V

Health Effects of Air Pollution in the U.S.-Mexican Border Region

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Abstract

Of the environmental problems researchers have addressed in the U.S.-Mexican border region, none appear more complicated than the problem of air quality. An understanding of atmospheric chemistry and long-distance (including cross-border) transport and an identification of source/receptor relationships are slowly unfolding in the hands of scientists and policymakers. Coupling air quality with the associated health effects transforms the problem from challenging to urgent.

The purpose of this chapter is to examine and link both criteria pollutants and hazardous air pollutants in the U.S.-Mexican border region with their associated health risks. While the chapter examines pollution sources throughout the border zone as defined by the La Paz Agreement, it focuses mostly on transboundary and boundary-related (i.e., ports of entry) pollutants. It is not intended to be an exhaustive study of either the border region's air quality or the health consequences of it, but rather to serve as a snapshot of selected pollutants from just a few locations along the border. It is intended to paint a picture showing that the air chemistry mixture in this region is a unique amalgam with contributions from both

countries, not a mere extension of either. This chapter is an overview of the type and magnitude of the health hazard and highlights insights gained from the decade-long examination of air quality and health effects along the border that has been supported by the Southwest Consortium for Environmental Research and Policy (SCERP).

Of the criteria pollutants identified by the Clean Air Act, ozone and particulate matter (PM) remain a serious threat to health in many parts of the U.S.-Mexican border region. This chapter uses the experience of San Diego, California, and Tijuana, Baja California, to illustrate the magnitude of health effects associated with ozone pollution. PM is addressed by examining research and conditions present in the Imperial-Mexicali Valley. This region has the second highest weighted annual mean concentration of PM_{10} in the United States. Between 1998 and 2000, Imperial County had the highest age-adjusted asthma hospital discharge rate in California.

This chapter also examines the problem of indoor air quality in the border region. SCERP research has identified the incidence of indoor carbon monoxide (CO) in Ciudad Juárez, Chihuahua. A comparison of this rate, as well as risk factors associated with CO poisoning, to rates and risk factors in the United States reveals an alarming problem in Ciudad Juárez.

Hazardous air pollutants (HAPs) are of concern to researchers because a growing body of evidence links them to health outcomes such as cancer and reproductive harm. Potential for exposure to HAPs is significant along the U.S.-Mexican border. This chapter specifically addresses the effects of polycyclic aromatic hydrocarbons, mercury, and tungsten. Each of these types of HAPs has different sources unique to the lifestyles and industrial activities that occur along the U.S.-Mexican border.

Efectos en la Salud de la Contaminación del Aire en la Región Fronteriza de México y los Estados Unidos

Shelley Scalzo

Resumen

De los problemas ambientales que los investigadores han tratado en la región fronteriza de México-Estados Unidos, ninguno parece ser más complicado que el problema de la calidad del aire. El entendimiento de la química atmosférica y del transporte a largas distancias (incluso el transfronterizo) y la identificación de las relaciones entre las fuentes y los receptores se desarrollan lentamente en las manos de los científicos y de los responsables de elaborar políticas. La calidad del aire aunada a los efectos asociados con la salud, convierte al problema de ser un reto a ser urgente.

Los objetivos de este capítulo son analizar y vincular tanto a los contaminantes criterio como a los contaminantes atmosféricos peligrosos en la región fronteriza de México y los Estados Unidos con sus correspondientes riesgos para la salud. Aunque el capítulo examina las fuentes de la contaminación en toda la zona fronteriza—como ésta se define en el Acuerdo de La Paz—se enfoca principalmente en los contaminantes transfronterizos o aquellos relacionados con la frontera (es decir, los puertos de entrada). Este apartado no pretende ser un estudio exhaustivo ya sea de la calidad del aire de la región fronteriza o de las consecuencias de ésta en la salud. Más bien pretende presentar una breve perspectiva de ciertos contaminantes de sólo unos pocos lugares a lo largo de la frontera. La intención es dibujar una imagen que muestre que la mezcla química atmosférica en esta región es una amalgama singular con aportaciones de ambos países, y no una simple extensión de cualquiera de los dos. Este capítulo es una sinopsis del tipo y

magnitud de los peligros para la salud. Resalta la perspicacia adquirida en una década de análisis de la calidad del aire y los efectos en la salud a lo largo de la frontera que ha contado con el apoyo del Consorcio de Investigación y Política Ambiental del Suroeste (CIPAS).

Entre los contaminantes criterio identificados por el La Ley de Aire Limpio, el ozono y el materia particulada siguen siendo una seria amenaza a la salud en numerosas partes de la región fronteriza de México-Estados Unidos. Este capítulo utiliza la experiencia de Tijuana, Baja California y San Diego, California para ilustrar la magnitud de los efectos en la salud asociados con la contaminación de ozono. El PM es abordado al examinar las investigaciones y condiciones presentes en el Valle Mexicali-Imperial. Esta región tiene la segunda más alta concentración media anual ponderada de PM_{10} en los Estados Unidos. Entre 1998 y 2000, el Condado de Imperial tuvo el índice más alto en California en cuanto a las dadas de altas en los hospitales de pacientes con asma de acorde a su edad.

Este apartado también examina el problema de la calidad del aire interior en la región fronteriza. Las investigaciones del CIPAS ha identificado la incidencia de monóxido de carbono en los interiores en Ciudad Juárez, Chihuahua. Una comparación de este índice, así como los factores de riesgo asociados con el envenenamiento de CO, con índices y factores de riesgo en los Estados Unidos revela un alarmante problema en Ciudad Juárez.

Los contaminantes peligrosos del aire (HAPs, por sus siglas en inglés) son de preocupación para los investigadores debido a la creciente evidencia que los relaciona con las consecuencias en la salud tales como el cáncer y el daño a la reproducción. El potencial de exposición a los HAPs es significativo a lo largo de la frontera de México-Estados Unidos. Este apartado aborda específicamente los efectos de hidrocarburos aromáticos policíclicos, mercurio y tungsteno. Cada uno de estos tipos de HAPs tiene fuentes diferentes y particulares a los estilos de vida y actividades industriales que ocurren a lo largo de la frontera de México y los Estados Unidos.

Introduction

In the past two decades, an increasing level of attention has been paid to the U.S.-Mexican border region after a long period of neglect. The movement toward globalization and free trade among nations has shifted the overall perception of the region. Once considered relatively barren and short on resources, the region is now viewed in an entirely different light. Sleepy towns have become bustling metropolitan areas with significant industrial sectors, and border crossings have become critical international economic links. Labor has emerged as the region's leading economic resource, supported by a predicted population growth rate of 23% over the next 10 years (Peach 2003). The unprecedented growth of the region has caused some of its limited natural resources to dwindle into despair and has caused an increase in the production of wastes and threatening emissions. Out of these dismal and undeniable side-effects of rapid growth, degradation of the environment has surfaced as a leading problem in the border region.

Attention drawn to the U.S.-Mexican border is overwhelmingly economic in nature. But the decline of the environment and the rise of related health complications have attracted the interest and efforts of a number of governmental agencies and non-governmental organizations (NGOs), which have targeted the U.S.-Mexican border region for research and assistance with the goal of improving the overall quality of life. In doing so, these organizations have encountered a host of environmental problems tightly wound to economic, political, social, and geographic factors unique to this region.

Of the environmental problems researchers have addressed in the U.S.-Mexican border region, none appear more complicated than the problem of air quality. An understanding of atmospheric chemistry and long-distance (including cross-border) transport and an identification of source/receptor relationships are slowly unfolding in the hands of scientists and policymakers. Coupling air quality with the associated health effects transforms the problem from challenging to urgent.

Researchers at the Southwest Consortium for Environmental Research and Policy (SCERP) have launched a series of studies focusing on air quality and associated health effects. These studies reinforce the complexity of air quality as well as the uniqueness of the U.S.-Mexican border region.

San Diego-Tijuana

Air Quality

Ozone is the leading air pollutant of concern in the part of the border region that includes San Diego, California, and Tijuana, Baja California. It is a secondary pollutant formed as sunlight breaks down nitrogen oxides (NO_x) and volatile organic compounds (VOCs, including hydrocarbons), a reaction that occurs readily in San Diego and Tijuana due to the prevalence of sunlight year-round. The major sources of NO_x and VOCs in this region are automobiles and heavy trucks. High densities of these vehicles are located north of San Diego in the South Coast Air Basin (the Los Angeles area). From that air basin, ozone precursors and ozone itself are transported off the coastline during Santa Ana wind conditions, when the normal on-shore wind flow shifts to off-shore. They then are pushed back on shore to the south in San Diego when prevailing on-shore conditions return (Sweedler, et al. 2003).

In 2004, monitoring stations at lower mountain slope areas in eastern San Diego County, such as in the city of Alpine, and coastal stations, such as those in Del Mar and at the Marine Corps' Camp Pendleton, recorded 12 days in which concentrations of ozone exceeded California's stringent standard for one-hour maximum concentration (>0.095 ppm) (San Diego Air Pollution Control District [SDAPCD] 2005). Ozone exceeded the federal one-hour standard (>0.125 ppm) for only one day in 2004 (SDAPCD 2005). In 1997, the U.S. Environmental Protection Agency (EPA) revised the federal one-hour ozone standard to an eight-hour ozone standard (>0.085 ppm), in which an average ozone concentration is calculated for eight hours. This change was needed to protect against longer exposure periods (EPA 1997). There were eight days in which ozone concentrations in San Diego exceeded the eight-hour standard. Monitoring of ozone peaks over the past 10 years shows an overall decrease in the number of days per year on which there are exceedances of state and federal standards; this is attributed to pollution control efforts (SDAPCD 2004).

In Tijuana, high densities of vehicles are located at border crossings and in industrial areas. Elevated NO_x levels occur in the morning and evening when commuter traffic is peaking. NO_x emitted in the morning is combined with VOCs, and together with energy from sunlight contribute to elevated ozone levels (Sweedler, et al. 2003).

Although San Diego remains a nonattainment area for ozone under both California and federal standards, the area has been moving successfully toward attainment despite growth in population and vehicle use. Control of vehicle emissions is the single most effective strategy in reducing ozone in the San Diego region. An example of an effective strategy is the Carl Moyer Air Quality Standards Attainment Program, which began in 1999. This program provides incentives for replacing engines in heavy-duty diesel trucks and other mobile sources. Although heavy-duty diesel engines account for less than 5% of engines used in mobile sources in California, they have been responsible for 40% of the state's NO_x emissions (California Environmental Protection Agency [CalEPA] 2004). In the first four years, the Carl Moyer Program had a total budget of approximately $114 million. The California Air Resources Board has estimated that heavy-duty engine projects supported by the Carl Moyer Program in the first four years removed 14 tons of NO_x per day at a cost of $3,000 per ton statewide (CalEPA 2004).

By removing the leading source of NO_x to the atmosphere through emission-control programs, San Diego has experienced a dramatic reduction in the number of days exceeding California's one-hour ozone standard. The number decreased from 96 days in 1995 to 12 days in 2004.

Across the border in Tijuana-Rosarito, air quality monitoring began in 1995 (EPA 2005). That monitoring program is relatively young compared to programs in California, which began in the late 1970s following the U.S. Clean Air Act. Monitoring of ozone in Tijuana-Rosarito from 1997 to 1998 showed a decline in the percentage of days exceeding the standard for ozone (EPA 2005). Although this trend points toward a positive development, a larger temporal view is required to assess changes in ozone concentration for the Tijuana region. It has been suggested that modernization of Tijuana's vehicle fleet through emission control equipment will strengthen the decline in ozone concentrations over the coming decades. Such changes will require the support of policy and government to absorb the cost of organizing and implementing effective air pollution controls.

Health

Elevated ozone concentrations are scientifically linked to medical conditions such as reduced respiratory function, eye irritation, and exacerbation of asthma. These conditions lead to mortality, hospital admissions, lost work and school days, and reduced activity days. The National Research Council (NRC) studied the financial impact of revising the one-hour ozone standard (0.12 ppm) to the more protective eight-hour standard (0.08 ppm). The council estimated the United States could save $491 million per year by avoiding cases of ozone-related mortality, hospital admissions, and treatment of acute respiratory conditions (NRC 2002).

Most of the data supporting the association between ozone exposure and asthma exacerbation are derived from clinical studies (Ostro 1994). Time-based studies may prove more valuable than clinical studies because they indicate adverse effects in specific locations, quantify short-term effects, identify pollutants, and support previously established associations between air pollution and health outcomes (National Research Council 2002). Epidemiological cohorts are recommended for the study of health effects of air pollution, specifically when mortality is the outcome of concern. Cohort studies "provide the most complete estimates of both attributable numbers of deaths and average reductions in life span attributable to air pollution" (NRC 2002).

In 2000, the Behavioral Risk Factor Surveillance System suggested the prevalence of asthma among adults in the United States was 7.5% (Centers for Disease Control and Prevention [CDC] 2004). Adults lost 11.8 million work days in 2002. In addition, some 14.7 million school days were missed by American children ages 15 to 17 (National Center for Health Statistics 2002). In

California alone it was recently estimated that 2,268,300 people suffer from asthma. The prevalence of asthma in California is 8.4%, placing the state among the 10 with the highest asthma prevalence (Henry J. Kaiser Family Foundation 2003). In California, 71.6% of the population lives in an area that does not meet EPA's National Ambient Air Quality Standards for all criteria pollutants, including ozone. California ranks second in the nation with respect to the percentage of people living in counties that exceed one or more National Ambient Air Quality Standard (Seitz 1995).

Despite the reduction in ozone concentrations in San Diego County, the number of hospital discharges for asthma has declined only slightly from 94.4 per 100,000 in 1997 to 83.4 per 100,000 in 2000 (San Diego Association of Governments 2000). This indicates other factors aside from ozone may be influencing the asthma hospitalization rates. Hospital discharge rates (HDR) can be used to derive a broad association between ozone concentration and health outcomes. When looking at the San Diego-Tijuana region, or any cities along the U.S.-Mexican border, it is challenging to distinguish the cause of a specific outcome because other regional factors such as other air pollutants, allergic reactions, smoking, and occupational exposures can induce a similar outcome. Using HDRs captures the number of people who suffered symptoms so severe hospitalization was required; they are perhaps the most vulnerable members of the population. But the HDR will capture only the number of people who seek medical attention at a hospital for ozone-related asthma and omit cases that were not treated by a hospital. It is common in border communities for residents to self-medicate, seek only primary care or emergency room physicians, or not seek medical attention at all, leading to an unquantifiable underestimation of asthma incidence.

A recent study published by the Journal of the American Medical Association (Bell, et al. 2004) revealed an alarming relationship between ozone and mortality. The study measured the short-term effects of ozone on daily death rates and deaths attributed to cardiovascular and respiratory complications. The population was drawn from 95 urban communities in the United States. The study found that mortality increased 0.52% when a 10 parts per billion (ppb) increase in the daily average occurred, 0.64% when a 15 ppb increase in the eight-hour maximum ozone concentration occurred, and 0.67% for a 20 ppb increase in the daily hourly maximum occurred. Researchers advise that these results underestimate the effect of ozone on mortality. In addition, the study did not address the effects of long term-exposure to ozone. The results of this study can be loosely applied to the border region. In applying these results, it is likely a greater underestimation would exist because of differences between the cities along the U.S.-Mexican border and other U.S. urban centers.

Imperial and Mexicali Valleys

Air Quality

The Imperial and Mexicali Valleys share similar topographic conditions. The valleys are situated in a closed basin below sea level (Sweedler, et al. 2003). Closed basins and low elevations are notorious for contributing to the formation of an inversion layer that prevents vertical mixing of pollutants. The effect of low-laying basins on atmospheric mixing was first observed in the Los Angeles area during the 1940s and contributed to the infamous London Smog in England in 1952.

In addition to the region's topographic conditions, seasonal and daily temperature patterns contribute to particulate matter (PM) events. The Imperial and Mexicali Valleys are known for long summers and short winters. Extended periods of dry weather cause the formation of dust from undeveloped lands. Atmospheric cooling in the winter months reduces vertical mixing and produces inversion conditions (Meuzelaar, et al. 2005).

The Imperial Valley has the second highest weighted annual mean concentration of PM_{10} (PM with an aerodynamic diameter of 10 microns or less) in the United States. In 2003, EPA reported the weighted annual mean concentration of PM_{10} in Imperial County as 75 micrograms per cubic meter ($\mu g/m^3$). The National Air Ambient Quality Standard for annual mean PM_{10} concentration is 50 $\mu g/m^3$ (EPA 2003).

Health

A SCERP study completed in 2004 showed a strong correlation between asthma, temperature, and PM_{10} in both the Mexicali and Imperial Valleys. The correlation was slightly lower in Imperial Valley. Similar results were achieved by correlating acute respiratory syndrome and pneumonia with temperature and PM_{10}. This same study noted that humidity and temperature were less important variables in analysis of respiratory illnesses in the Imperial and Mexicali Valleys. In 2000, the Imperial Valley had California's highest hospital discharge rate for asthma—approximately 20 cases per 10,000 in the population. CDC has established a target annual discharge rate of approximately 15 cases per 10,000 people. The majority of all other counties in California fall well below this target (California Department of Health Services 2003).

Daily PM_{10} events occurring during evening hours are observed in many suburban and rural communities (Meuzelaar, et al. 2005) where major sources of PM_{10} generally do not exist. It is hypothesized that the PM responsible for the events is transported from nearby metropolitan or industrial areas. Mechanisms of transport vary between locations. A second part of the 2004 SCERP study identified the effect of evening PM events on individuals. This study occurred outside Ciudad Juárez, which unlike Imperial-Mexicali Valley is prone to wind gusts. Despite these conditions, researchers were able to detect a significant relationship between the evening PM_{10} events and instantaneous physiological effects such as reduced lung function and increased heart rate.

Investigating the health risks of PM is complicated because the composition of PM and its associated health effects varies based on a number of local conditions. A pilot study completed by SCERP researchers in 2003 attempted to estimate exposure risks and health effects of PM in the Paso del Norte airshed. This study integrated a number of local factors, including the nature and origin of PM and wind patterns with spatial distribution of at-risk populations. A result of the study was a GIS-referenced database. This technology allows researchers to produce more advanced models to uncover trends and anomalies in regional transport, air chemistry, atmospheric deposition, and at-risk populations (Meuzelaar, et al. 2005).

There are a variety of PM sources in the Mexicali and Imperial Valleys. Often the source determines the diameter of the particle emitted. Particles with a diameter of 2.5 microns (µm) to 10 µm are largely produced by factory smoke, mineral dusts, agricultural practices, pesticide use, and dust from construction sites and unpaved streets. These larger particles mainly deposit into the upper respiratory tract, initially causing mild respiratory conditions that eventually lead to weakened immune systems and immune responses. Particles 2.5 µm and smaller ($PM_{2.5}$) can penetrate the lower respiratory tract and the deep lung. $PM_{2.5}$ is a concern because health outcomes associated with it include severe immediate conditions such as aggravation of asthma, cardiovascular disease, acute respiratory illness, and premature death. The smaller particles are produced by the combustion of fossil fuel and include aerosols (Collins, et al. 2001). In 1997, EPA added new standards to cover $PM_{2.5}$—an annual mean of 15 $\mu g/m^3$ and for a 24-hour average of 65 $\mu g/m^3$.

Aside from the diameter of PM_{10}, composition is an important indicator of health outcomes. In 1997, EPA identified geologic material as the major component of PM_{10} in U.S.-Mexican border valleys. An earlier study by Alvaro, et al., in 1991 analyzed PM_{10} from Mexicali and further characterized the geologic material as a mixture of 75% potassium aluminum silicates and 20% silica. Rats exposed to this dust developed a specific lung fibrosis condition similar to asbestos exposure (Collins, et al. 2001). Fine silica dust is associated with silicosis or "black lung disease" (Anderson, et al. 2001). Although cases of such conditions have not been identified or quantified, these studies allude to the severity of potential health conditions for Mexicali residents.

Health conditions related to PM in the Imperial Valley have been characterized to a greater extent than in Mexicali. Imperial Valley has lower annual average concentrations of PM_{10} (75 $\mu g/m^3$) than Mexicali (240 $\mu g/m^3$). Imperial County had the highest asthma hospitalization rate in California from 1983 to 1994. During that same period of time, childhood asthma hospitalizations in Imperial County increased by 54%. In the city of Calexico, the prevalence of doctor-diagnosed asthma in 6- to 7-year-olds was 15.1% and in 13-year-olds was 26.5% (Impact Assessment Inc. 2001). Imperial County had the highest age-adjusted asthma hospital discharge rate from 1998 to 2000—approximately 20 per 10,000 residents. This rate is two times greater than the state rate (10 per 10,000 residents) (California Department of Health Services 2003). Based on a positive association between PM_{10} and death rates in more than 20 U.S. cities studied for eight years by Samet, et al. (2000), it was estimated that reducing the daily mean PM_{10} concentration by 10 $\mu g/m^3$ would yield a 3.0% reduction in asthma attacks (Sadalla 2005).

Given the nature and prevalence of health outcomes related to PM, it follows that a financial burden exists for families and communities where PM concentrations are elevated. The National Research Council (2002) analyzed the new $PM_{2.5}$ standards and estimated they would reduce the amount of money spent nationally treating PM-related illness by $1.8 billion to $75.1 billion annually by preventing 3,300 to 15,600 fatal cases. Additional savings for preventing lost workdays, restricted activities, hospital admissions, and treatment of chronic respiratory diseases amounted to more than $1 billion (NRC 2002).

El Paso-Ciudad Juárez

Traditionally, air quality has been associated with the ambient environment. In the past few decades, an increasing number of episodes of illness and mortality related to air quality within buildings and homes, including in Ciudad Juárez, Chihuahua, has brought indoor air quality to the attention of researchers and policymakers. A study performed by CDC from 2001 to 2003, for example, estimated that 480 U.S. residents died per year and 15,000 were treated in hospitals as a result of non-fire-related CO poisoning (CDC 2005) in an indoor environment.

Carbon monoxide poisoning is an acute reaction to the inhalation of CO. Symptoms vary according to dose. A low dose of CO produces headache, nausea, dizziness, and shortness of breath. Such symptoms can easily be ignored or attributed to other causes. Occupational studies have shown that exposure to low levels of CO over extended periods of time can result in long-term effects such as heart disease and neurobehavioral effects (Raub, et al. 2000). Exposure to high concentrations (approximately 1,000 ppm or greater) of CO will cause death.

A number of studies performed in the United States have identified common risk factors for CO poisoning, and the leading risk factor for CO poisoning is cool, winter temperatures. During the CDC study, each December approximately 59 U.S. residents died from CO poisoning and 69 died in January. Over the course of the two-year study, 480 deaths were attributed to CO poisoning. A secondary risk factor identified for unintentional CO poisoning in California by Lui, et al., in 2000 is the use of a forced-air gas heater (Montoya 2003). Both these risk factors are important to the Ciudad Juárez region because extreme temperatures in the winter force families to run heaters throughout the night. Poor construction in the unplanned communities of Ciudad Juárez leaves these homes with inadequate ventilation to prevent concentration of CO (Corella-Barud 2001).

In Ciudad Juárez, elevated CO levels in the home affects approximately one-third of low-income households. For the past 12 years the number of CO poisoning cases in Ciudad Juárez was 1,381, or approximately 115 per year (Montoya 2003). Incidence of unintentional CO poisoning in Ciudad Juárez is approximately one-fifth of the incidence of CO poisoning in United States, while the population of Ciudad Juárez is 3/1,000 the population of the United States. If incidence in the United States is used as a comparative baseline, this indicates the incidence of CO poisoning disproportionately affects Ciudad Juárez.

It follows that the numerous cases of unintentional CO poisoning in Ciudad Juárez may indicate risk factors that differ greatly from those of the United States. One striking difference between the U.S. border cities and Ciudad Juárez is the gender of the at-risk population. In the United States, men are 2.3 times more likely to die from CO exposure (CDC 2005). The CDC study suggested men were more likely to operate generators or power tools in poorly ventilated areas such as a workshop or garage. A study performed by SCERP researchers in Ciudad Juárez identified women and children as the at-risk population for indoor CO poisoning because of their greater likelihood to spend time in the home and the greater incidence of poor ventilation in those homes. Sources of CO in the household were un-vented cooking and heating units (Corella-Barud 2001).

Air Toxics

In 1990, the U.S. Clean Air Act was amended to add 189 new chemical compounds to the list of regulated air pollutants. This diverse group of chemicals is known as Hazardous Air Pollutants (HAPs), and they range from hydrocarbons such as benzene to heavy metals and fibers such as asbestos. All HAPs have negative health effects, including cancer, immune system suppression, neurological harm, and reproductive harm. Some developmental and respiratory health problems are associated with exposure to HAPs.

In light of the risk factors that exist in border communities, the potential for human exposure to HAPs is great. The rapid industrial development that has occurred at the border over the past two decades has brought increasing point sources, such as power plants and factories, and mobile sources, such as diesel engines. Rapid population growth, of course, means more people are exposed to HAPs. Unhealthy living conditions also contribute to the generation of HAPs. One condition, for example, is the open burning that occurs when waste disposal services are insufficient.

In some cases, health effects of HAPs are intensified by the presence of PM. PM, specifically PM_{10}, acts as a vehicle for transporting HAPs to the lung, where it can access the target organs via the bloodstream. PM_{10} can assimilate chemical contaminants of diverse origins on their irregular surfaces or in their porous interior, according to Vogel, et al. (1995). One specific family of compounds, polycyclic aromatic hydrocarbons (PAHs), is known to exhibit this type of interaction. PAHs can exist in two forms, vapor phase (low molecular weight) and particle phase (high molecular weight). Although the phase of PAHs can be helpful in determining the source, either form has carcinogenic effects on human health (Bi, et al. 2003).

To characterize the extent of PAHs in PM, a SCERP study in 1995 sampled high-traffic and industrial areas in Nuevo Laredo, Tamaulipas. This study observed weekend peaks in PM_{10} and higher concentrations of particle phase PAHs in sampling sites near high-traffic areas. The study identified particle phase PAHs, which are more readily transported by PM_{10} and more likely to be inhaled by humans, thus causing irritation of the upper respiratory tract (Vogel, et al. 1995). The peaks in PAHs and PM_{10} were attributed to increased vehicle traffic during weekends. Overall concentrations of PAHs were lower in winter than summer, but the difference was not significant. PAH concentrations remained well below concentrations experienced in other urban communities such as London and Manchester, in Britain. Fortunately, the Nuevo Laredo region is prone to contaminant dispersion, largely due to winds originating from the Gulf of Mexico and adjacent plains. Carcinogenicity of PAHs was not addressed by this study, but identifying PAH distribution and concentration in PM_{10} yielded a framework for future investigations.

Future studies should be implemented in regions with high levels of commercial traffic, specifically areas where heavy trucks are left idling for extended periods of time, such as at border crossings. Exhaust from diesel engines is a primary source of PM_{10} and PAHs. Approximately 20,000 premature deaths per year in the United States are attributed to diesel exhaust (Barrett 2005). Studies identified by Lwebuga-Mukasa, et al. (2004) focused on the increased risk of asthma and respiratory illness associated with living near congested portions of the U.S.-Canadian border. In the cross-sectional study conducted by Lwebuga-Mukasa, et al. (2004), findings showed people living in proximity to the border ports of entry and main corridors have a greater risk for developing asthma and respiratory illness than residents of neighboring communities (Lwebuga-Mukasa, et al. 2004). An earlier study by Oyana and Lwebuga-Mukasa found that people living between 204 meters and 700 meters from pollution sources (such as a border crossing) comprised two-thirds of the asthmatic sufferers in the study region (Oyana and Lwebuga-Mukasa 2004).

Open burning of trash is another important source of PAHs in the U.S.-Mexican border region because this activity may regularly occur near homes, thus exposing the residential populations. Open burning is known to release significant amounts of PAHs, including compounds linked to endocrine disruption (Sidhu, et al. 2005). A growing body of evidence is strengthening the association between PAH exposure and fetal harm. A study published in March 2005 by Cancer Epidemiology Biomarkers and Prevention shows fetuses exposed to PAHs in utero may be 10-fold more susceptible to DNA damage (which increases the risk of cancer) than the mother (Perera, et al. 2005).

Heavy metals are included in the list of HAPs. Within the category of heavy metals, none has gained more notoriety in the past decade than mercury. A SCERP study in the Caballo Reservoir, located in south-central New Mexico, showed mercury deposition was occurring, but not at levels that threatened humans or wildlife (Caldwell, et al. 2000). Dry deposition (the process of particles falling directly from the atmosphere to the earth's surface) was responsible for 13% to 85% of the total depositional input to the Caballo Reservoir. Wet deposition (the process whereby compounds are stripped from the air by rain or moisture) is not likely to be a major mechanism of transport for mercury at the U.S.-Mexican border because the region receives relatively small amounts of rainfall. In the United States, mercury deposition is greatest in the Northeast (National Atmospheric Deposition Program 2003). A combination of rainfall and sources of mercury, such as coal-fired power plants, are present in the region. Similar sources are found in the Mexican border region (for example, Carbon I and II near Piedras Negras, Coahuila). Modeling mercury emissions and deposition in this region may yield a better understanding of potential human exposures. Mercury causes developmental and neurological effects in adults, children, and fetuses when consumed in the methyl-mercury form, which is found in fish and shellfish. Other forms of mercury can result in damage to the gastrointestinal tract, nervous system, and kidneys (EPA 2005).

Another heavy metal, tungsten, has come under scrutiny only recently. Tungsten was nominated for inclusion in the National Toxicology Program (NTP) in 2004 because of its ability to form fibrous whiskers, similar to asbestos or silica (NTP 2004). The city of Sierra Vista, Arizona, is located within the U.S.-Mexican border region and there are a number of tungsten mines within close proximity. In addition, the region has suffered from lack of rainfall over the past decade, theoretically allowing for tungsten particles to become airborne. Studies supported by the community have found elevated levels of tungsten in trees as well as in air samples. Twelve cases of leukemia have appeared among children in Sierra Vista since 1997, four times the expected number, given a population of 40,000, over the same period of time (McClain 2005). An investigation of typical environmental causes of leukemia was conducted by the Arizona Department of Health Services; it ruled out benzene, arsenic, and radiation as causes for the increased rate of cancer (Arizona Department of Health Services 2003). A number of abandoned mines and metal smelters exist throughout the U.S.-Mexican border region, and coupled with arid conditions, this makes for a grave potential for human exposure to HAPs.

Conclusion

On a regional level, the health effects of air pollution should be addressed by identifying the specific health impact that is most significant because of the combination of its intensity and the number of people affected. As well, implementing controls proven to reduce the output of pollutants scientifically linked to a particular health impact can also help address the health effects of air pollution. Although health outcomes range from simple eye and respiratory irritation to cancer, many of the controls for pollutants can target more than one pollutant and health outcome.

To date, asthma and respiratory ailments appear to be the leading health effect of air pollution in the region. Both ozone and PM have been scientifically identified as causes or triggers of asthma. Control of ozone and control of PM emissions can be conducted in parallel, as they share the common source of vehicle emissions. Controlling vehicle emissions will reduce ozone and PM levels, as has been seen in Los Angeles and San Diego. Such a control strategy would target not only ozone precursors but also pollutants such as PAHs, which can also be problematic when intensified in the presence of PM. This strategy has a trickle-down effect to less prevalent health outcomes, including cancer. One such specific control, which would require cooperation at the regional level, is the construction of a transborder freight rail expressway, similar to the Alameda Corridor in Los Angeles. The construction of the Alameda Corridor, a 20-

mile rail line that links the Ports of Long Beach and Los Angeles to a transcontinental freight network hub near downtown Los Angeles, is predicted to reduce traffic congestion on surface streets, reduce emissions from idling cars and trucks by 54%, and increase efficiency of the cargo distribution network to accommodate growing international trade in the two busy ports, according to the Alameda Corridor Transportation Authority.

On a local level, efforts to increase personal responsibility for health should be undertaken in communities. Without individuals understanding and respecting air pollution controls, the controls will not be effective because the will to comply will be diminished. In the border region, where enforcement is lacking, personal responsibility for health is a plausible alternative. Targeting air quality problems, such as open burning of trash and indoor air quality, by increasing awareness and offering alternatives to traditional methods can improve current conditions.

Local interventions should have a health education component so local community health service workers are able to identify symptoms of air pollution-related diseases accurately. This effort should be made in conjunction with increasing access to community health services. The overall effects would be a decrease in the underestimation of health outcomes attributed to air pollution.

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