatively weak in water regulation; it is focused on commercial aspects such as setting rates, granting concessions, and supervising that services are delivered. On the other hand, surveillance of water quality relies on companies self-monitoring with the support of accredited private laboratories, but with rather loose control from the state. Each company (currently 60 nationwide)[74] reports compliance (yes/no) of each regulated item in 1 sample per month.[75]

Compliance is high for mandatory parameters, such as total coliforms, turbidity, and residual free chlorine for urban water companies, but other data may be incomplete. For example, in December 2013, only 54% of monthly reports (386/720) included arsenic measurement and 2% (8/386) surpassed the current maximum allowance of arsenic in potable water, with levels between 0.01 and 0.03 mg/L.[75] Other parameters that occasionally do not meet national regulations are nitrates (88.2% compliance) and sulfates (64.3% compliance), even under considerably more lax standards (50 mg/L and 500 mg/L, respectively) than, for example, the US Environmental Protection Agency requirements (10 and 250 mg/L, respectively).[76,77] Nitrates should be an agent of concern, particularly in agricultural regions, because they can be an indicator of contamination by fertilizers or organic wastes.[78]

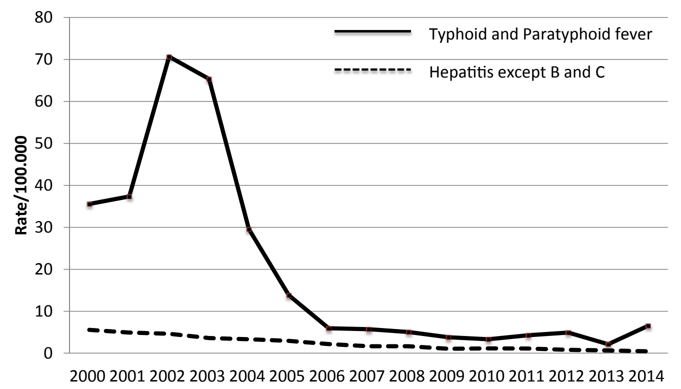

Figure 4. Trends in hepatitis and typhoid fever, Chile, 2000–2014. (Sources: Department of Statistics Ministry of Health, Chile,[130] and National Institute of Statistics.[131])

Furthermore, failures in the current system have occurred. In 2010 and 2013, important norovirus outbreaks occurred in 2 cities, affecting at least 40,000 persons. In 1 case, treated wastewater that was still contaminated was used for vegetable irrigation and entered the food chain, which led to questioning the efficacy of regulations.[79] In the other case, the origin of the outbreak was attributed to direct contamination of drinking water, showing failures of surveillance in basic parameters of fecal contamination.[80] Both cases affected cities in northern Chile where water is scarce, a situation that according to the scenarios of climate change will worsen, as discussed later.

Chilean water standards have been slow to change compared with international standards that have become stricter over time. Compared with the current WHO standards, Chilean regulation includes 23 fewer agents (especially pesticides); and among those that are included, the WHO reference value is between 0.5 and 20 times more stringent than the Chilean national standard.[81,82] It seems likely that Chilean standards have been slow to change as a result of several factors, including insufficient government attention to environmental problems, the opposition of private water companies, and a lack of public pressure.

Finally, as will be noted later, Chile is affected by natural climatic phenomena and, since 2009, by a persistent drought. Rivers, lakes, and reservoirs are depleted, a worrying preview of the drying trend expected with climate change. Yet, though scarcity

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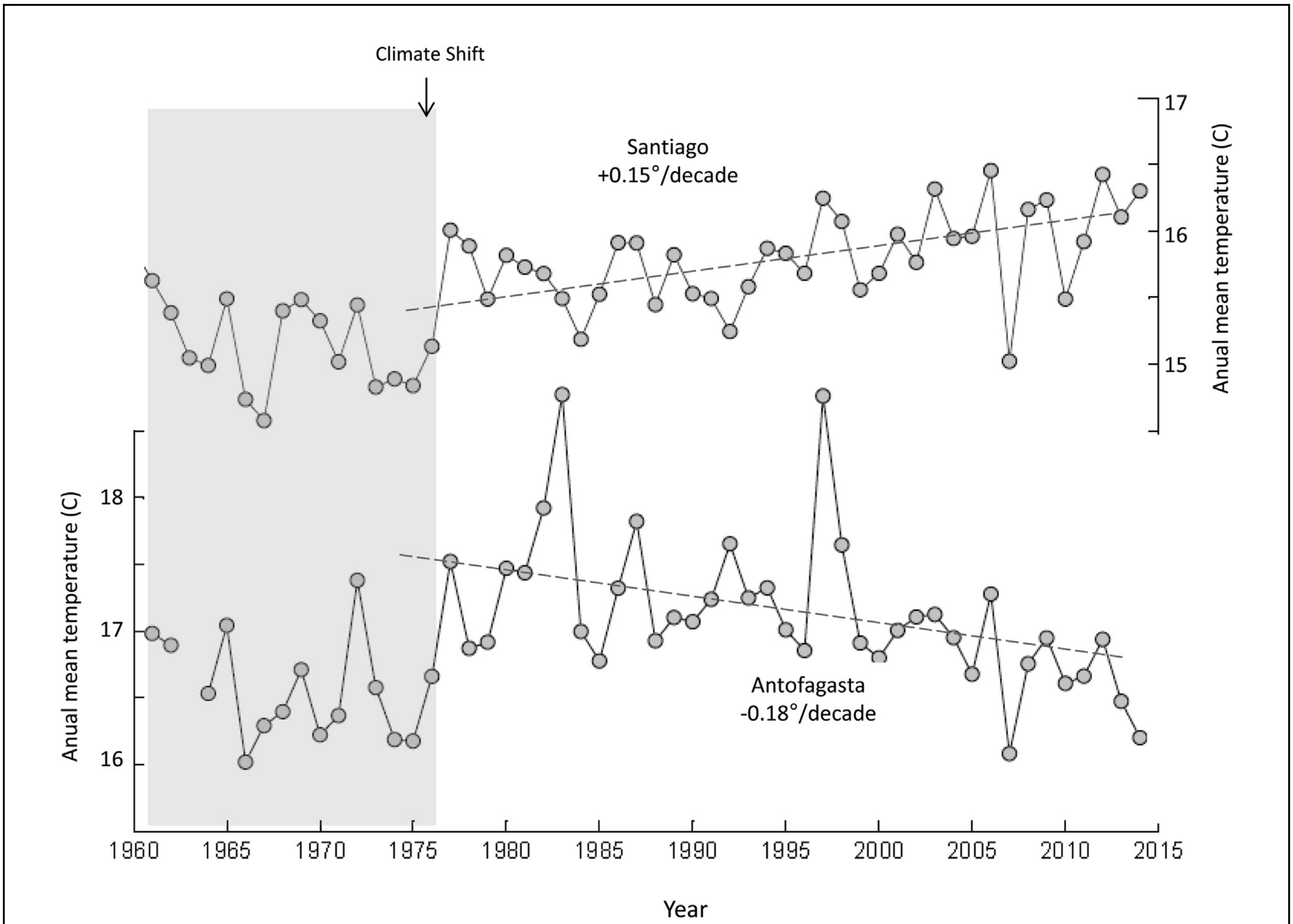

Figure 5. Time series of the annual mean temperature at Santiago (upper line) and Antofagasta (lower line) from 1960 to 2013.

may be a concern, experts have cited good water governance as a key for managing mitigation and adaptation under scientific uncertainties and have recommend policy changes to promote transparency, accountability, and coordination among pertinent institutions.[83,84] Among OECD countries, Chile appears as one of the least prepared for water shortages, with high fragmentation among regulatory agencies.[85]

CLIMATE CHANGE: PAST AND FUTURE

There are unambiguous indications of a planetary-scale climate change, as reflected in the warming of the troposphere and upper ocean, decreases in snow and ice coverage, the rise in sea levels,[86] and an overall global trend toward drying in dry regions and wetting in wet regions.[87,88] The magnitude and rate of these changes are unprecedented and largely attributed to the human-driven increase in the atmospheric concentration of greenhouse gases, as well as massive changes in land use.

Climate change is more complicated at a regional scale (eg, subtropical South America) than at the global scale because of more variability in year-to-year and decade-to-decade fluctuations of atmospheric and oceanographic conditions. A 2011 report from Chile to the United Nations Framework Convention on Climate Change provides a good background on climate change on Chile.[89] Here we seek to provide a summary and update of this information, as well as to discuss potential health effects of climate change in Chile.

In the case of central and northern Chile, there has been a warming trend of about +0.15°C per decade in the inland valleys and Andean foothills (eg, Santiago) observed over the last few decades, in sharp contrast with a cooling trend of similar magnitude along the coast and offshore (eg, Antofagasta) (Fig. 5).[90,91] Much weaker temperature trends are observed to the south of Santiago (<35°S). Superimposed on these trends one can observe the impact of El Niño Southern Oscillation (ENSO) on the temperature record: There is a coastal warming during El Niño years, whereas La Niña years feature an overall cooling.

Also prominent in Figure 5 is a climate shift that took place in the mid-1970s both at the coast and inland: The decade after the shift has a mean temperature ~0.5°C warmer than the previous mean temperature. It is thought that such climate shift has a natural origin and exhibits an ENSO-like structure.[92]

Precipitation records reveal a drying trend in south-central Chile (most pronounced between 37°S to 44°S) during the last 4 decades. No significant trends are detected in central Chile or farther north, where the impact of the ENSO cycle is particularly prominent.[93] As an example, the annual precipitation in Santiago (average 280 mm) varied from 710 mm in 1997 (El Niño year) to 90 mm in 1998 (La Niña year).

Projections for the climate during the rest of 21st century are based on numerical models of the coupled atmosphere-ocean systems, run at global scale (global circulations models) or regional scale (regional circulations models). In the current generation of model integrations performed in support of the Intergovernmental Panel on Climate Change Fifth Assessment Report, the so-called representative concentration pathways (RCPs) consider a wide range of options of population growth and socioeconomic development, each of them leading to distinct greenhouse gas concentrations in the future. Which RCP will actually occur is unknown, yet it has major consequences for the magnitude and timing of the climate change that will be felt in Chile. As an example, the global mean temperature is projected to increase between 0.5°C (under RCP 2.6) and 4.0°C (under RCP 8.5) toward the end of the century relative to current values.[86]

Along continental Chile, different global circulations models and regional circulations models produce projections differing in magnitude but not in direction.[86,94] Generally, the projected trends are similar to those observed in the last few decades. Considering a continuation of the heavy emission scenario sustained during the rest of century, there is an overall predicted warming in north-central Chile that is modest along the coast (+1°C above current values) but increases inland to reach a maximum over the Andes (up to +4°C) (Fig. 6A), as well as a drying trend in central-south Chile that can reduce annual precipitation to 70%–80% of the current values (ie, a rainfall deficit between 20%–30%; see Fig. 6B).

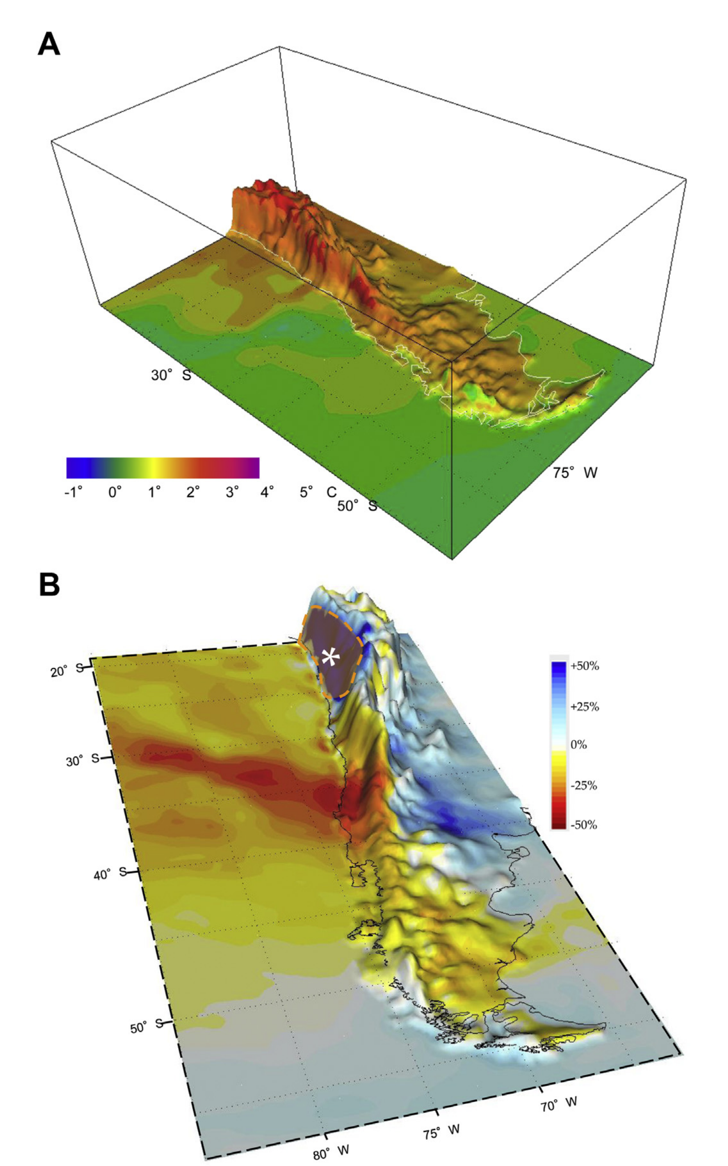

Figure 6. Projected climate change in Chile.[132] The Chile-Argentina border (dashed line) follows the crest of the Andes. (A) Difference in annual mean surface temperature (in °C) between the future (average 2070–2100) under the A2 emission scenario and the baseline period (1960–1990). Note the warming everywhere but most marked over the Andes cordillera. (B) Relative change in precipitation (expressed in %) between the future (average 2070–2100) under the A2 emission scenario and the baseline period (1960–1990). The change is calculated as the difference between the values in future and baseline period divided by the values in the baseline period. This ratio is misleading in northern Chile (signaled by the large asterisk) because the baseline precipitation is very low (Atacama Desert).

These projections suggest that some impacts on public health may be expected over the long term. This situation is exemplified by the drought that has afflicted central Chile since 2009, likely caused

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by a persistent La Niña–like condition in the central Pacific. Whether this drought continues for the next 5 years depends on the internal variability of the atmosphere–ocean system. Currently, there is little ability to predict this kind of interannual and interdecadal variability. Likewise, significant year-to-year fluctuations in temperature and precipitation will continue to characterize our climate in the near and far future. These ENSO-related anomalies can produce short-lived but intense climate extremes, with the potential to trigger vector-borne diseases and affect other health outcomes.

Although there is a large body of scientific literature on the effect of climate change on the incidence of vector-borne diseases, potential impacts in Chile have not been described.[95]

Chagas disease, transmitted by *Triatoma infestans*, affects 1.5% of rural population and is endemic north of the capital city.[96] Warmer climate has been associated with spread of the Chagas vector, including decreased mortality, increased fertility, higher proportion infected, and wider breadth of range.[97-108] In Chile, unexpected wild foci have been detected in uninhabited rural setting,[109,110] suggesting that this new nondomestic rural setting for *T infestans* may be related to warming ensuing after an ENSO episode. *Aedes aegypti*, the vector of dengue, was last reported in 1961 in continental Chile, but in 2000 new populations were detected in Chile's Easter Island,[111] followed by a severe outbreak in 2002. It reappeared in 2006 and intermittently up to now, giving rise to fear that it could reach the mainland.[112] Finally, the rodent-borne hantavirus disease has been endemic in Chile since 1995. Increased rainfalls result in increased plant productivity, which in turn gives rise to higher rodent populations, ultimately followed by increases in human cases.[113,114] This dynamic has been studied in relation to rains during El Niño.[115-118] More extreme precipitation events accompanying climate change may increase rodent populations and hantavirus cases.

Regarding the effects of climate change on air and water quality, some educated guesses can be made. In south-central Chile, wintertime air pollution episodes are mostly produced by particulate matter that is associated with cool, stable, and dry atmospheric conditions.[119] On the other hand, models consistently predict a warming-drying trend for this region. Given the already semi-arid climate of central Chile, the drying trend is likely the most important driver in this region, leading to an increase in wintertime air-pollution episodes in cities like Santiago because of the dramatic reduction of rainfall episodes that tend to clean the troposphere. The warming trend may be the more important driver in humid southern Chile, and the most probable outcome is a reduction of air pollution episodes in cities like Temuco, by reducing the number of very cold nights, when particulate matter is trapped in the lower troposphere. Summertime air pollution events are largely produced by increase in lower-tropospheric ozone, whose rate of production increases with air temperature. Thus, the projected warming trend is conducive to an increase in this type of episode.

The projected increase in air temperature will also modify the annual cycle of stream flow. Currently, the peak flow occurs around December in Andean valleys of central Chile, but less precipitation and warmer temperatures could lead to a more rapid snowmelt and earlier peak flow, thus causing an extended and more intense dry season.

There are some studies projecting the availability of surface water resources under climate change scenarios.[120,121] Given the projected reduction of precipitation (between 20% and 30% of the baseline values), the annual mean flow in rivers should also drop. The flow reduction is about 10% more acute than its precipitation counterpart, given the increased losses by evaporation in a warmer climate. Reductions in surface water flows would reduce the Chilean capability of hydropower generation, which has the potential to increase greenhouse gas emissions as a result increased reliance on thermal energy sources if renewable sources do not emerge as an effective alternative. The fate of Chilean aquifers has not yet been sufficiently investigated, but the drying trend in south-central Chile will eventually reduce groundwater levels. Furthermore, pressure on groundwater will likely intensify with reductions in surface flows, as evidenced by the current prolonged drought period.[122] Likewise, less precipitation and higher temperatures will result in shrinking glaciers, although a detailed, quantitative estimate of this reduction is not yet known.

Less water in the rivers will have a negative impact especially for agriculture, which currently uses 73% of the available water in Chile.[123] The impact would differ in the geographical regions. Decreased quality and quantity of crops may be expected in the north, affected by severe drought, hot temperature in the inland, and decreased availability of water.[89] Agricultural areas may be pushed to the south, changing the type of crops as seen lately in southern Araucania

(Chile's poorest region) and Los Lagos regions, where production of corn and potatoes increased as much as 200% as a result of a favorable balance of rainfall and maximum-minimum daily temperature range.[124] Other anticipated effects include rises of meat prices because of reduced viability of cattle production and migration of agricultural workers to southern areas or to the cities.[89] Possible adaptation strategies include genetically improved crops, more efficient use of irrigation systems, and sustainable management of groundwater.[89]

Research on health effects of climate change should incorporate the impact of extreme hydroclimatic events as that seen recently (March 2015) in the north, where an unexpected rainfall exceeded the 18 mm annual average, causing floods of water and mud, killing 30 people, and posing serious health risks to the survivors. The most affected are the poor in the north, an area where inequality is very high, who live in areas most likely to be affected by the risks of water scarcity and contamination and flooding.

Children are of special concern for possible health effects of climate change, because they are more vulnerable to these threats.[125] An area of future research should be the differential health impacts of climate change in Chile on children.

DISCUSSION

This overview of the current state of the environment and environmental health research in Chile illustrates the limitations of the "neoliberal" model of development in recent years (ie, free markets with little state intervention). There have been notable successes in terms of basic sanitation and availability of safe drinking water, but state control remains sporadic and private water companies may not regulate themselves sufficiently, as the recent outbreaks of norovirus suggest.[126]

The case of air pollution is another example where Chile has met with some success, but there are still persistently high pollutants in parts of the country. In spite of arduous efforts over 25 years to lower $PM_{2.5}$ levels, Chile has failed to reach national air pollution standards for $PM_{2.5}$ (20 $\mu g/m^3$) in the capital, and other cities are contaminated at even higher levels as a result of mobile sources, large fossil-fuel power plants, and primitive use of wood in homes of central-south Chile. These flaws are likely to be typical of environmental progress in many Latin American countries emerging from poverty: initial successes followed by stagnation.

The threat of climate change adds urgency. Because many of the same sources of greenhouse gases affect both climate change and air pollution, most experts believe that these issues should be addressed in a coordinated manner.[49,127] Climate change is also likely to result in water shortages in southern Chile, again requiring coordination with agencies regulating water, to address this problem.

In 2010, Chile joined the OECD, a group of high-income countries, and recently was officially classified as a high-income country by the World Bank. However, economic inequality is far higher than in other OECD countries.[125] In our view, Chile should take advantage of its new status to readjust its institutions regarding the environment in order for them to work in a transparent, coordinated, and cooperative manner.[85,127] Profound structural changes will be required in Chile to reach the higher environmental standards of OECD countries.[128]

Research on environmental health to date in Chile has been largely insufficient and has lacked a multidisciplinary approach. Lack of funds from the state, lack of or difficult access to private and even public data, and unreliable laboratory capabilities pose significant limitations to environmental health research. Chile has one of the leading economies in Latin America and a growing body of researchers in environmental health. With this strong foundation, the government and the research community of Chile can and should identify and implement necessary changes to move beyond the current somewhat stagnant environmental health situation. It is likely that other emerging economies in Latin America are or soon will be coming to a similar juncture. If Chile can find a way to move forward, perhaps it can be a model not only for economic progress but also for progress in environmental health.

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