THE SPATIAL AND ENVIRONMENTAL PREDICTORS OF ADULT MORTALITY IN THE NORTHERN MEXICO BORDER REGION

by

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DEDICATION

To my husband Thiago, who patiently and lovingly supported my work

To our baby on the way, my motivation to finish!

To my parents and brother, who never pushed, but somehow got me there anyways

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CHAPTER 1

Introduction

The Northern Border Region of Mexico has experienced rapid industrialization and urbanization in the past four decades. Between 1960 and 2005, the population of the Mexican Border States grew from 5.5 to 18.1 million people[1]. Much of this rapid growth stemmed from the creation and expansion of the maquiladora export industries (MEI's) under Mexico's Border Industrialization Program in 1965 and the North American Free Trade Agreement in 1994 (NAFTA).

While the MEI's have been a catalyst for economic growth in the region, serious concerns persist about the health impact of rapid industrialization and urbanization of the border [2-11]. The growth in this region, coined by Cypher as the "maquilization" of Northern Mexico, has placed a strain on the arid ecosystem and the urban infrastructure of the northwestern states [2-11]. Rapid in-migration and insufficient affordable housing have spurred the growth of squatter settlements or "poverty belts" around many border communities[12]. According to the Border 2012 Initiative of the U.S. Environmental Protection Agency: "rapid population growth in urban areas has resulted in unplanned development, greater demand for land and energy, increased traffic congestion, increased waste generation, over burden or unavailable waste treatment and disposal facilities, and

more frequent chemical emergencies. Water quality, air quality and other natural resources have been adversely impacted.[13]"

The accumulated deficit in urban infrastructure and environmental hazard management along the border exacerbates local inequalities and may well offset the health gains of economic development [14-21]. While the health status of the border has improved significantly with development in the past 50 years, in 2000, the Pan American Health Organization reported significantly higher rates of age-standardized mortality in Mexican Border Cities when compared to their sister communities in the United States [22].

The *Mexico: Maquila, Environmental Vulnerability and Health* project (Vulnerability Project) is an ongoing research project designed to assess the impact of export-based industrialization and rapid urbanization on population health in the Northern Mexican border region. As part of this project, this dissertation has focused on the capital of the state of Sonora, Hermosillo. Chapter 2 evaluates the reliability and validity of adult mortality statistics available from the Secretary of Health while Chapter 2 and 3 investigate the relationship between patterns of marginality, temperature and adult mortality in the border community of Hermosillo, Mexico.

Study Justification

This collaborative project has placed a strong emphasis on capacity building, with the goal of developing tools for use in research and policy in the border region of Mexico.

An essential component to monitoring the impact of the maquiladorization of the border is functional state mortality registries. Such registries allow for tracking of changes in the burden of diseases over space and time and can be used for both research and health policy and planning. To our knowledge, few studies have evaluated the quality of the mortality statistics from the Mexico Border States. In a previous stage of this project, Dr. Gerardo Alvarez completed a dissertation on the quality of the underlying cause of death coding data in the Epidemiologic and Mortality Statistic System (SEED) database for infant deaths in 2003 and 2004[23]. This dissertation focused on evaluating the reliability and validity of underlying cause of death statements in the same database for a sample of adult deaths in 2005. This aspect of the project speaks directly to several of the goals established for the betterment of the Mexican Health system created by the Mexican National System for Health Information (SINAIS) including: 1) bettering the quality of health information and 2) strengthening the Mexican Center for the Classification of Disease[1].

In Mexico, despite four decades of development under the MEIs, few studies have focused on the impact of the migration, population growth and urbanization associated with the industrialization on the health of the border communities. While studies, primarily in developed countries, have demonstrated an increased rate of adult mortality in environmentally and economically vulnerable populations, this work has yet to be translated to the unique urbanization process found in the Mexico Border. The goals of

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[1] Exact Wording: 1) Mejorar la Calidad de la Información en Salud and 2) Fortalecer el Centro Mexicano de Clasificación de Enfermedades

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the second and third phases of this project were to 1) document the spatial distribution of mortality in Hermosillo; 2) to assess whether this distribution is related, at an ecologic level, with level of socio-environmental vulnerability of the population and 3) to investigate if the hot desert summer temperatures are associated with increased mortality in vulnerable populations.

Specific Aims

i. To determine the reliability and validity of the underlying cause of death (COD) on death certificates and reported by the SEED system through comparison of this COD with a gold standard COD created through the abstraction of decedents medical records.

ii. To characterize the spatial distribution of all cause mortality and cause specific mortality for the years of 2004-2005 in adults over the age of 15 in Hermosillo.

iii. To characterize the spatial distribution of socio-environmental vulnerability (SEV), as measured by an index of marginality for the years of 2004-2005 at the census tract level in Hermosillo.

iv.To assess whether socio-environmental vulnerability, as measured by an index of marginality, is spatially associated with all-cause or cause-specific-adult mortality at the census tract level in Hermosillo.

v.To determine if daily temperature is associated with the daily count of mortality for the years of 1998-2005 in Hermosillo

Background and Significance

The following section will review 1) the maquiladora industry 2) adult mortality trends and the vital registry system in the border region 3) socioeconomic vulnerability and mortality and 4) the association between mortality and temperature.

The US-Mexico Border

The northern border of Mexico, which includes the states of Baja California, Chihuahua, Coahuila, Nuevo Leon, Sonora and Tamaulipas expanded rapidly in the past half a century. Between 1960 and 2005, the population of the border states grew from 5.5 to 18.1 million people [24]. Along with population growth, came rapid urbanization. Between 1980 and 1990, the population of the Nogales area at the US-Mexico border in the state of Sonora, shifted from 26% to 70% urban [25]. Much of this rapid growth stemmed from the creation and expansion of the maquiladora export industries (MEIs) in this region, under the Border Industrialization Program signed in 1965 and the North American Free Trade Agreement, signed in 1994. The MEIs currently employ 1.2

million people in 2,815 maquiladoras [26].

A maquiladora is a factory that assembles goods for export, ranging from apparel and electrical appliances to transport-equipment and pesticides, under a preferential tariff system[27][2]. The maquiladoras, and other similar enterprises around the world, are intended to create jobs, increase the skilled workforce (especially in areas with depressed economies), to attract foreign direct investment (FDI), and to foster backward linkages between local and foreign industry [28].

The MEIs have been successful in attracting foreign investment to the border region. Although growth of the industry was relative slow during its first decade after signing the BIP in 1965, it accelerated following the economic crisis of the 1980's. This economic downturn in the 1980's, along with another in the 1990's depressed the value of peso, lowered the labor cost for foreign companies and encouraged investment[29]. By 2001, the maquiladora industries provided approximately 1,350,000 jobs in Mexico, with 82 percent located in the border area. The MEI grew at an average annual rate of 8 percent between 1990-2001. In 2002, the economic slowdown in the United States was associated with a 10% loss in jobs, but in 2005 the annual rate of growth has returned to 4.6%.

This rapid growth in investment in the MEI spurred significant job creation and Mexican border municipalities are among Mexico's wealthiest in terms of per capita income and

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[2] Before NAFTA was signed in 1994, production inputs entered Mexico duty-free, and finished products are exported out of Mexico to the US under lowered tariffs (exports are taxed on the "value added" during assembly) With the implementation of NAFTA, tariffs have been incrementally eliminated, with a final tariff elimination in 2008, and strict restrictions on importing and exporting no longer apply

standard of living[30]. On average, per capita income in the border region is about 48% higher than the Mexican average. While average wages are higher, income inequality has increased in the border region in the past 20 years [31-33]. In the maquiladoras, wages for direct line workers are often below the poverty level and have remained stagnant, while the wages for engineers and technicians, who represent a minority of the labor force, are above the national average and have increased with inflation [34]. Nevertheless, alternative development indicators such as the Human Development Index (HDI), which includes inequality measures, also suggest that development in the border region is greater than the national average[35].

The strategic placement of the maquiladoras in the high altitude desert along the Mexico/US border allows for low cost transport of production inputs and outputs between the US and Mexico, while taking advantage of low-cost labor and lower environmental protections in Mexico[2]. While the proximity of this region to the United States is economically beneficial, it also highlights the economic, environmental and health disparities which exist between the two countries. In 1996, Gerber and Rey [36] estimated that the per-capita income of all United States border metropolitan areas averaged US$ 17,475. Although, 35% below the US national per-capita income, it is four times larger than the average per-capita income of the Mexican border states, estimated to be US $4,419. This economic asymmetry is also reflected in the level of investment in urban infrastructure. In 1995, for example, the per-capita expenditure of the city of San Diego was approximately US $1,060, while Tijuana, its twin city, spent approximately US $52 [37]. Unfortunately, the economic opportunities created by the export-led

industrialization model have contributed in only a limited way to strengthening local government's resources and planning capabilities, while they have aggravated many regional social and environmental problems.

Adult Mortality in Mexico and Sonora

Population health in Mexico and on the Border improved significantly in the past century. Life expectancy in Mexico increased from 57.5 years in 1960 to 75.2 years in 2004[38]. The infant mortality rate decreased from 130 to 13.5 per 1000 live births between 1930 and 2002. In the past 15 years, death from chronic diseases increased, while death from accidents, infectious diseases and perinatal causes decreased as percents of total mortality[39]. The leading cause of death for the past 15 years has been heart disease, which has increased from 12.5% to 16.4% of total deaths. In 2004, diabetes mellitus overtook malignant tumors as the second highest underlying cause of death, after increasing rapidly, from 6.1% to 13.1% of the total mortality in 15 years. Currently diabetes is responsible for 14% of the total number of deaths occurring in women and 9.1% in men. Diabetes, coronary heart disease and stroke comprise close to 30% of total deaths[40].

While adult mortality rates in Sonora match the general pattern at the national level, there are notable exceptions (Table 1). Ischemic heart disease, diabetes mellitus and cerebrovascular diseases are the three leading causes of death in Sonora and Mexico for both men and women, but Sonora has noticeably increased rates of mortality from ischemic heart disease for both genders compared to national statistics. Sonora also had

higher crude rates of cardio and cerebrovascular disease and diabetes mellitus than any other northwestern state (Baja California, Baja California Sur and Sinaloa) in 1995 [41].

Despite economic improvement and an influx of both goods and services across the border, the Mexican Border States have higher mortality rates in both chronic and infectious diseases when compared to the United States side of the border. In 1999, PAHO reported an age-standardized death rate of 672.5 deaths per 100,000 people for border cities in Mexico, compared to 470.5 in the sister cities on the US side of the border. In the border city of Nogales, the rate was the highest in the region with 797.6 deaths per 100,000[42]. The inequality is also demonstrated by cause-specific mortality. The top leading causes of death and the age and sex standardized rates for Nogales and the US sister city Santa Cruz are seen in Table 2. Nogales has increased mortality rates for the top five leading causes, with the exception of malignant tumors. There are significant differences in mortality rates, with a 50% increase in death from diseases of the heart, a six fold increase in mortality from diabetes mellitus and a three-fold increase in death from accidents and related adverse events[43].

The causes for the substantial increase in mortality from diseases of the heart and diabetes are not known. A portion of the increase may be due to differential diagnosis between the United States and Mexico. For example, given the knowledge of a "diabetes epidemic" in Mexico, there may be a potential for over-reporting diabetes as the underlying cause of death in Mexico. As discussed in the next section, the reliability of

the vital registry system is an essential component for research into the causes and distribution of mortality.

Reliability of the Vital Statistics

The analysis of the association between socioeconomic vulnerability and mortality depends on the quality of the mortality registry data in Hermosillo. The information provided by the collection of birth and death certificates is an essential tool for health research, policy and health program implementation and evaluation globally[44]. Currently, 192 countries report a vital registry system, 64 of which are considered complete. Mexico has a well-established vital registry system dating back to 1950, with the underlying cause of death available since 1955. According to a study by the WHO, the system has a high quality of data, when compared to 192 countries with registries globally, with 96% coverage of all deaths and 5% of deaths coded to ill-defined causes[44].

In order for the vital registry system to be of use for research and policy development, the registry must be validated and reliable source of data. Essential components of a vital registry system which determine its usefulness include completeness, coverage, timeliness of death reporting, and the accuracy and reliability of the coding of cause of death on the death certificate. Important considerations for meeting these requirements and achieving a valid and reliable data system include the use of trained personnel to fill out the death certificate, increasing the proportion of deaths occurring in medical

facilities and ensuring accurate coding of the underlying cause of death through the use of trained nosologists[44].

While little research has been done on the validity and reliability of the Sonora vital registry system, according to the Mexican secretary of health, in Sonora 99.7% of death certificates are completed by a physician, with 19.9% of these physicians having formal training in the completion of death certificates. Additionally, 58.7% of reported deaths occur in medical units. The records are generally complete depending on the variable of interest, less than 1% of the death certificates are missing age and 7% are missing the complete address of the deceased.

The coding of the appropriate underlying cause of death (uCOD) is essential for the use of such statistics in research or in policy. Mexico currently uses the international system for the classification of diseases and related health problems (ICD-10) as recommended by the World Health Organization. One of the key barriers to reliable mortality statistics is the use of ill-defined or obscure codes to indicate the uCOD[3][44, 45]. According to the Mexican Secretary of Health, in Sonora, 1.7% of deaths are ill-defined (R00-R99). The accuracy of coding varies by cause of death: 4.7% of tumors are ill-defined, while 0.6% of external causes are ill-defined. Another key barrier to the use of vital statistics for research is the tendency to code the mechanism of death instead of the underlying cause of death. For example, in Sonora, 7.7% of mortality due to cardiovascular disease is

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[3] Such codes include: deaths from injuries where intent is not determined (ICD-10 Y10-Y34 and Y872); cardiovascular disease categories lacking diagnostic meaning (ICD-10 I47.2, 49.0, 46, 50, 51.4-51.6, 51.9, 70.9); and cancer deaths coded to secondary or unspecified sites (ICD-10 C76, 80, 97)

44.   Mathers, C.D., et al., *Counting the dead and what they died from: an assessment of the global status of cause of death data.* Bulletin of the World Health Organization, 2005. **83**(3): p. 171-177.

coded as cardiac insufficiency, instead of the true underlying cause[46]. These errors can be a significant detriment to the use of statistics for research into cause-specific mortality.

There have been few published investigations into the reliability and validity of the health statistics in Sonora. In 2000, the SEED began to digitalize its death certificate information, creating a valuable source of epidemiologic data for research and policy. Using data from 2003 and 2004, Dr. Gerardo Alvarez, investigated the quality of the underlying cause of death coding in the SEED registry in Sonora for a sample of infant deaths [23]. This dissertation found that an overall agreement rate of 52% between the SEED uCOD and a gold standard uCOD derived from abstraction of the decedent's medical chart. Inaccuracies in coding were common for infectious and parasitic diseases (Kappa =0.35), while good agreement was found for diagnosis of congenital malformations, deformations, and chromosomal abnormalities (Kappa =0.77). Dr. Alvarez's work indicates a need for improvement in the coding of the underlying cause of death for accurate interpretation of the mortality statistics for research and policy. This study will repeat the methodology of Dr. Alvarez in a sample of adult deaths, to assess the quality of the underlying cause of death statistics available for research in Sonora.

Mortality, Socio-Environmental Vulnerability and the Border Region
The Vulnerability Project defines vulnerability as "the capacity of persons or groups to anticipate, cope with, resist, and recover from the impacts of environmental change [47]." Under this definition a neighborhood's vulnerability to a given hazard, or adverse health exposure, is both the existing level of the hazard and the population's resilience to this

hazard[4]. While traditionally used in research on the health impacts of environmental hazards, this concept can be transferred to research into socially defined health hazards such as changes in lifestyle and diet, or cultural beliefs associated with urbanization. For example, the vulnerability of a neighborhood to a health hazard, such as a change in diet and increase in sedentary lifestyle associated with urban living, is both the level of the hazard, the measure of diet and activity levels, and the population's resilience to this hazard, such access to healthy food choices, access to preventative care, social support networks or access to green spaces for exercise. From this perspective, vulnerability depends on the capacity of population to gain access to economic and societal resources, which in turn modify their specific resilience to hazard.

While a difficult concept to measure, Macintyre and colleagues suggest a multi-dimensional framework for the relationship between neighborhood and health that outlines specific aspects of vulnerability including 1) the physical features of the environment 2) the availability of healthy environments for exercise and play at home and at work 3) service provision and access 4) socio-cultural features of the community and 5) perception of the neighborhood by both residents, and external observers [48].

Socio-Environmentally Vulnerable Communities in Northern Mexico

The rapid in-migration and lack of urban infrastructure in the northwest of Mexico has spurred the growth of unplanned, socio-environmentally vulnerable communities, in the periphery of the large border cities. These communities lack necessary infrastructure,

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[4] Here, hazard is defined as a latent condition of potential damage to residents resulting from the spatial convergence of natural or manmade factors and vulnerable social groups. Resilience is defined as the ability of persons or groups to resist, cope and adapt to hazard.

such as electricity, water and trash collection and in some cases are exposed to greater range of environmental hazards [25, 49]. In her 1996 study of maquila workers in Nogales Mexico, Kopinak found that 24% lived without electricity, 40% without sewer and 36% lived in substandard housing (earthen floors or non-durable walls)[25]. In addition, the desert location and the dry, hot summer seasons exacerbate the poverty level-living conditions in the vulnerable communities. Dust from unpaved roads, heavy traffic and respiratory illness were cited as a major health issues by residents during interviews in Sonora, Mexico in the summer of 2004 (unpublished data, Vulnerability Project). Heat stroke is also an important health concern, with the combination of high temperatures over 50 degrees Celsius during the summer months, scarce water and housing of substandard building materials (unpublished data, Vulnerability Project).

Along with deficits in basic infrastructure, these communities are also more likely to be exposed to environmental hazards. Kopinak, Barajas and Sanchez [3, 4, 25, 50-53] have shown in Tijuana that such communities cluster around maquila establishments, as does the spatial distribution of environmental hazards. Industrialization and the associated increase in heavy traffic, without sufficient infrastructure to widen roads, build city bypasses and expand border crossings have been associated with poor air quality in the border communities exposing the border population to air contamination[13, 54]. A study by Blackman et al demonstrated that the border cities of Ciudad Juarez and El Paso exceed national ambient air quality standards for ozone, carbon monoxide, and particulate matter less than 10 microns in diameter (PM10)". In this study, while the large maquiladoras produced significant air pollution, the major source of particulate matter

came from smaller unregulated maquiladoras, and from local manufacturing, such as brick production[54]. These domestic production industries are often located in the marginalized communities. Nevertheless, published data from the Vulnerability project indicates that the relationship between socioeconomic status and proximity to industrial hazards on the border is complex. Using GIS, Lara and Colleagues found that in Nogales, the maquila industry was located in high-income neighborhoods, not low-income communities as demonstrated in previous literature. The authors hypothesize that the lack of basic infrastructure in low-income neighborhoods has forced maquiladoras to compete with high income neighborhoods for location in areas of the city with adequate infrastructure[55].

To date, in Mexico, there has been little formal investigation of the association between living in these vulnerable communities within the urban setting and the burden of mortality from chronic diseases. Infant mortality has traditionally been used as a sensitive indicator of economic development and health, but it is now clear that poor urban populations in many developing countries may carry a double burden of high rates of infant mortality and of adult mortality from chronic disease [56]. In a previous stage of this project, Dr. Gerardo Alvarez demonstrated that socio-environmentally vulnerable neighborhoods in Hermosillo had an increased rate of infant death[23]. This study posits that these communities also face an increased burden of adult mortality, focusing on cardiovascular and cerebrovascular disease and diabetes, when compared to more advantaged populations.

Marginality and Adult Mortality

While the theoretical framework for the relationship between neighborhood socio-environmental vulnerability and health is multi-faceted, the methodology for accurately measuring the neighborhood vulnerability is limited. The literature has widely used measures of socio-economic status, marginality or deprivation as a proxy for the broader concept of the socio-environmental vulnerability of a community.

The association between derived or aggregate measures of neighborhood marginality (deprivation or socioeconomic status) and adult mortality has been well-established in the literature at the individual and ecologic level in developed countries [51-53, 57-62] [63] [64]. In a review of multi-level analysis of the association between socioeconomic status and mortality, 8 of 10 studies showed a significant (RR<2), but modest positive association between neighborhood deprivation and mortality. All studies used aggregate income as a marker of deprivation, while some studies included education, employment, house tenure, car ownership and health insurance to create indices of deprivation. None of the studies reviewed were set in developing countries[63].

Economic deprivation has also been associated with mortality from cardiovascular disease at both the individual and ecologic level in developed countries [51-53, 57-62]. Borrell and colleagues, in the Atherosclerosis Risk in Communities Study in the US, found a modest increase in cardiovascular mortality (Hazard Ratio = 1.4 95% CI 1.0-2.0) for those living in poorest tertile census block group compared to the most advantaged tertile in white persons after adjusting for individual risk factors[57]. In a cohort of 5228

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persons in an industrial city in Canada, Finkelstein and colleagues (throughout) demonstrated an association between deprived census tracts and exposure to pollutants, both particulate matter generated by industry and proximity to major traffic routes; and associations between exposure to pollutants and death from cardiovascular disease and stroke and neighborhood deprivation levels [64].

While the majority of research on mortality and neighborhood deprivation has been done in developed countries, this research can be translated to developing countries, when sufficient data is available. An analysis using GIS in Rio de Janeiro, Brazil, identified significant concentration of poverty in parts of the city and a correlation between this regional clustering of deprivation and increased standardized mortality and infant mortality, and a decreased life expectancy[65].

Following this line of research, the Vulnerability Project has created an index of marginality to investigate the relationship between neighborhood vulnerability and infant mortality at the census tract level in Hermosillo, Mexico. Using Geographic Information Systems (GIS), Dr. Gerardo Alvarez and colleagues identified clusters of marginality and increased infant mortality in the Northwestern section of the city. The association between marginality and infant mortality rates at the census tract held when controlling for individual factors in multi-level analysis[23]. This study will use this same index of marginality to investigate the association between adult mortality and marginality in Hermosillo.

The desert ecosystem and the temperature and mortality relationship

Another aspect that determines the socio-environmental vulnerability of a population is the environment, and the resources a population has to counter any negative health effects of that environment. The Northern Mexico Border region is an arid desert ecosystem, with minimal precipitation and extreme high temperatures, ranging up to 115 F, during much of the year. While increasing temperature due to global warming and their possible effects on health are of international concern, there has been little research done outside of developed countries in similar climates[66]. Increasing temperatures are expected to have both direct impacts on health, including increased morbidity and mortality due to extreme heat.

Of particular concern are poor urban communities, such as the informal *invasions* in Northern Mexico discussed previously. These communities lack consistent access to electricity, water and transportation. The combination of extreme temperatures and lack of access to cooling/heating methods may adversely impact population health in these populations.

While current research on the effects of extreme hot and cold weather effects on mortality demonstrate a J or U shaped association between temperature and mortality, the relationship between temperature and mortality is modified by the temperature norms in a given geographic area. In normally hot climates, the association between heat and mortality has been found to be attenuated, and the cold effect stronger, when compared to colder climes [67-72]. The majority of studies in both hot and cold climes

demonstrate an increase in mortality with both extreme cold and heat, with the highest mortality rates seen during the cold season [67, 73-79].

This dissertation investigated, over an 8 year period, the association between maximum daily temperatures and mortality, including socio-demographic factors, in the capital of the northern Mexico border state of Sonora.

Overview of Study Methods

This study is set in the city of Hermosillo, in the state of Sonora in the Northwest corner of Mexico. Hermosillo is the capital of Sonora with a population of 662,924 in 2003[80]. This project has been reviewed and approved by the University of Michigan Institutional Review Board and will be reviewed by the Ethics Committee of El Colegio de Sonora in Hermosillo.

The primary data source used for all three components of this project was provided by the Epidemiologic and Mortality Statistic System (SEED) and included all deaths between 1998 and 2005 of residents of Hermosillo, from all causes. In Mexico vital statistics are collected on a standard death certificate. All death certificates are sent to the SEED, at the state department of health where a trained nosologist codes the underlying cause of death and digitally captures the information on all deaths including cause and date of death, age of decedent and address information. The SEED currently used the international system for the classification of diseases and related health problems10

(ICD-10). The database included information on the underlying cause of death (ICD-10 code), age at death; sex (male/female); personnel who certified the death (attending physician/other physician); medical insurance enrollment (yes/no); type of hospital facility (for people with no medical insurance/people with medical insurance); type of underlying cause of death; and time of death (07:00-14:30 hrs./14:31-21:30 hrs./21:31-06:59 hrs.) based on the usual employment shifts of each hospital. For 1998-2005, there were approximately 20,000 deaths in Hermosillo residents.

Analysis of Validity of the Underlying Cause of Death

The initial stage of the project was a cross-sectional study designed to assess the validity of in-hospital adult (age >=15) mortality statistics from the SEED system for 2005 in the capital of the state of Sonora, Hermosillo. A sample of death certificates was selected at random from residents of Hermosillo who died in the study years. To test the reliability of the underlying COD reported by the SEED, the original underlying uCOD, was compared to a gold standard uCOD based on the abstraction of the deceased patient's medical chart.

From the de-identified database provided by the SEED, a random sample was taken of all records to achieve a study sample size of 300 decedents. This list was matched by the SEED to the decedent's hospital medical chart for abstraction by trained physicians from the Secretary of Health.

The medical charts review was undertaken in the Secretary of Health hospital system, including the General Hospital (SSA) which provides care for patients who do not have social security and by the hospitals IMSS[5] which provide care for those with social security[81]. Of the total population of Hermosillo in 2006, the secretary of health projected that 69.4% would be covered by the social security[82], therefore a majority of our sample was from the social security system.

Based on the list of sampled decedents, two trained physicians from the Secretary of Health, blinded to original uCOD coding, reviewed and abstracted the causes of death from the medical record. The abstract was then coded for a new underlying cause of death by a trained and blinded coder.

The underlying cause of death established by a review and abstraction of the hospital medical record was considered the gold standard for analysis of validity [83]. The gold standard uCOD was compared to the SEED uCOD by calculating sensitivity and specificity and by positive and negative predictive values. Cohen's Kappa was also calculated to determine the level of agreement between the gold standard and the SEED COD, beyond that expected by chance.

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[5] SSA: Secretaría de Salud; IMSS-Solidaridad: Instituto Mexicano del Seguro Social Régimen de Solidaridad; IMSS:

The association between predictor variables such as the time of death, location of diagnosis, age and sex and the accuracy of the underlying cause of death was assess with logistic regression. [84]

Spatial Analysis of Marginality and Mortality

This cross-sectional ecologic study, utilized census data on marginality and adult mortality statistics from the vital registry, to evaluate the spatial association between marginality and all-cause and cause-specific adult mortality in Hermosillo at the census tract level. This study utilized the SEED mortality data for 2004 and 2005. Address data was geocoded to census tract. The denominator used to create mortality rates was the census tract population over the age of 15 created from the 2000 census.

Using Geographic Information Systems (GIS) software and smoothed standardized mortality ratios, we first mapped the distribution of mortality all cause death and from cardiovascular and cerebrovascular disease (ICD10- codes I00-199), Neoplasms (ICD- codes C00-99) and diabetes mellitus (ICD-10 E10-E14). Then we used GIS and spatial analysis techniques to identify potential clusters of increased mortality from these underlying causes of death and then linear regression models to analyze the association between these underlying causes of death and marginality at the ecologic level.

The Vulnerability project had previously compiled information from the 2000 census to create an index of marginality for Hermosillo[85]. Such indices increase statistical efficiency and avoid the problem of collinearity when including several correlated

variables in the same analysis[63]. The index uses five measures of education, income and housing quality to measure the "marginality index" of each census tract. The specific components used were (1) proportion of people aged more than 15 years with no more than elementary education (1-6 years of schooling); (2) proportion of employed people aged more than 15 years, who earned less than or equal to twice the Mexican minimum salary monthly ($\leq$ 268 US dollars); (3) proportion of overcrowded households (inhabited households with only one sleeping room); (4) proportion of households built with precarious materials; and (5) proportion of families with no car ownership.

Each census tract has been categorized, using the Dalenius and Hodges method, into five strata of social marginality: (1) Very high; (2) High; (3) Intermediate; (4) Low; (5) Very low. The scores ranged from -3.1514 to 6.6456: a higher score indicates a higher level of social marginality. Approximately 25% of the Hermosillo population is in the high or very high levels of marginalization [85].

This study utilized base maps delineating AGEBs for Hermosillo from the Instituto Nacional de Estadística, Geografía e Informática (INEGI), the Mexican equivalent of the US Census Bureau. Like the US census tract, AGEBs in Mexico are small, relatively permanent statistical subdivisions of a municipality delineated by INEGI based on technical criteria of distance, density and area homogeneity. For simplicity, we will therefore use the term "census tract" to refer to AGEBs throughout the dissertation. In Mexico, the spatial size of census tracts varies widely depending on the density of settlement. When first delineated, census tracts are designed to be homogeneous with

respect to population characteristics, economic status, and living conditions with the primary purpose of providing a stable set of geographic units for the presentation of decennial census data. As of the national census of 2000, Hermosillo had 254 census tracts [86].

The mortality data was geo-coded to census tract using the methodology previously set forth by the Vulnerability project. The street name and colonia were used to identify the tract of residency. All data points were geocoded to the street centroid within the area.

Once geocoded, the mortality data from the SEED, along with population count data from the 2000 and 2005 census, were used to create maps of both crude mortality rates, and smoothed mortality ratios for Hermosillo. To create crude mortality rates, counts of death in each census tract that occured over the 2004-2005 study period were divided by the total "at risk" population count in that census tract over the same period. At risk persons were considered to be the number of adults (=> 15) that resided in that census tract, based on the population counts of the 2000 census.

Along with crude mortality rates, we mapped standardized mortality ratios (SMRs) in order to adjust for the age and sex distribution of the census tract. An SMR is defined as the ratio of the observed count within a tract to the expected count based on the at risk background [87]. To create age-sex specific SMRs for each geographic area we used the method of indirect standardization described by Gotway and Waller (Equations 1) [88]. An SMR greater than 1 means that more cases were observed in that area than expected,

while and SMR less than 1 means that less cases were observed in that geographic area than expected based on the age and sex distribution of the area and the population rates of mortality from that disease. The SMR was used to generate an indirectly standardized rate for each geographic area.

Equations 1

$$r_j{}^{(s)} = y_j{}^{(s)}/n_j{}^{(s)} \text{ for } j = 1\ldots I \qquad\qquad (1.0)$$
$$E_j = r_j{}^{(s)} * n_j = y_j{}^{(s)}/n_j{}^{(s)} * n_j \qquad\qquad (1.1)$$
$$E_+ = \sum E_j \text{ for } j = 1\ldots I \qquad\qquad (1.2)$$
$$SMR = y_+/E_+ \qquad\qquad (1.3)$$
$$\text{Standardized rate } (r) = SMR(y_+{}^{(s)}/n_+{}^{(s)}) \qquad\qquad (1.4)$$

Indirect standardization, or the use of the standard population as the rate and the census tract age-sex structure as the weight, was chosen for this study because of the anticipated instability of the age and sex specific mortality rates at the census tract level. The use of this method for standardization and comparison of SMRs between geographic areas depends on an assumption of proportionality of the age-specific rates in a given geographic area to those in the standard population [88]. According to Waller and Gottoway [88], while not ensuring that this assumption is met, the use of the internal standard population (for example: the entire city of Hermosillo) is beneficial for meeting this assumption.

Smoothing of SMRs is recommended in geographic analysis when small population counts in some areas yield unstable rates, as was anticipated in this analysis. Smoothing uses information from surrounding geographic areas (locally weighted averages) or from the population as a whole (such as Bayes Smoothing) to stabilize the SMR at each small

geographic area and avoids the need to aggregate or exclude areas with a small at risk population. Assuming the data follows a Poisson distribution and following the methodology of Waller we used an empirical bayes estimator (ξ_i) to create smoothed SMRs for each geographic area based on the weighted counts in the surrounding areas. With a Bayesian approach, mortality rates are assumed to be governed by prior distributions and inference about the true value of the mortality rate is based on a posterior distribution which incorporates both likelihood and prior distributions [87].

The general equation for the empirical Bayes Estimator for census tract i is given in equation 2.1. For the analysis we used a local Bayes empirical estimator, which uses the equation 2.1, but is estimated using the SMRs of adjacent census tracts only. The estimates were calculated using GEODA.

Equations 2:

$$\xi_i = m_\xi + C_i \, (SMR_i - m_\xi) \qquad\qquad (2.1)$$

Where:
SMR= crude standardized mortality ratio
$$m_\xi = \sum SMR_i E_i / \sum E_i = \text{Weighted sample mean} \qquad (2.2)$$
$$C_i = (s^2 - m_\xi / n)) / [(s^2 - m_\xi)/(n + m_\xi)/n] \qquad (2.3)$$
if $s^2 \geq m_\xi / \sum (E_i/N$, otherwise $C_i = 0$

$$s^2 = \sum n_i (r_i - m_\xi)^2 / \sum n_i \qquad\qquad (2.3.b)$$
$$n = \sum (E_i/N) \qquad\qquad (2.3.c)$$

The next step of mapping and analyzing the distribution of mortality in Hermosillo was the identification of hotspots or clusters. This analysis tested the *constant risk*

hypothesis[6], that age and sex standardized disease rates are constant across census tracts, against the alternative hypothesis that spatial autocorrelation, or similarities in counts between geographically close regions and clustering of counts greater than the expected value exist within the cities[88]. This analysis was based on the assumption that the mortality data in Hermosillo represents counts arising from a heterogenous Poisson process and that population counts for each region are fixed and nonrandom.

Spatial autocorrelation was measured by the Moran's I statistic. Moran's I tests the similarity in incidence rates between two regions. If the pattern of mortality is regular among census tracts, then Moran's I will be less than one, if the pattern is nonregular, or clustered the statistic will take a value of greater than 1[88].

Clustering of census tracts with standardized mortality rates above the expected value was analyzed using local indicators of spatial association (LISA). LISA analysis categorizes the cross product of the mortality in a given census tract and the average mortality in adjacent census tracts into areas of 1) census tracts with high mortality surrounded by neighbors with high mortality 2) census tracts with low mortality and low mortality neighboring tracts 3) census tracts with low mortality and high mortality neighbors and 4) areas with high mortality and low mortality neighbors[89]. To

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[6] $E_i = \sum_j (r_j * n_{ij})$

Such that E_i (the expected count in the ith geographic area) is equal to the sum across all j age-sex categories of the constant rate (r_j) for the jth age-sex category times the population in the ith geographic area in the jth category.

investigate the association between marginality measured at the census tract level and all
and cause-specific mortality rates aggregated to the census tract level, this analysis used
linear regression models.

Analysis of the association between temperature and mortality in Hermosillo

The third chapter explores the relationship between temperature and mortality in
Hermosillo using an ecologic, cross-sectional study for the years of 1998 through 2005.
Generalized additive models and Poisson regression are used to illustrate the association
between daily maximum temperature and the count of deaths for both all cause mortality
and mortality by demographic subsets, including age, insurance status, sex, education and
cause of death.

This analysis utilized the previously described SEED mortality dataset and weather data
from the Hermosillo International airport, downloaded from Weatherbug.com. Data,
including average and maximum daily temperature, barometric pressure, precipitation
level and humidity is collected data from the Hermosillo International Airport and is
available freely to the public.

We used generalized additive models (GAMS) with a Poisson distribution to assess the
association between the predictor variable, maximum daily temperature and the daily
count of deaths, controlling for age, education, insurance status and cause of death.
GAMS contain both a linear and non-linear components [90]. The linear component is a
basic Poisson regression which gives the log relative risk of mortality based on the

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expected count in the population, while controlling for given predictor variables. The

model is given below where E[Y(i)] is the expected value of the Poisson variable Yi and,

X_1-X_p is a set of k predictors or explanatory variables, B_0 is the intercept and B_1-B_p is the

set of p regression coefficient parameters. The GAM generalizes this model by

calculating univariate smoothing functions (s_0-s_p) for predictor variables (Model 3.1). The

number of degrees of freedom for the smoother is determined by the user or the software

package.

Equations 3:

$$\ln \{ E [Y(i)]\} = \beta_0 + B_1X_1 (i) +....B_pX_p(i) \qquad (3.0)$$
$$\ln \{ E [Y(i)]\} = s_0+s_1(X_1)+ ... + s_p(X_p) \qquad (3.1)$$

Summary

In summary, this dissertation used diverse methodology to investigate the quality of

mortality statistics and the spatial and temporal distribution of mortality in an urban

center in Northern Mexico. Chapter 2 reviews the reliability the underlying cause of

death reported by the state vital registry system; Chapter 3 provides maps and spatial

clustering analysis of mortality and marginality at the census tract level in Hermosillo,

Mexico and Chapter 4 will present the data from an analysis of temperature and mortality

for Hermosillo. This dissertation provides a unique perspective on the population health

in a region of world heavily impacted by the global development strategy of export-led

development.

Table 1.1a-b: Age-Adjusted [a] Mortality Rates per 100,000 in Sonora and Mexico for Selected Categories of Principle Causes of Adult Mortality in Men (1a) and Women (1b) for 2003 - All Age Groups

Table 1.1a: Age-Adjusted [a] Mortality Rates per 100,000 in Men

	ICD-10	Sonora	National
Ischemic Heart Disease	I20-I25	158.4	91.3
Diabetes Mellitus	E10-E14	79.7	86.3
Cerebrovascular Diseases	I60-I69	45.6	41.4
Chronic liver diseases	K70,K73,K74,K76	37.5	57.9
Accidents		34.8	35.3
Lung Cancer	C33-C34	33.3	15.2
Obstructive Lung Disorder	J44	32.1	24.9
Traffic Accidents with Motor Vehicles		24.6	24.7
Prostate Cancer		18.2	15.9

Table 1.1b: Age-Adjusted [a] Mortality Rates per 100,000 in Women

	ICD-10	Sonora	National
Diabetes Mellitus	E10-E14	95.4	90.2
Ischemic Heart Disease	I20-I25	94.2	60.7
Cerebrovascular Diseases	I60-I69	37.9	38.0
Breast Cancer	C50	12.3	10.0
Obstructive Lung Disorder	J44	12.2	15.6
Cervical/uterine Cancer	C53	10.5	11.2
Other Accidents		10.5	11.3
Cirrosis and chronic liver diseases	K70,K73,K74,K76	9.3	16.7
Lung Cancer	C33-C34	7.9	5.9
Stomach Cancer	C16	7.8	6.5

[a] Rates are age-standardized using the WHO standard population

Table 1.2: Distribution of the Five Leading Causes of Death in Nogales with corresponding rate in Sister City Santa Cruz for 1990-1997- both sexes

	ICD-9	Nogales	Santa Cruz
Diseases of the Heart	390-429	152.5	101.3 [1*]
Malignant Tumors	140-208	82.9	90.1 [2]
Diabetes Mellitus	250	65.0	10.9
Accidents and Adverse Events	E800-E949	60.1	21.0 [4]
Cerebrovascular Disease	430-438	39.3	25.7 [3]

*Ranking for Santa Cruz

Rates are age-standardized using the WHO standard population * adapted from [43]

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CHAPTER 2

Reliability of the Mortality Statistics in Hermosillo, Sonora

Introduction

Information provided by birth and death certificates is an essential tool for health research and policy, and for health program implementation and evaluation globally[44, 91, 92]. In developing and transition economy countries, vital registry data is often the only viable health data available for tracking the longitudinal consequences of development on population health and making evidence based policy decisions to effectively address community health needs.

The *Mexico: Maquila, Environmental Vulnerability and Health Project* is an ongoing research effort designed to assess the impact of export-based industrialization and rapid urbanization on population health in the Northern Mexican border state of Sonora. This project included a goal of assessing the reliability of mortality statistics available from the vital registry of the state's Secretary of Health. The mortality statistics are an essential component of monitoring to assess the impact of development in northern Mexico and have been used to set national priorities for health care reform[93].

Mexico has a well-established vital registry system dating back to 1950, with the underlying cause of death available since 1955. In 2000, the state of Sonora's Secretary of Health began to digitalize its death certificate information, creating a valuable source of epidemiologic data for research and policy. When compared to the 192 countries with registries globally, the Mexico national data system is of high quality with 96% coverage of all deaths and just 5% of deaths coded to ill-defined causes[44].

Studies of the quality of the underlying cause of death statement are essential in supporting epidemiologic research and have been conducted in various settings globally[83, 94-112]. Information on the quality of adult death certification is limited for developing and transition economy countries[92]. Previously published studies in Latin America have focused on the reliability of specific underlying causes of death or have limited information across all disease categories[83, 105, 106, 110-114]. While annual assessments of vital registry data quality are published in Mexico at the national level [46], such data is scant at the state level for Sonora and does not include information on the reliability of the underlying cause of death statements. In 2003, Alvarez and colleagues investigated the quality of underlying cause of death coding in the vital registry for a sample of infant deaths [85]. That study indicated a need for improvement in the coding of the underlying cause of death to ensure accurate interpretation of the mortality patterns for research and policy.

This paper assesses the quality of the underlying cause of death statistics in Sonora, Mexico in a sample of adult deaths. This analysis directly addresses goals established for

the betterment of the Mexican Health system by the Mexican National System for Health Information (SINAIS) including: 1) bettering the quality of health information and 2) strengthening the Mexican Center for the Classification of Disease[7].

Methods

This cross-sectional study was designed to assess the reliability of in-hospital adult (age >=15) mortality statistics from the Epidemiologic and Mortality Statistic System (SEED) for 2005 in Hermosillo, the capital of Sonora (population 662,924). The SEED uses the international system for the classification of diseases and related health problems (ICD-10) as recommended by the World Health Organization. The study was reviewed and approved by the University of Michigan Institutional Review Board, the Ethics Committee of El Colegio de Sonora, the Sonoran Secretary of Health and the Ethics Committees of the hospitals where medical record abstraction took place.

In 2005, there were 2,586 deaths in adults over the age of 15 with residency in Hermosillo. Death certificate information was provided in a de-identified database from the SEED system that included information on the underlying cause of death (ICD-10 code), age at death; sex (male/female); neighborhood of residence; personnel who certified the death (attending physician/other physician); medical insurance enrollment (yes/no); type of hospital facility (for people with no medical insurance/people with medical insurance); type of underlying cause of death; and time of death (07:00-14:30

Exact Wording: 1) Mejorar la Calidad de la Información en Salud and 2) Fortalecer el Centro Mexicano de Clasificación de Enfermedades

hrs./14:31-21:30 hrs./21:31-06:59 hrs.) based on the usual employment shifts of each hospital.

A sample of 300 in-hospital, non-accidental deaths in the study years was selected at random from this SEED database. The study was limited to patients in the Secretary of Health hospital system, General Hospital (SSA) which provides care for patients who do not have social security and IMSS hospital[8] which provide care for those with social security[81]. In 2005, SSA and IMSS in-hospital deaths accounted for approximately 90% of total deaths in Hermosillo. Of the 300 deaths sampled, 111 (37%) occurred in SSA and 189 (63%) were in IMSS. Each decedent was assigned a unique study identifier by the SEED that was used to associate the case with the medical chart.

Two physicians, from the Secretary of Health, blinded to original underlying cause of death (COD) coding, used a standard form to review and abstract the causes of death from the medical record. Prior to the study, these physicians underwent training, in identifying the cause of death and filling out death certificates using the CDC's training manual [115]. One of the physicians is currently the physician trainer for death certification in Sonora. The standard form used for abstraction included: 1) a section for systematically reviewing the test results and physician notes in the patient medical chart and 2) a section identical to the cause of death section of the WHO approved death certificate used by the hospitals in Mexico.

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[8] SSA: Secretaría de Salud; IMSS:Instituto Mexicano del Seguro Social Régimen de Seguridad Social

After chart abstraction with Part I of the form, the physicians independently filled out Part II of the study "death certificate" for each decedent. To reach a final underlying cause of death the physicians compared their independent certifications and filled out a consensus death certificate to be used for nosologist coding. For the 29 charts where the two independent death certificates did not agree, the two physicians reviewed their medical chart abstractions, or the medical chart itself, and came to consensus. A third physician was consulted in one case. The nosologist was trained in ICD-10 coding and blinded to the underlying COD specified in the original death certificates. The final underlying COD assigned by the study physicians is subsequently referred to as the "reviewer underlying COD".

This study was designed to mimic the process by which the vital registry underlying cause of death is assigned in Sonora, using fully trained and experienced physicians and a single nosologist trained in the ICD-10 coding rules. The outcome of this process is the most accurate underlying COD that can be abstracted from hospital data, thus the reviewer underlying COD is used as the gold standard in this analysis.

Data Analysis

The original underlying COD was compared to the reviewer underlying COD at the ICD-10 Chapter level by calculating sensitivity, specificity, positive predictive values and negative predictive values. Cohen's Kappa was calculated to determine the level of

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agreement between the reviewer and the original COD, beyond that expected by chance. Agreement was analyzed at the level of ICD-10 chapters and at 2-digit ICD-10 codes.

A Kappa value greater than 0.75 was considered excellent agreement beyond chance; values from 0.61 to 0.74 were considered substantial; from 0.41 to 0.60 as moderate; and a value below 0.40 as poor agreement[116]. False-positive and false-negative percentages higher than 10% and 40%, respectively, were considered unacceptably high.

To evaluate the effect of errors in the coding of uCODs on mortality statistics, changes in cause specific mortality fractions were estimated. To understand the re-distribution of causes of death upon review, a misclassification matrix was created.

Logistic regression was used to assess the association between the accuracy of the underlying COD and the following hypothesized predictor variables: time of death, whether the person who filled out the death certificate was the treating physician, the hospital where death occurred, and age and sex of the deceased. [84]. For this analysis, underlying CODs were categorized into four broad categories: Neoplasms, Disease of the Circulatory System, Communicable Diseases and Other. Backward stepwise regression was used to determine the final model. All analysis was done in SAS 9.1.

Of the 300 deceased originally sampled, a chart was available for 258. Of these, the physicians determined that there was sufficient data in the medical chart to determine an

underlying cause of death in 250 (83%) of the deaths which constitute the final analytic sample.

Results

Table 1 shows the demographic characteristics of the full study population (300), the analysis population (250) and the missing data population (50). The mean age of the analytical sample was 66.2 years, 26.8% were from the hospital for the uninsured, and 88.8% were certified by the treating physician. The three leading causes of death as originally coded were Diseases of the Circulatory System (27.6%), Neoplasms (20.4%), and Diabetes Mellitus (10.8%). Deaths with incomplete or missing charts were more likely to have occurred at the SSA, be under the age of 65 and be certified by the treating physician (p <0.05).

When comparing at the broad level of ICD-10 chapter blocks, the reviewer's underlying COD matched the underlying COD reported by the vital registry in 173 cases (69.2%) (Table 2). The overall weighted kappa statistic was 0.62 (95%CI 0.52, 0.71). When comparing agreement down to the 2 digit ICD-10 classification, 126 cases (50.40%) were in agreement (results not shown).

At the chapter level, there was excellent agreement for neoplasms (Kappa=0.87 95%CI 0.79, 0.94), diseases of the nervous system (Kappa= 0.82 95%CI 0.61,1.00), ischemic heart disease (Kappa= 0.76 95%CI 0.64, 0.89), cerebrovascular disease (Kappa= 0.79

95%CI 0.62,0.95), and diseases of the digestive system (Kappa= 0.77 95%CI 0.62, 0.91). There was moderate agreement for infectious and parasitic diseases (Kappa= 0.60 95%CI 0.38, 0.81), and diseases of the genitourinary system (Kappa= 0.41 95%CI 0.08, 0.74). There was poor agreement for diabetes mellitus (Kappa= 0.35 95%CI 0.17, 0.53), hypertensive diseases (Kappa= 0.35 95%CI 0.04, 0.66), and acute upper and lower respiratory disease (Kappa= 0.21 95%CI 0.07, 0.48).

The false-positive rate was the highest for diseases of the circulatory system (10.4%) and the false-negative rate was the highest for infectious diseases (43.8%), endocrine and metabolic diseases (48.6%), and hypertensive diseases (57.1%).

The positive predictive value was highest for neoplasms (94.1%) and lowest for hypertensive disease (33.3%), acute upper and lower respiratory disease (22.2%) and disease of the genitourinary system (33.3%).

Sensitivity was the highest for neoplasms (85.1%), diseases of the nervous system (87.5%) and cerebrovascular diseases (85.2%) and lowest for diabetes mellitus (44.0%), hypertensive diseases (42.9%) and acute respiratory disease (25.0%). Specificity was lowest for diabetes mellitus (92.4%) and diseases of the circulatory system (89.6%).

The category of underlying COD was the only statistically significant predictor of agreement (Table 3). Compared to the all other disease categories, Neoplasms were over

12 times more likely (OR 12.5, 95%CI 3.7, 42.6) and Circulatory Disease were more than twice as likely (OR 2.2, 95%CI 1.2, 4.2) to be in agreement. Dying during the late afternoon shift, when compared to the day shift, was marginally associated with poor agreement in univariate analysis (OR 0.62, 95% CI 0.32, 1.21). Sex, age, hospital, and who certified the death did not predict agreement.

A cross-tabulation showing the misclassification of selected diseases can be found in Table 3. Of the diseases with low sensitivity, discrepancies in the underlying COD between the original and reviewer coding tended to involve common co-morbidities. Diabetes Mellitus was commonly misclassified by the original coder as diseases of the circulatory system, infectious diseases or diseases of the genitourinary system. Hypertensive disease was most commonly misclassified as diabetes mellitus or respiratory diseases. Respiratory diseases were misclassified as diabetes mellitus, neoplasms, and disease of the circulatory system.

The change in the cause-specific mortality fraction due to a particular category of disease in the study population was minimal (Table 2). While agreement was poor for a number of disease categories, the mutual misclassification of disease between these categories minimized the effect of poor agreement on the distribution of estimated disease at the population level. The largest changes in disease occurred in Diseases of the Respiratory (-2.4%), Neoplasms (+2%) and Ischemic Heart Disease (-1.6%).

Discussion

Vital registry systems are crucial sources of data on population disease burden[44, 91, 92]. This study is the only identified evaluation of quality of cause of death coding of adult mortality in the Sonoran vital registration system. The study used systematic review of the hospital medical chart to determine a "gold standard" underlying COD and compared this COD to the data reported by the vital registry system [117]. The electronic vital registry database, released annually, is the primary source of quality data on mortality in the northern Mexican Border region.

Overall agreement between the reviewer and original COD at the ICD-10 chapter block was 69.2% with a weighted Kappa of 0.62. This study focused on agreement at the level of ICD-10 chapter, because the majority of Mexican National Statistics are published and used for health policy priority setting at this level. When comparing agreement down to the 2-digit classification, agreement dropped to 50% between the reviewer and vital underlying CODS, a proportion was similar to that reported in a study of infant deaths in Hermosillo that found 52% agreement at the three digit ICD-10 level [85]. In contrast, a study of the accuracy of the underlying cause of death in adults in Brazil found a higher rate of overall agreement (83%) and Kappa (0.76) between the original and gold standard underlying COD when comparing at the three-digit ICD-10 level. In that Brazilian study, one-third of the original statements of death were based on autopsy results which may have increased accuracy of the original COD[106].

Many previous studies of reliability or accuracy of the underlying cause of death statements have limited their assessments to recoding of an existing death certificate and measuring agreement between the original and expert code [118]. While many of these studies show higher percentage agreements than we found in the Sonoran data, they follow similar trends, with high rates of agreement for neoplasms, and lower levels of agreement for hypertension related deaths[118].

Agreement between the underlying COD reported by the vital registry system and the underlying COD determined by trained physician reviewers varied broadly across ICD-10 chapters. Excellent agreement and sensitivity was found for neoplasms, diseases of the nervous system, cerebrovascular disease and ischemic heart disease. Poor agreement was found for diabetes mellitus, hypertensive disease and acute upper and lower respiratory disease. A recent study of urban vital registry statistics in China also reported high sensitivities for cancers and low sensitivity for diabetes mellitus and hypertensive diseases[98]. In contrast to our findings, in two large community cohorts studies, Lloyd-Jones and colleagues and Coady and colleagues found overestimation of coronary heart disease as the underlying cause of death[94, 100], while Lu and colleagues in a study in Taiwan and Brown et al in a study in Mexico/US border of the United States observed a low rate of agreement for cerebral infarction [118, 119].

The net change in mortality fraction after physician review was minimal across all chapters as there was mutual misclassification among common co-morbidities. This "compensatory effect of errors" has been documented in other death certificate studies

[118, 120], but contrasts with previously studies that consistently reported over-estimation for specific categories of disease, such as coronary heart disease[94, 100].

Misclassification between common co-morbidities, such as diabetes mellitus and circulatory disease was common. Identifying the principal cause of death among one or more competing causes or co-morbidities has been identified as a barrier to accurate death certification[101, 121]. In a study by Mackenbach et al, competing causes were most often present for respiratory disease and cardiovascular disease, two categories with low agreement in our study [103]. Much of this misclassification, with particular reference to Diabetes Mellitus, has been attributed to coder preference for particular ICD rules which are used to determine the underlying cause of death code [118, 122]. Investigations of specific categories of disease, that have common co-morbidities or competing causes of death, should consider multiple cause of death analysis, which uses both the underlying and contributing causes of death as recorded on the death certificate[123]. Such analyses can have profound effects on policy makers' understanding of cause-specific mortality burden in a population. Brown et al. found that using multiple causes of death to identify "stroke-related" deaths increased population stroke mortality estimates by 100%[119].

A review by Johansson and colleagues demonstrated that a common fallacy in cause of death studies is the lack of reproducibility of the research methods, including the failure to use a standard form for medical chart review[117]. In order to increase potential reproducibility, this study mimicked the process by which the official COD is assigned

by the Sonoran Vital Registry. By utilizing a systematic approach to medical chart review including a standardized abstraction form, our study demonstrated good overall agreement on underlying COD (88%) between independent physician reviewers. This level of agreement is higher than previous studies [119, 124].

Determinants of Agreement

In this sample, 88.8% of the death certificates for in-hospital, non-accidental deaths were filled out by the treating physician and 100% of the deaths had complete demographic information including age, sex, time and place of death. Being completed by a trained, treating physician has been shown to be an important determinant of death certificate quality[44].

Our study found a marginal association between dying during the late afternoon shift and reduced agreement (OR 0.62, 95% CI 0.32, 1.210) when compared to the day shift. Similar findings were reported in an analysis of 2003 infant data from Sonora[85].   As hypothesized in this previous paper, it is likely that less experienced physicians and/or students are working the later shift and therefore certification may be less accurate.

Seventeen per cent of the medical charts could not be located. The major factors related to having a missing or incomplete chart were dying at the hospital for the uninsured and being less than 65 years old. Uninsured and younger patients may be less likely to have sought care previously and are more likely to present with acute, late-phase illness.

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Specialization of the hospital has previously been shown to be a determinant of death certification quality[103].

The accuracy of death certification for out-of-hospital or external causes of death cases is likely to be lower than for in-hospital deaths. Hospital medical chart data are not appropriate for studying many out-of-hospital deaths and were therefore, these deaths were not considered in this study. Johansson et al reported that incompatibility between hospital discharge data and mortality statistics increases with greater time elapsed since last hospitalization, therefore limiting the utility of medical chart review to in-hospital deaths or deaths with a history of recent hospitalization[125].

Although the autopsy is the gold-standard for determining the underlying cause of death[126, 127], in Mexico, autopsy is not a common practice[84]. Currently, the medical record is the best source of data available for cause of death studies in Hermosillo. In our study, 83% of the hospital medical charts had sufficient data to identify a confirmed or probable underlying cause of death.

This study covered all causes of death, thus we were unable to adequately address the validity of the medical chart information used to determine the gold standard underlying COD or to create case definitions for all possible causes of death. Validation studies of the underlying cause of death are often limited to specific causes of death and use a panel of specialists to determine the underlying COD [83, 94, 100, 105, 111]. Limiting the scope of death certificate review in this manner has advantages when attempting to

address both validity and reliability of the underlying COD data, including the ability to use specialists to review the medical chart data and the ability to base validity estimates on a definitive case criteria for confirmed and probable cases. Future analysis of underlying CODs for specific disease groups reported within the vital registry system in Sonora should consider the use of specialists on the review panel and other methodologies, such as certifying physician interview, to further assess the validity of COD classification.

Conclusions

While the vital records system in Hermosillo is currently functional and provides complete mortality data, some important inaccuracies in the coding of the underlying cause of death statements exist. Suggested improvements to the system include physician training, querying of ill-defined causes of death, installation of an automated classification program and strengthening of the research capacity in the region to effectively use analyze and distribute data from the vital registry system.

According to the Mexican Secretary of Health while 99.7% of death certificates are completed by a physician, only 19.9% of these physicians have formal training in the completion of death certificates. Incorrect completion of the death certificate is still a major barrier to accurate mortality statistics[104]. An emphasis on death certificate training and raised awareness of the importance of vital statistics among current

physicians and medical students would improve the accuracy of underlying COD coding [101, 128-131].

Establishing a panel of physicians and nosologists to review and query certifying physicians on questionable death certificates has been shown to improve the quality of death certificates[102]. Misclassification may be reduced by implementing an automated classification program, such as ACME, which has been shown to reduce errors and improve accuracy of underlying COD classification[132].

One of the primary goals of the collaborative *Mexico: Maquila, Environmental Vulnerability and Health Project* is to build epidemiologic research capacity in the Northern Mexico Border region.   The ability to regularly analyze and disseminate data from the vital registry, on both quality and prevalence, will be crucial for increasing physician and government officials awareness of the importance of a complete and accurate vital registry system, which is essential for improvements in the system [91]. Mortality statistics are one of the few digitalized, systematically collected health databases available to researchers tracking the health of populations in the Northern Mexico border. Quality vital registry systems are an essential component for evidence based health policy decisions, which foster sustainable development. This research shows that, while caution is recommended for use of vital registry statistics in Sonora for individual level analysis or for analysis by specific diseases (ICD-10 2 and 3 digit codes), the ICD-10 chapter level underlying cause of death codes can be used for estimates of disease burden in the population.

Table 2.1: Demographic Characteristics of the Sample of Deaths in Residents of Hermosillo in 2005

	Full Sample		Analysis Sample		Missing Sample	
	Deaths	*Percent of Total*	*Deaths*	*Percent of Total*	*Deaths*	*Percent of Total*
Overall	300	100.00	250	83.00	50	17.00
Sex						
Male	187	62.30	152	60.80	35	70.00
Female	113	37.70	98	39.20	15	30.00
Age						
Mean	65.51	NA	66.21	NA	62	NA
Range	19-97	NA	19-97	NA	32-91	NA
<65	124	41.30	97	38.80	27**	54.00
65+	176	58.70	153	61.20	23	46.00
Hospital						
IMSS	189	63.00	183	73.20	6**	12.00
SSA	111	37.00	67	26.80	44	88.00
Broad Underlying COD Categories						
Communicable	15	5.00	14	5.60	1	2.00
Circulatory	86	28.70	69	27.60	17	34.00
Neoplasm	62	20.70	51	20.40	11	22.00
Other	137	45.70	116	46.40	21	42.00
Time of Death						
7:00-14:30	99	33.00	73	29.20	16	32.00
14:31-21:30	94	31.30	75	30.00	18	36.00
21:31-6:59	107	35.70	102	40.80	16	32.00
Certifier						
Treating Physician	271	90.30	222	88.80	49**	98.00
Other	29	9.70	28	11.20	1	2.00

** Chi-square p value <0.05 for difference between analysis and missing sample

Table 2.2: Agreement between the original and reviewer underlying COD for selected ICD-10 Chapters in a sample of deaths from residents of Hermosillo from 2005

Title	Vital Statistics	Reassigned to other Causes	Reassigned from other Causes	Reviewer	Positive Predictive Value	False Positive Pr	False Negative Pr	Sensitivity	Specificity	Kappa	Kappa 95% CI		Change in Cause Specific Mortality Fraction (%)
Infectious and parasitic diseases	14	4	7	17	71.43	1.72	41.18	58.85	98.28	0.62	0.42	0.83	-1.20
Neoplasms	52	3	8	57	94.23	5.77	14.04	85.96	98.45	0.87	0.80	0.95	-2.00
Endocrine, nutritional and metabolic diseases	40	19	17	38	52.50	8.96	44.74	55.26	91.04	0.45	0.30	0.60	0.80
Diabetes Mellitus	30	18	14	26	40.00	8.04	53.86	46.15	91.96	0.36	0.02	0.53	1.60
Mental and behavioral disorders	1	1	1	1	0.00	0.43	100.00	0.00	99.57	0.00	-0.01	0.00	0.00
Diseases of the nervous system	9	2	1	8	77.78	0.88	12.50	87.50	99.17	0.82	0.62	1.00	0.40
Diseases of the circulatory system	69	18	17	68	73.91	9.89	25.00	75.00	90.11	0.65	0.54	0.75	0.40
Hypertensive Diseases	10	7	5	8	30.00	2.89	62.50	37.50	97.11	0.31	0.02	0.60	0.80
Ischemic Heart Disease	33	9	4	28	72.73	4.05	14.29	85.71	95.95	0.76	0.63	0.88	2.00
Cerebrovascular Disease	16	3	4	17	81.25	1.29	23.53	76.47	98.71	0.77	0.61	0.94	-0.40
Diseases of the respiratory system	31	16	10	25	48.39	7.11	40.00	60.00	92.89	0.48	0.31	0.65	2.40
Acute Upper and Lower Respiratory	9	7	6	8	22.22	3.08	75.00	25.00	96.92	0.21	-0.07	0.48	0.40
Chronic Lower Respiratory	16	7	4	13	56.25	2.95	30.77	69.23	97.05	0.60	0.38	0.78	1.20

Table 2.3: Factors effecting agreement between the original and reviewer underlying COD

Factor	OR	95% CI	
Sex			
Male	1.25	0.72	2.15
Female	Ref		
Age			
65+	1.01	0.58	1.75
<65	Ref		
Hospital			
IMSS	1.25	0.69	2.27
SSA	Ref		
Underlying COD Category			
Communicable	1.41	0.45	4.47
Circulatory	2.22	1.16	4.26
Neoplasm	12.55	3.70	42.63
Other	Ref		
Time of Death			
14:31-21:30	0.62	0.32	1.21
21:31-6:59	1.01	0.52	1.97
7:00-14:30	Ref		
Certifier			
Treating Physician	1.38	0.56	3.40
Other	Ref		

Table 2.4: Misclassification Matrix between the original and reviewer underlying cause of death

Reviewer uCOD	Original uCOD											
	Certain infectious and parasitic diseases	Neoplasms and Diseases of the blood and blood-forming organs	Diabetes Mellitus	Diseases of the nervous system	Hypertensive Diseases	Cerebro-vascular Disease	Ischemic Heart Disease	Diseases of the respiratory system	Diseases of the digestive system	Diseases of the genitourinary system	All Other Diseases	Total Deaths on Original
Certain infectious and parasitic diseases	**10**		2				1	1	1		2	17
Neoplasms and Diseases of the blood and blood-forming organs		**49**	1				3	2		1	0	56
Diabetes Mellitus	1	1	**12**	1	3			3	2	2	1	26
Diseases of the nervous system				**7**						1	0	8
Hypertensive Diseases			1		**3**			1		3	0	8
Cerebrovascular disease			1			**13**	1	1			2	18
Ischemic Heart Disease			2				**24**	1			1	28
Diseases of the respiratory system	1	1	2		2	2	1	**15**	1		0	25
Diseases of the digestive system	1						1		**19**		2	23
Diseases of the genitourinary system			2							**3**	0	5
All Other Diseases	1	1	7	1	2	1	2	7	1	0	**13**	36
Total Deaths By Reviewer	14	52	30	9	10	16	33	31	24	10	21	**250**

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CHAPTER 3

The Spatial Distribution of Adult Mortality and Marginality Hermosillo, Mexico:
2004-2005

Introduction

While a wealth of literature exists on the association between socioeconomic status and mortality at the small area level [52, 53, 58-62, 133-137] , few studies have focused on this association in rapidly expanding transition economies, such as Northern Mexico. The population of the northern border of Mexico increased rapidly over the past half a century, stemming from the creation and expansion of the maquiladora export industries (MEIs) and cross border migration[24, 26]. Population growth led to rapid urbanization, with the percent urban population tripling in some areas[25]. The rapid in-migration and lack of urban infrastructure in northwest Mexico spurred the growth of unplanned, marginalized communities, in the periphery of the large border cities. Due to their informal creation and growth, many of these communities lack necessary infrastructure, such as electricity, water and trash collection and in some cases are exposed to greater range of environmental hazards [25, 49].

The association between derived or aggregate measures of neighborhood marginality and adult mortality is well-established at the individual and ecologic level in developed countries[52, 53, 58-64, 134-136, 138]. In a review of multi-level analysis of the

association between socioeconomic status and mortality, 8 of 10 studies showed a modest (RR<2), but significant positive association between neighborhood deprivation and mortality[63]. All studies in the review used aggregate income as a marker of deprivation, while some studies included education, employment, house tenure, car ownership and health insurance to create indices of deprivation. A few studies have been conducted in transition or developing economies: an analysis using GIS in Rio de Janeiro, Brazil, identified significant concentrations of poverty in parts of the city and a correlation between this regional clustering of deprivation and increased standardized mortality, increased infant mortality, and a decreased life expectancy [65].

Following this line of research, we have created an index of marginality to investigate the relationship between neighborhood vulnerability and infant mortality at the census tract level in Hermosillo, Mexico [139]. Using Geographic Information Systems (GIS), Alvarez and colleagues identified clusters of marginality and increased infant mortality in the Northwestern section of the city[139]. The association between marginality and infant mortality rates at the census tract held when controlling for individual factors in multi-level analysis. This paper uses the same index of marginality to investigate the association between adult mortality and marginality in Hermosillo.

In Mexico, despite four decades of development under the MEIs, few studies have focused on the impact of the migration, population growth and urbanization associated with industrialization on the health of border communities. While studies, primarily in developed countries, have demonstrated an increased rate of adult mortality in

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environmentally and economically vulnerable populations, this work has yet to be translated to the unique urbanization processes found at the Mexico Border. Most urban areas in this region have large, unplanned communities on their peripheries, which lack access to sewer, water and electricity connections and quality materials for housing construction [140]. The goal of this paper is to document the spatial distribution of mortality in Hermosillo and to assess whether this distribution is related, at an ecologic level, with socio-economic marginality.

Methods

This cross-sectional ecologic study, was designed to describe the spatial distribution of adult mortality and to evaluate the association between marginality and adult mortality in Hermosillo, Mexico in 2004 and 2005. The city of Hermosillo, the capital of the northwestern Mexico border state of Sonora, had a population of 662,924 in 2003[80]. This project has been reviewed and approved by the University of Michigan Institutional Review Board and by the Ethics Committee of El Colegio de Sonora in Hermosillo

In 2004 and 2005, there were 5,027 deaths in adults over the age of 15 with residency in Hermosillo. Death certificate information was provided in a de-identified database from the Epidemiologic and Mortality Statistic System (SEED) that included information on the underlying cause of death (ICD-10 code), age at death; sex (male/female); neighborhood of residence; marital status; street name of residence; medical insurance enrollment (yes/no); and underlying cause of death. The denominator used to create

mortality rates is the census tract population over the age of 15, by age category, derived from the 2000 census.

Base Maps and Geocoding of Address Data. Base maps delineating, streets, neighborhoods and census tracts (área geoestadísticas básicas) for Hermosillo were provided by the Instituto Nacional de Estadística, Geografía e Informática (INEGI), the Mexican equivalent of the US Census Bureau. Like the US equivalent, census tracts in Mexico are small, relatively permanent statistical subdivisions of a municipality delineated by INEGI based on technical criteria of distance, density and area homogeneity.

Mortality data was geo-coded to census tract using the street name and neighborhood (*colonia*) of residence reported on the death certificate. Events were placed on the centroid of the street within the neighborhood. All data points were then assigned to the overlapping census tract. When an event was missing a street name, the centroid of the listed colonia was used. Those events missing colonia were excluded from analysis, unless a street was contained in only one colonia in Hermosillo. Of the 5027 deaths, 4420 (92%) deaths were geocoded to a census tract. Of the ungeocoded deaths, 330 were not in the 2000 census map boundaries of Hermosillo and 277 had no viable address. The 4420 deaths were mapped to 254 census tracts in Hermosillo. To increase stability of rates and to ensure confidentiality, 26 census tracts with less than 50 adults, containing a total of 17 deaths, were excluded from maps and cluster analysis.

Index of Marginality The index of marginality, has been described previously[139]. The index uses five measures of education, income and housing quality to measure the "marginality index" of each census tract. The specific components used were (1) proportion of people aged more than 15 years with no more than elementary education (1-6 years of schooling); (2) proportion of employed people aged more than 15 years, who earned less than or equal to twice the Mexican minimum salary monthly ($\leq$ 268 US dollars); (3) proportion of overcrowded households (inhabited households with only one sleeping room); (4) proportion of households built with precarious materials; and (5) proportion of families with no car ownership. Each census tract has been categorized, into five strata of social marginality: (1) Very high; (2) High; (3) Intermediate; (4) Low; (5) Very low. The scores ranged from -3.15 to 6.65: a higher score indicates a higher level of social marginality. In the analysis of the association between marginality and mortality, both the index of marginality and the specific components of the index were used.

Calculation and Mapping of Age Standardized Mortality Rates. Rates calculated from age standardized mortality ratios (SMRs) were mapped for all cause death, and the top three causes of death: circulatory diseases (ICD-10 codes I00-199), neoplasms (ICD-10 C00-D48) and diabetes mellitus (ICD-10 E10-E14). Age specific rates for each geographic were calculated using indirect standardization (equations 1.0-1.4) [88]. The age categories available from the census were 15-24, 25-59, 60-64 and 65 and older. The age specific rate of mortality for the overall population in Hermosillo ($r_j^{(s)}$) was used as the internal standard population. Indirect standardization was chosen for this study

because of the anticipated instability of the age and sex specific mortality rates at the census tract level.

Equations 1:

$$r_j^{(s)} = y_j^{(s)}/n_j^{(s)} \text{ for } j = 1 \ldots I, \text{ s=age category} \qquad (1.0)$$
$$E_j = r_j^{(s)} * n_j = y_j^{(s)} * n_j/n_j^{(s)} \qquad (1.1)$$
$$E_+ = \sum E_j \text{ for } j = 1 \ldots I \qquad (1.2)$$
$$y_+^{(s)} = \sum y_j^{(s)} \text{ for } j = 1 \ldots I$$
$$n_+^{(s)} = \sum n_j^{(s)} \text{ for } j = 1 \ldots I$$
$$SMR = y_+/E_+ \qquad (1.3)$$
$$\text{Standardized rate } (r) = SMR * (y_+^{(s)}/n_+^{(s)}) \qquad (1.4)$$

n_j = *population at risk in each age/sex category for each census tract*
$r_j^{(s)}$ = *age specific rate of mortality for the overall population in Hermosillo*
E_+ = *expected number*
y_+ = *total number of cases observed in the study population*

Due to small population counts in some census tracts, the standardized rates were smoothed using a local spatial empirical Bayes procedure in Geoda based on the methods of Assuncao-Reis and colleagues [141, 142]. A rook weight matrix with one degree of contiguity was used for spatial weighting.

LISA (local indicators of spatial association) analysis in Geoda was used to identify areas of homo and heterogeneity in mortality rates. LISA analysis categorizes the cross product of the mortality in a given census tract and the average mortality in adjacent census tracts into areas of 1) census tracts with high mortality surrounded by neighbors with high mortality 2) census tracts with low mortality and low mortality neighboring tracts 3) census tracts with low mortality and high mortality neighbors and 4) areas with high mortality and low mortality neighbors[89]. This analysis was based on a Rook spatial weight with one degree of connectivity. Spatial autocorrelation, was measured by

the Moran's I statistic. Moran's I tests the similarity in standardized mortality rates between two regions. If the pattern of mortality is regular among census tracts, then Moran's I will be less than zero, if the pattern is nonregular, or clustered the statistic will take a value of greater than zero [88]. LISA analysis in Geoda was also used to visualize the spatial association between marginality and mortality. The bivariate LISA analysis determines clustering by categorizing the cross product of the standardized mortality of a given census tract and the marginality of the neighboring census tracts categorizing into 4 groups: 1) census tracts with high mortality surrounded by neighbors with high marginality 2) census tracts with low mortality and low marginality neighboring tracts 3) census tracts with low mortality and high marginality neighbors and 4) areas with high mortality and low marginality neighbors[89]

Finally, linear regression models in SAS 9.1 were used to investigate the association between the measures of socioeconomic vulnerability measured at the census tract level and age standardized mortality rates aggregated to the census tract level. No spatial component was included in these models. The outcome in all regression models was the log transformed age standardized mortality rate (per 10,000 population). The standardized mortality rate was log transformed in order to meet the assumption of normality. Also, to achieve a normal distribution, 12 census tracts with outlying standardized mortality ratios (SMR > 12) were omitted from the analysis, leaving a total of 216 census tracts. Predictor variables used in the regression model included the previously described marginality index and each component of the index individually.

Results

Of 5027 adult deaths (≥15) in Hermosillo, Mexico during the years of 2004 and 2005, 4420 had sufficient data to be geocoded to census tract. Of these deaths, 57% were male, 50% were married or in a free union, 60% were over the age of 65, 28% were uninsured and 73% percent had less than a high school education (Table 1). The top three leading causes of death by ICD-10 Chapter were diseases of the circulatory system (28%), neoplasms (20%) and diseases of the endocrine system including diabetes mellitus (14%).

Maps of the census tract demographic characteristics of marginality and age are presented in Figure 2. Considered individually, both age and marginality in Hermosillo are clustered spatially. The central census tracts in Hermosillo have the highest percentage of the population over 65 (9-16%). These census tracts are the original settlements of Hermosillo and the area with the lowest degree of marginality. The northern central census tracts have intermediate to high marginality and 3-8% of population over the age of 65; these census tracts are areas of long standing poverty in Hermosillo. The periphery of the city, including the north and southwest, are new settlements with younger populations (0-2% of the population over the age of 65). Many of these areas began as illegal or informal settlements and have the greatest concentration of high and very high marginality.

The adult mortality rate for Hermosillo for 2004 and 2005 was 119 deaths per 10,000 population for all-cause death, 34 deaths per 10,000 population for circulatory diseases,

23 deaths per 10,000 population for neoplasms and 17 deaths per 10,000 population for diabetes mellitus. Standardized mortality rates at the census tract level ranged from 0 deaths per 10,000 population to 421 deaths per 10,000 population for all-cause death; from 0-95 deaths per 10,000 for diseases of the circulatory system, from 0-117 deaths per 10,000 for neoplasms, and from 0-55 deaths per 10,000 for diabetes mellitus.

Deaths were geocoded to 254 census tracts; 26 census tracts (17 deaths) were excluded due to a population of less than 50 adults (Table 2). The highest crude rates of mortality were found in the central census tracts (Figure 3a); these areas are the oldest parts of the city and have the highest percentage of population over the age of 65 (Figure 2). Age-standardized mortality rates per 10,000 population are mapped by quintiles for all categories of death in Figure 3b. High mortality areas (dark brown colors) are scattered throughout the city, with concentration in the northern census tracts. There is no significant clustering between areas on a global scale (Moran's I = 0.0458) (Figure 4d). On a local scale, using one degree of connectivity there is clustering of high mortality (red) in the north central census tracts and areas of low mortality (dark blue) in central Hermosillo (Figure 4c).

Age standardized mortality rates per 10,000 population are mapped by quintiles for deaths with neoplasm as the underlying cause of death in Figure 5. High mortality areas (dark brown colors) are scattered heterogeneously throughout the city (Figure 5a). There is no significant clustering between areas on a global scale (Moran's I = -0.0040) (Figure 5c). On a local scale, no significant clusters were identified (Figure 5b).

Standardized mortality rates per 10,000 population are mapped by quintiles for deaths with diabetes mellitus as the underlying cause of death in Figure 6. High mortality areas (dark brown colors) are found in the northern and western outskirts of the city (Figure 6a). There is no significant clustering between areas on a global scale (Moran's I = 0.0447) (Figure 6c). On a local scale, a cluster of low mortality (dark blue) was identified in the central area of the city (Figure 6b).

Standardized mortality rates per 10,000 population are mapped by quintiles for deaths due to diseases of the circulatory system in Figure 7. High mortality areas (dark brown colors) are found in the north central, northwestern and southwestern parts of the city (Figure 7a). There is no significant clustering between areas on a global scale (Moran's I = 0.0281) (Figure 7c). On a local scale a cluster of high mortality census tracts (red) was identified in two areas of north central Hermosillo; these areas were surrounded by some census tracts of low mortality (light blue) (Figure 7b).

Mortality and Marginality

Of 228 census tracts used in the analysis, 58 (25.4%) were considered very high or high marginality, 39 (16.7%) were intermediate marginality, and 131 (57.5%) were low or very low marginality. The standardized mortality rates varied in a statistically significant manner by the marginality of the census tract, such that the rate increased as marginality

increased. High marginality tracts and very high marginality census tracts had rates 1.11

and 1.38 times that of low marginality census tracts (Table 3.2).

In the linear regression, the marginality index of a census tract was significantly

associated with the log of the standardized mortality rate of that tract (ß Coeff 0.06, p =

0.004) (Table 3.3). For each one category increase in marginality the predicted mortality

rate increases by approximately 6 percent. Similarly, the percent of population with no

car (ß Coeff 0.004, p = 0.019), the percent of population living in overcrowded

households (ß Coeff 0.080, p = 0.034) and percent population earning less than 2

minimum salaries (ß Coeff 0.012, p < 0.001) were significantly associated with an

increase in the tract's (log) standardized mortality rate. Percent living with less than a

high school education and percent living in substandard housing were not statistically

significant predictors of mortality at the census tract level. In multivariate analysis, when

including all variables in the final model, only the percent earning less than twice the

minimum salary remained a statistically significant predictor of mortality (ß Coeff 0.029,

p = < 0.001).

In bivariate LISA, the mortality rates in a given census tract were positively correlated

with marginality of the neighboring census tracts (Moran's I = .08, p =0.001). This

analysis uses the cross-product of the census tract mortality rate and the marginality

index of the surrounding census tracts to classify the correlation into four categories: high

mortality and high marginality (dark red), low mortality and low marginality (dark blue),

high mortality and low marginality (light blue) and low mortality and high marginality

(pink). Figure 3.6a provides the crude results for the bivariate LISA analysis, showing the trend for the correlation between mortality and marginality in the city. Figure 3.6b shows the census tracts for which the correlation between the mortality and marginality is significant. As shown in the maps, areas of high mortality that were surrounded by areas of high marginality (dark red) were clustered in the northwestern census tracts, areas of low marginality and low mortality (dark blue) were found in the central census tracts and an area of high marginality and low mortality (pink) was found in the southwestern census tracts. Figure 3.6c is the Moran's I showing that globally, the mortality rate of a given census tract is positively correlated with the marginality of the surrounding census tracts.

Discussion

This analysis is one of the first studies to map the geographic distribution of adult mortality and to investigate the association between marginality and mortality at the census tract level in northern Mexico. Local clustering was identified for all cause death, deaths due to circulatory diseases and diabetes mellitus, but not for deaths due to neoplasms. Mortality was significantly associated with both an index of marginality and with the education and income components of that index at the census tracts level. Global and local clustering of mortality and marginality at the census tract level were observed. This study demonstrates that the underutilized public data from the electronic vital registry system in Sonora, Mexico can be a valuable resource for investigating the effects of marginality on population health in the northern border region.

The overall crude adult mortality rate for Hermosillo was 119 deaths per 10,000 persons. Census tracts with high crude mortality rates were heavily concentrated in the center of city, due to the high percentage of elderly living in those census tracts. After age standardization, mortality rates were higher in the northern tracts and in the periphery of the city, where the population is younger and marginality tends to be higher. Our study utilized indirect standardization, with the total Hermosillo population as the internal standard. Due to the type of standardization used, the mortality rates presented in this study at the census tract level are not directly comparable to commonly cited rates for the border region, such as those published by the Mexican government or by the Pan American Health Organization (PAHO), which are not age standardized or use national population estimates as the age standard[143]. However, these adjusted rates permit internal comparisons of mortality within the city and suggest areas of unmet need that warrant attention by public health authorities.

On a global scale, no clustering of standardized mortality was observed throughout the city of Hermosillo at the census tract level, indicating that across the city census tracts with high mortality did not tend to cluster with other areas of high mortality, nor low with low. This lack of global clustering of mortality was also found for infant mortality[85]. One hypothesis for this lack of relationship is that portions of this border city may have a greater degree of spatial integration of different socioeconomic groups than is found US cities or than existed in previous research. While poverty levels are generally uniformly high on the western and northern periphery of the city, the center of city has areas with

historical, persistent poverty closely integrated with areas of historical wealth reducing global clustering of mortality. In addition, hypothesized health hazards in some similar cities in the region, such as industrial facilities are distributed in locations that are contrary to expectations: in previous research in Nogales, Sonora, Lara and colleagues found that large industrial facilities tended to cluster in high-income areas[55]. They hypothesize that this is due to lack of basic infrastructure, such as electricity and water, in the more marginalized communities, which prohibits industrial growth. This research has not been replicated for Hermosillo. Air pollution, from industry and traffic emissions, has been associated with increased morbidity and mortality at the neighborhood level and could be a confounding factor in this analysis[64, 144]. Further research into the distribution of marginality, mortality and health hazards between and within census tracts in this region is necessary.

Using local indicators of spatial clustering, areas of both high and low marginality clustering were found throughout the city. For both all cause death and death from diseases of the circulatory system, clustering of high mortality was identified in the northern census tracts. In comparison to informal settlements found at the periphery, these census tracts are in older, established sections of the city that have long standing high marginality. The relationship between higher rates of cardiovascular disease and low socioeconomic status in developed and transition economies has been shown at both the individual and neighborhood level and is hypothesized to be related to environmental and individual factors such as the distribution of healthcare, food availability, green space and availability of areas for physical activity, rates of cardiovascular co-morbidities and

obesity, and rates of tobacco and alcohol consumption[134, 145-148]. The longitudinal effect of persistent poverty, including exposure to many of the above risk factors, in the central north census tracts of Hermosillo cannot be measured with our current data, but could be an explanatory factor in the clustering of circulatory deaths in the area.

For diabetes mellitus, a clustering of low mortality was found in the center of city, the area of lowest marginality. Diabetes mellitus has been found to cluster spatially in areas of high deprivation in other settings[149]. While no spatial analysis was available for Mexico, a national study of the prevalence of diabetes mellitus in the Mexican population showed that diabetes was most prevalent in the economically vulnerable urban population and in the northern border region where this study is located[150]. While this study did not find statistically significant clustering of high rates of diabetes mellitus in the high marginality areas, further research using additional years of data would further elucidate this relationship. Diabetes mellitus prevalence in the Mexican population is expanding rapidly and is a priority for the Mexican health system[151]. While the distribution of specialized prevention clinics has been suggested to address the issue, little research has been done on the geographic distribution of the disease in the urban population, which is necessary for proper placement of such clinics.

For deaths from neoplasms, no local clustering was found. During focus group interviews with residents of Hermosillo, rates of cancer in the city were a primary concern (unpublished findings). We found no statistical evidence to support areas of elevated

cancer risk within the city. Further research into specific cancer types, with more years of data, would be needed to further investigate this public concern.

Using non-spatial linear regression, high and very high marginality at the census tract level were statistically associated with higher standardized mortality rates of the corresponding census tract, when compared to low marginality census tracts. This relationship between marginality and mortality held when analyzing the association spatially; high mortality areas tended to cluster in areas of high marginality and low mortality areas tended to cluster with low marginality. The positive association we observed between marginality and mortality is consistent with results of other studies conducted in developed and developing countries, including a recent study of infant mortality in the same city[52, 53, 58-62, 85, 133, 134].

A noteworthy deviance from the clustering of high marginality and high mortality was observed in the southwestern census tracts, which were characterized by high marginality and low mortality rates. Further investigation into qualities of these southwestern census tracts is warranted. A previous study of infant mortality in Hermosillo did not find the same converse relationship in this area of the city [85]. The southwestern census tracts, which developed originally as illegal settlements, may have developed resilience to poverty-associated mortality, through increased social capital or community activisim, which could be a model for similarly marginalized areas of the city[152]. These census tracts are one of the primary residential areas for workers in the maquiladoras, located in the southeastern portion of the city. It is possible that there is a healthy worker effect

among residents of this area, as has been suggested in some previous research of female employees of the maquiladora industry[153, 154].

When considering each aspect of the marginality index individually, percent of the population with no car, percent living in an overcrowded household, percent earning less than twice the minimum salary were significantly associated with mortality. In Hermosillo, healthcare availability, particularly emergency services, is heavily centralized. Previous mapping of bus routes in Hermosillo by this project (data not shown) demonstrated limited bus availability to some peripheral communities. Lack of public transportation and lack of personal vehicle ownership in some marginalized communities could be a factor in the relationship between mortality and marginality and will be future direction for this research.

When including all components of the index in a model, only minimum salary was found to be statistically significant. Income may be the most robust indicator of marginality at the census tract level and have been shown in previous literature to be associated with mortality disparities [63].

In univariate and multivariate analysis, the education level of the census tract was not significantly associated with the mortality rate, in contrast to previous research on infant mortality in the region[85]. The association between education and mortality in northern Mexico may not be directly comparable to data from developed countries. In the US, education is often a strong indicator of low socioeconomic status, with a high percentage

of the population receiving at least a high school education. In the older population in Northern Mexico, having less than a high school education is not limited to highly marginalized populations (73% of the deaths had less than a high school education). Education in the border region has become increasingly available over the last half century, and as the current population ages, the association between education and mortality may become more analogous to that observed in research conducted in the US and Europe where minimal education is limited to a smaller and more impoverished sector of the population.

This spatial analysis was cross-sectional and therefore could not assess temporal aspects of the relationship between neighborhood marginality and mortality, including intra and interurban migration[61, 146]. The ecologic nature of the study limits inference to the census tract level, and does not give information on individual risk. It is possible that any ecologic association found is an artifact of individual risk and not a characteristic of the neighborhood [87, 146]. Geographic studies based on regional count are also susceptible to the modifiable areal unit problem, or MAUP, in which we have chosen to aggregate at the census tract level, an arbitrary political deliminator which may or may not be related to risk [87, 88]. By limiting our analysis to census tract aggregation we may identify or fail to identify clusters of mortality that are identifiable at one level of aggregation, but not at another. It has been recommended to use case-event data when possible to maximize the opportunity to find clusters [88], but this was not possible in this study due to the potential loss of confidentiality and the quality of the geographic information available. Finally, because we had limited data on confounders, any association identified

at the census tract level may be due to confounding at the contextual level and not our variable of interest. For example, residence in a particular census tract may be a proxy for similar work environments of census tract residents and not our measure of socioeconomic vulnerability [61, 63]. Future studies should be designed to include both individual and ecologic variables in a multi-level analysis.

This analysis used address and cause of death (COD) data from the Sonoran vital registry system. Given the rapid growth of Hermosillo and the informal expansion of the city, inaccuracies in the geocoding of addresses are of concern in this analysis. In particular, the informal settlements in the outskirts of the city have unmapped streets and unassigned addresses. We attempted to circumvent the possibility of miscoding the location of a death by fieldwork in the invasions to identify and map new streets and clarify neighborhood address nomenclature, but some miscoding is possible and may be biased towards the periphery of the city.

A previous analysis of the quality of the cause of death statements demonstrated good agreement at the ICD-10 chapter level, but found low reliability of the reported COD when considering at the two-digit ICD-10 classification level for many categories of disease, including diabetes mellitus and some diseases of the circulatory system. Some misclassification of cause of death may be present in the data used for this analysis, although there no evidence was found that the level of misclassification is differential across socioeconomic groups[155].

Conclusions

This study demonstrates that the vital registry data in Sonora is sufficient for geographic analysis of mortality. Geo-coding in Mexico is time-consuming and requires extensive knowledge of the geographic layout of the city. Nevertheless, this paper demonstrates that geo-coding at the census tract level is feasible and provides valuable public health information. A longitudinal study of the spatial distribution of mortality in Hermosillo would provide valuable insights into patterns of mortality as the city rapidly transitions both in economic viability and in the age and spatial distribution of population. With the introduction of a new large automotive factory and supplier complex in 2004[156] and other relatively well-paying employment, the level of marginalization in some areas may quickly change. Other government programs that are new to the city, including an improved bus line in 2004 and low-income housing developments to discourage the development of informal settlements[157], will have important consequences on the demographic factors found to be associated with mortality in this paper. In particular, areas on the outskirts of the city that were informal, illegal settlements are rapidly being incorporated into the municipality, with a subsequent improvement in resources and living conditions in some areas. Strong community activism has led to improvements in the availability of bus lines, trash collection and water and electricity provision; this activism, as a reaction to sparse resources in unplanned communities, particularly among female residents, has been shown as a strong agent for change in other border communities in northern Mexico[158]. Qualitative and quantitative study of areas that have seen community driven improvements may lead to valuable information on how to improve community resilience to the impact of marginalization on mortality. With

support of qualitative data, longitudinal studies utilizing the vital registry system will be a valuable tool in tracking the effect of rapid border immigration and economic development on the health of the border populations.

Table 3.1: Demographic Characteristics of 2004-2005 Adult Deaths in Hermosillo

Variable		N	%
Sex			
	Male	2529	57.2
	Female	1891	42.8
Age			
	15-25	102	2.3
	25-45	473	10.7
	45-65	1175	26.6
	65-85	2028	45.9
	85+	642	14.5
Education			
	No Schooling	536	12.1
	Incomplete Primary	1648	37.3
	Complete Primary	923	20.9
	Incomplete Secondary	125	2.8
	Complete Secondary	524	11.9
	Bachelors	256	5.8
	Professional	337	7.6
	Unknown	71	1.6
Underlying Cause of Death			
	Diseases of the circulatory system	1244	28.1
	Neoplasms and Diseases of the blood and blood-forming organs	866	19.6
	Endocrine, nutritional and metabolic diseases	637	14.4
	External Causes	557	12.6
	Diseases of the respiratory system	412	9.3
	Diseases of the digestive system	285	6.4
	Infectious and parasitic diseases	157	3.6
	Other	225	5.1
Marital Status			
	Single	771	17.4
	Widow	1288	29.1
	Divorced	140	3.2
	Free Union or Married	2199	49.8
	Unknown	22	0.5
Insurance Status			
	SSA (Uninsured)	1254	28.4
	IMSS	2130	48.2
	ISSTE	425	9.6
	Other (PEMEX, SEDENA, SEMAR)	435	9.8
	Unknown	176	4.0

Figure 3.1: Demographic characteristics of census tracts in Hermosillo: a) percent population over the age of 65 and b) marginality index at the census tract level Hermosillo, Mexico
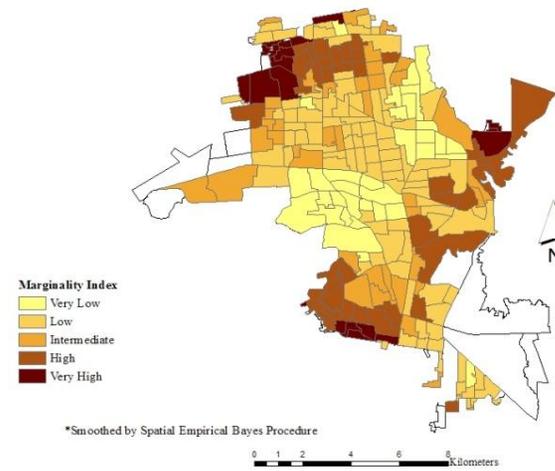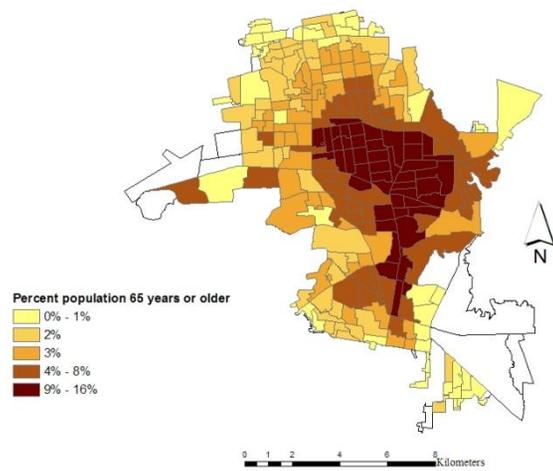
Figure 3.2: Mortality Rates (SMR) at the census tract level, All adult deaths (≥15) in Hermosillo, Mexico 2004-2005 a) crude mortality rate b) age standardized mortality rate (SMR) c) LISA analysis of local clustering of SMRs d) Moran's I analysis of global clustering of SMRs.
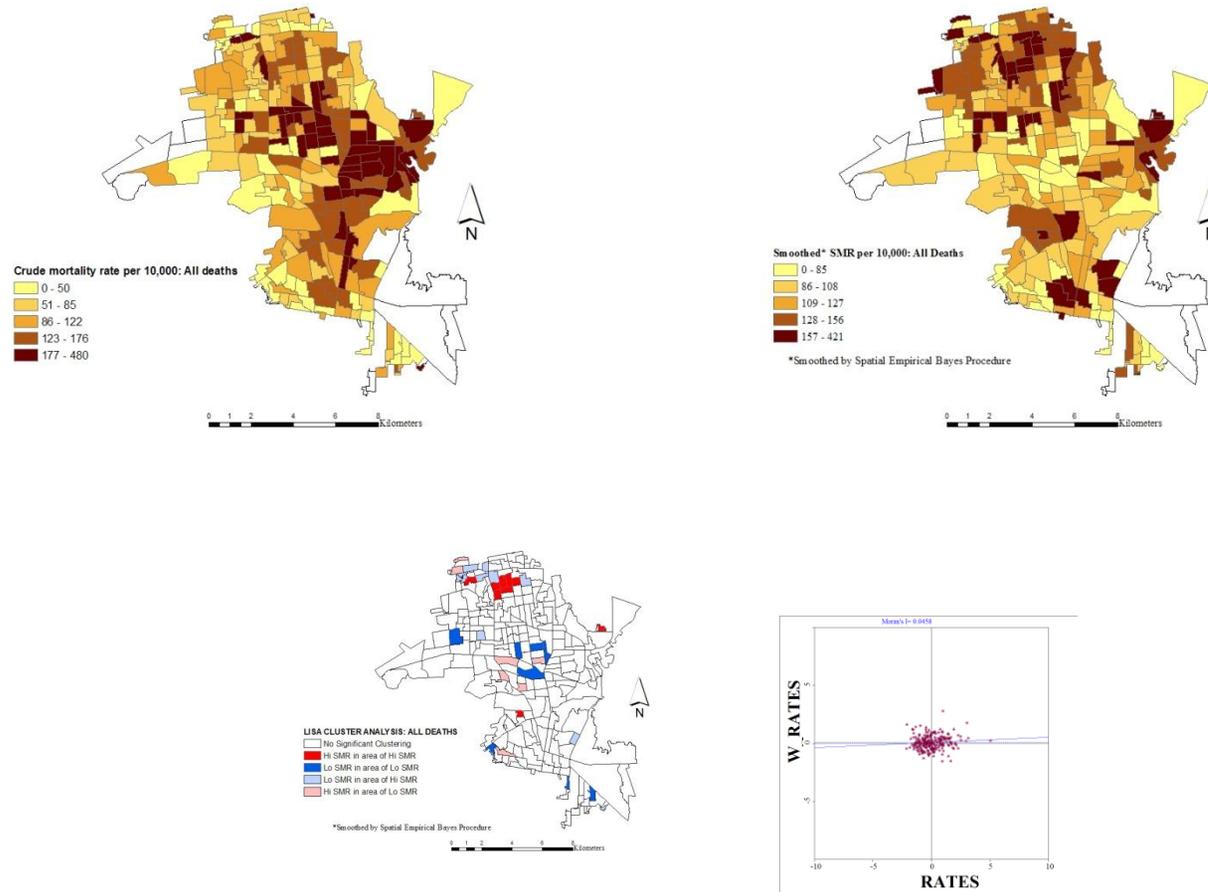
Figure 3.3: Smoothed, Age Standardized Mortality Rates (SMR) at the census tract level: Neoplasm associated deaths in adults (≥15) in Hermosillo, Mexico 2004-2005 a) age standardized mortality rate (SMR) c) LISA analysis of local clustering of SMRs c) Moran's I analysis of global clustering of SMRs.
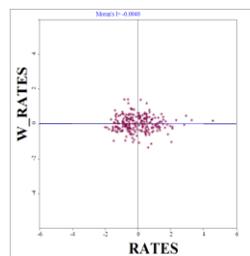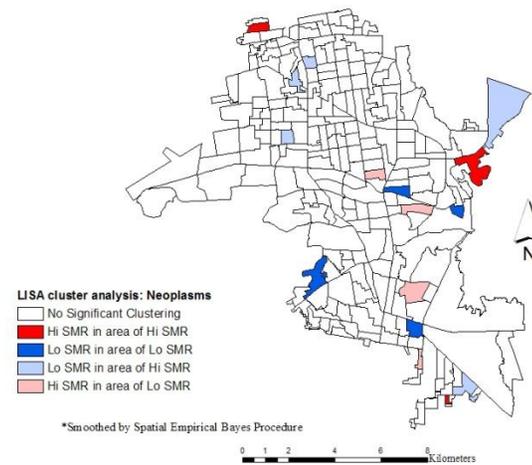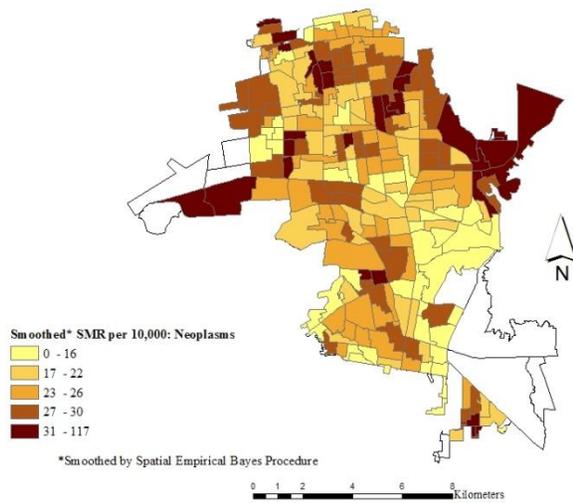
Figure 3.4: Smoothed, Age Standardized Mortality Rates (SMR) at the census tract level: Diabetes Mellitus associated deaths in adults (≥15) in Hermosillo, Mexico 2004-2005 a) age standardized mortality rate (SMR) c) LISA analysis of local clustering of SMRs c) Moran's I analysis of global clustering of SMRs.

Smoothed* SMR per 10,000: Diabetes Mellitus
- 0 - 8
- 9 - 13
- 14 - 16
- 17 - 19
- 20 - 55

*Smoothed by Spatial Empirical Bayes Procedure

0 1 2 4 6 8 Kilometers

LISA cluster analysis: Diabetes Mellitus
- No Significant Clustering
- Hi SMR in area of Hi SMR
- Lo SMR in area of Lo SMR
- Lo SMR in area of Hi SMR
- Hi SMR in area of Lo SMR

*Smoothed by Spatial Empirical Bayes Procedure

0 1 2 4 6 8 Kilometers
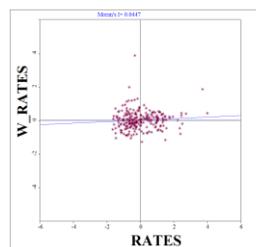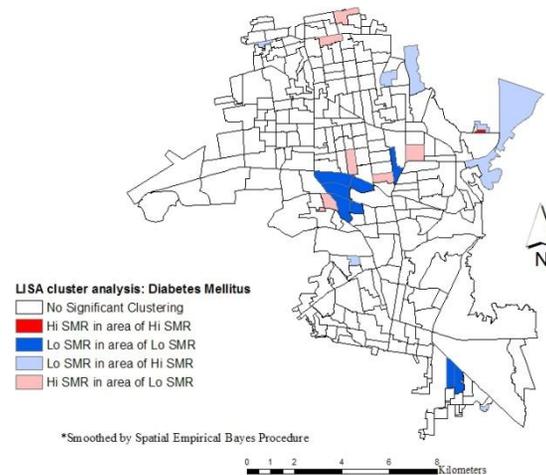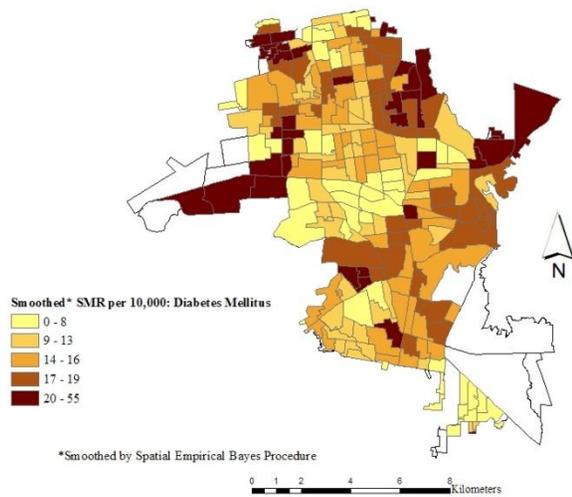
Figure 3.5: Smoothed, Age Standardized Mortality Rates (labeled as SMR) at the census tract level: Deaths due to diseases of the circulatory system in adults (≥15) in Hermosillo, Mexico 2004-2005 a) age standardized mortality **rate** (SMR) c) LISA analysis of local clustering of SMRs c) Moran's I analysis of global clustering of SMRs.
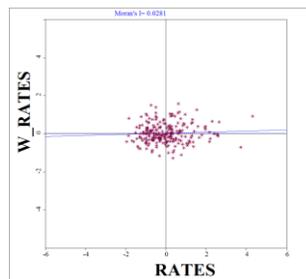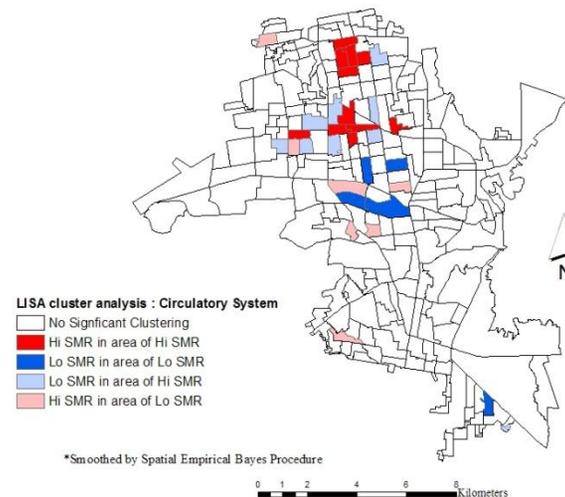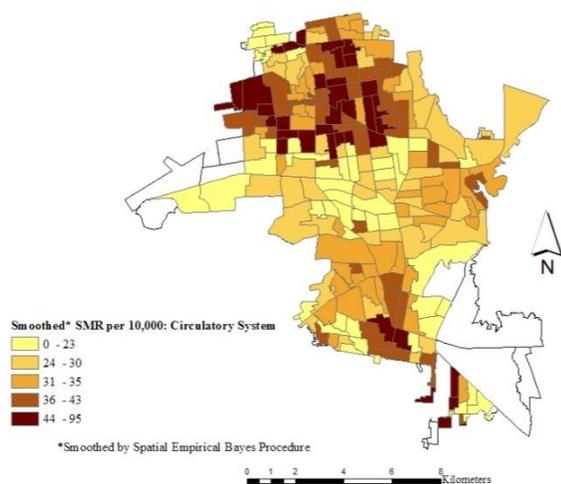
Table 3.2: Age Standardized Mortality Rate by Degree of Marginality for Hermosillo Mexico

Degree of social marginality	Census Tracts	Population	Deaths	Expected Number of Deaths	Standardized Mortality Rate a	Standardized Mortality Rate 95% CI	Rate Ratio
Overall Hermosillo	254	370344	4420	4420	119.42	115.90, 122.94	--
Very low	34	53103	534	648	98.38	90.04, 106.73	0.82
Low	97	162162	2122	2112	119.92	114.82, 125.02	Referent
Intermediate	39	67469	755	789	114.25	106.10, 122.40	0.95
High	38	66306	802	720	132.99	123.78, 142.19	1.11
Very High	20	18211	190	137	166.02	142.42, 189.63	1.38
Excluded from Analysis	26	3093	17	15	139.44	73.15, 205.72	--

Table 3.3: Linear Regression Models of the Association between Marginality and the Log-Transformed Standardized Mortality Rate (deaths per 10,000 population). The B coefficient can be interpreted as increase in the log number of deaths per 10,000 population predicted for a one point increase in marginality index or marginality index component.

Variable1	Adjusted R-Square	B Coefficient	Standard Error	t Value	P Value
Model 1	0.032				
Intercept		4.740	0.038	125.020	<.0001
Marginality Index		0.059	0.021	2.860	0.005
Model 2	0.021				
Intercept		4.529	0.094	48.250	<.0001
Percent with no car		0.005	0.002	2.370	0.019
Model 3	0.016				
Intercept		4.622	0.064	72.020	<.0001
Percent living in overcrowded household		0.004	0.002	2.130	0.034
Model 4	0.080				
Intercept		4.360	0.092	47.580	<.0001
Percent earning < 2 minimum salaries		0.012	0.003	4.440	<.0001
Model 5	0.011				
Intercept		4.603	0.081	56.690	<.0001
Percent with < highschool education		0.005	0.003	1.810	0.071
Model 6	0.008				
Intercept		4.698	0.044	107.850	<.0001
Percent living in substandard housing		0.004	0.003	1.650	0.101
Model 7	0.109				
Intercept		4.387	0.102	42.800	<.0001
Percent with no car		-0.009	0.006	-1.510	0.132
Percent living in overcrowded household		-0.004	0.003	-1.070	0.288
Percent earning < 2 minimum salaries		0.029	0.006	4.960	<.0001
Percent with < highschool education		-0.004	0.006	-0.690	0.494
Percent living in substandard housing		0.001	0.004	0.140	0.889

Figure 3.6: Bi-variate LISA cluster analysis of Standardized Mortality Rates (SMR) and Marginality at the census tract level: Adult Deaths (≥15) in Hermosillo, Mexico 2004-2005. a) LISA categorization of census tracts by the relationship between mortality of given census tract and the marginality of adjacent neighbors b) Census tracts that were statistically significantly clustered (p < .05) c) Moran's I test for spatial autocorrelation between standardized mortality rates and the marginality of surrounding census tracts. The two lines show the moran's I with (blue) and without (red) the exclusion of an outlying census tract that significantly skewed results.

Lisa Analysis of Clustering between Mortality and Marginality
- Hi Mortality in Area of Hi Marginality
- Lo Mortality in Area of Lo Marginality
- Hi Mortality in Area of Lo Marginality
- Lo Mortality in Area of Hi Marginality

Lisa Analysis of Clustering between Mortality and Marginality
- Hi Mortality in Area of Hi Marginality
- Lo Mortality in Area of Lo Marginality
- Hi Mortality in Area of Lo Marginality
- Lo Mortality in Area of Hi Marginality

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CHAPTER 4

Characterization of the Temperature and Mortality Relationship in Northern Mexico

Introduction

The effect of extreme temperatures on population health is a pressing concern brought on by predicted increases in global temperature over the upcoming decades [66]. Increasing temperatures are expected to have both direct and indirect impacts on health, including increased morbidity and mortality due to extreme heat and cold waves, food scarcity, the increased distribution of infectious disease vectors and decreased air quality[66, 159].

Previous research on the direct effects of extreme hot and cold weather effects on mortality have demonstrated a J or U shaped association between temperature and mortality. These studies show an increase in mortality with both extreme cold and heat, with the highest mortality rates seen during the cold season [67, 73-79, 159, 160]. For cold temperatures, increased mortality is primarily attributed to an increase in respiratory and cardiovascular deaths, particularly in the elderly[70, 73, 161]. For hot temperatures, increases in death are associated with salt loss and increased burden on the cardio respiratory systems needed for cooling the body [162].

The relationship between temperature and mortality is modified by the temperature norms in a given geographic area. In normally hot climates, the association between heat and mortality has been found to be attenuated, and the cold effect stronger, when compared to colder climes [67-72].

The majority of research on temperature and mortality has occurred in developed countries. The most recent ICPP report indicates that there is a need for replication of this research in low income countries [66]. Four studies conducted in Latin America found increased death at higher temperatures, with significant variation in effect size across countries and between demographic groups [71, 163-165]. O'Neill and colleagues found a smaller heat effect in the Mexico City population, when compared to the northern border city of Monterrey, Mexico. In a case-crossover study of three Latin American countries, the effect estimates of heat on mortality and the low education effect modification of the temperature-mortality relationship were highly significant in Brazil, compared to non-significant results in Chile and Mexico. In contrast to these findings in Brazil, an earlier study in Sao Paulo showed no significant effect modification of the temperature-mortality relationship by socioeconomic status[71]. Of particular concern in low and middle income countries are poor urban communities, such as shanty towns, favelas or invasions, which lack consistent access to electricity, water and transportation. The combination of extreme temperatures and lack of access to cooling/heating methods may have a greater adverse impact population health in these populations than less socially disadvantaged communities [166, 167].

The northern Mexican border is arid desert ecosystem, with average maximum temperatures ranging from 60 to 115° F. This region of Mexico has urbanized rapidly in the past 30 years, shifting from 26% to 70% urban between 1980 and 1990[25]. This rapid growth has included the formation of illegal or informal settlements surrounding urban areas that lack basic utilities and may be more susceptible to extreme temperatures. The city under study, Hermosillo, had roughly 650,000 inhabitants during the study period. Both the climate profile and the size of urban area in this study are unique from other studies done on temperature and mortality in Latin America. Previous studies have been conducted in sprawling megacities in tropical and subtropical climates[71, 163, 164] with the exception of a study by O'neill et al which includes data from Monterrey, Mexico[165]. This study analyzed, over an 8 year period, the association between maximum daily temperatures and mortality, including socio-demographic factors, in the capital of the northern Mexico border state of Sonora.

Methods

This ecologic study was designed to assess the association between high temperatures and mortality from 1998-2005 in Hermosillo (2003 population 662,924), the capital of the northwestern Mexico border state of Sonora. Mortality data was provided by the Epidemiologic and Mortality Statistic System (SEED) of Sonora. The SEED uses the international system for the classification of diseases and related health problems (ICD-10). The study was reviewed and approved by the University of Michigan Institutional

Review Board and the Ethics Committee of the research institution, El Colegio de Sonora.

Between 1998 and 2005, there were 20,242 deaths, an average of 2,500 deaths per year, in residents of Hermosillo. Mortality data was provided in a de-identified database from the SEED system that included information on the underlying cause of death (ICD-10 code); age at death; education; sex (male/female); medical insurance enrollment (yes/no); and type of hospital facility (for people with no medical insurance/people with medical insurance). Daily weather data, including temperature, barometric pressure, precipitation and dew point was collected from the Hermosillo International Airport via wunderground.com. Due to lack of complete weather data for April through June of 2000, 826 of the 20,242 deaths (4.1%) were excluded from the analysis leaving a total of 19,416 deaths.

Data analysis was conducted in SAS 9.1. The association between temperature and mortality was modeled using generalized additive models with a Poisson distribution:

$$Log\ (u_i) = f(X_i) = s_0 + s_1(X_i)$$

Where the outcome was the log of the daily count of deaths in Hermosillo (u_i) and the predictor was the maximum temperature on the day of death (X_i) modeled using a B-spline univariate smoother (s_i). In initial models temperature was modeled using apparent temperature, which is an index that includes temperature and daily humidity

levels, but due to very low humidity in the region and no statistically significant variation in the temperature mortality relationship using apparent temperature (data not shown), maximum daily temperature was chosen for the final model. Other covariates initially included in the model included: 1 to 3 day time lags of temperature, daily barometric pressure, daily dew point average, year, and day of week. A zero day lag for temperature was used in the final model due to the strongest effect estimate and consistency with prior research on hot temperatures and mortality [67, 68, 164]. Barometric pressure was eliminated due to high correlation with temperature. Dew point, year and day of week had minimal, non-significant effects on the temperature-mortality relationship and therefore were not included in the final model. Degrees of freedom and knot placement for the smoothing function were determined using the Generalized Cross Validation (GCV) method in SAS 9.1. A reduced dataset, removing outlying temperatures under 70° F and over 110°F, did not provide a statistically altered effect estimate of temperature. To estimate effect modification by socio-demographic variables, separate GAM models were run with maximum daily temperature and interaction terms, modeled parametrically, for age (<= 65, 65 +), sex, education level (primary education or less, greater than primary), insurance status (insured/uninsured) and underlying cause of death (diseases of the circulatory/respiratory system, neoplasms, accidental deaths, other). Accidental deaths were excluded from the analysis of all cause mortality and were modeled separately.

Results

Between 1998 and 2005 there were 20,242 deaths, 19,416 of which occurred on days with complete weather data available for the analysis (Table 1). Of these deaths: 58%

were male, 8% were under 5 years old and 52% were over the age of 65; 31% had no health insurance; and 47% died in the hospital for the uninsured. The leading underlying causes of death were diseases of the circulatory system (27%), neoplasms (18%), diseases of the endocrine system (12%) and accidental deaths (10%). In adults, 18 years of age and older, 50% had a primary education or less.

A histogram of daily maximum temperature in Hermosillo from 1998 to 2005 is presented in Figure 4.1a. Temperatures range from 51° F to 114° F and are skewed in frequency toward higher temperatures. There is a bimodal distribution of temperature, with peaks in frequency at $80\text{-}84^{\circ}$ F and $95\text{-}104^{\circ}$ F. The annual fluctuations of both daily temperature and mortality are presented in Figure 4.1b and 4.1c. A general increase in mortality is seen during the winter temperature trough.

The results of the generalized additive model for all cause mortality are presented in Table and Figure 4.2. The association between temperature and mortality had significant linear and non-linear component. While the linear effect coefficient varied in magnitude throughout the range of temperatures, the association between daily count of death and temperature was consistently negative (linear term, $\beta = -0.0072$, $p = <0.0001$). The counts of death for a given temperature predicted by the linear and non-linear components of the GAM model are shown in Figure 2. According to model predictions, there are approximately 2.17 (28%) additional deaths per day on a 59° F (15°C) degree day when compared to a 104° F (40°C) degree day.

Results of the GAMs that included interaction terms for demographic characteristics and cause of death are presented in Table 4.3. After including age in the GAM model, the negative association between daily temperature and total mortality held across age groups, but was statistically greater in the over 65 age group (β = -0.0082, p = <0.01), than in the under 65 age group (β = -0.0036, p = <0.01). This effect modification by age translates to 31% percent reduction in daily count of deaths between 59 and 104° F in over 65 compared to a 15% reduction in those 65 and under (Figure 4.3).

The negative association between daily count of mortality and temperature held for people with primary education or less (β = -0.0082, p = <0.01) and for those with greater than a primary education (β = -0.0050, p = <0.01), although the effect was stronger in the population with less education. The model predicts a 31% reduction in daily deaths for the population with primary education or less and a 20% reduction for those with higher than a primary education when comparing a 59 and 104° F day (Figure 4.3).

The association between daily count of mortality and temperature was strongest for the population whose underlying cause of death was diseases of the circulatory and respiratory system (β = -0.0101, p = <0.01). This translates into a 36% percent reduction in daily death count on a 104° F compared with a 59°F day for diseases of the circulatory system, compared to 9% reduction in all other diseases. When compared to other diseases, the relationship between the daily count of deaths due to neoplasms and temperature was reduced towards the null (β = 0.0009, p = < 0.01). In contrast to other causes of death, for accidental/external causes the relationship between temperature and

mortality was positive ($\beta = 0.0044$, p = <0.01), with a 22% increase in deaths on a 104° F compared with a 59°F day.

When stratified by sex and insurance status, we observed a negative association between maximum daily temperature and mortality in both males and females and in the insured and uninsured. There was no significant modification of the temperature mortality relationship between the two sexes, nor by insurance status. No modification of the temperature/mortality relationship by year of death was found.

Discussion

This study is one of the first to assess the relationship between temperature and mortality in an arid desert region of a mid-size regional city in a middle income country. We demonstrated a negative association between daily maximum temperature and mortality using 19,416 deaths over an 8 year period from an urban area in the northern Mexico border region. The association between lower daily-maximum temperatures and counts of death was strongest in the elderly population, in women and in those deaths associated with diseases of the respiratory and circulatory system. In contrast accidental deaths demonstrated a positive association with temperature. While there is a substantial body of research on the association between mortality and temperature, there is a paucity of data considering this relationship in low and middle income countries [66]. Using urban mortality data from a hot, desert ecosystem in northern Mexico, this study was designed to address this need for additional research.

Utilizing generalized additive Poisson models, we observed a consistent downward trend in the temperature-mortality relationship, with highest daily mortality counts associated with colder temperatures. As shown by an additional piecewise model, based on the GAM, this negative association was statistically significant between 80 and 100 degrees, but non-significant outside of this boundary. This relationship is consistent with previous research showing highest mortality in the cold season[70, 73, 75, 78]. While much of the previous research has demonstrated a J shaped relationship between temperature and mortality, with both a "cold" and "hot" effect, this study demonstrated a flat line relationship between temperature and mortality at hotter temperatures, with excess winter mortality. This relationship has been shown in previous research in climates where similarly high temperatures are the norm[68, 69, 78, 165]. The lack of a J shaped relationship found in this study is most likely due to physiologic, infrastructural and cultural adaption to the extremely high average temperatures in this region[160]. Given the small number of days with temperatures less than 65°F, estimating the extreme cold weather effects on mortality in Northern Mexico was not feasible.

The over 65 population had one of the strongest associations between temperature and mortality. The effect was weaker in the 5 to 65 year olds. The over 65 population has been shown in previous literature to be the most susceptible to extreme temperatures with the highest mortality rate in the winter months [73, 168]. Higher mortality in the winter for the elderly may be associated, in part, with winter respiratory outbreaks, including influenza. A study by O'Neill and colleagues in Mexico controlled for winter influenza

outbreaks in their analysis, finding significant effects on the temperature mortality relationship [165].

The study population had relatively low level of formal education (50% had a primary education or lower), however consistent with previous research [69, 169], we still observed a temperature-related mortality gradient by education. The negative relationship between temperature and mortality, was stronger among people with a lower versus a higher levels of education (above primary). Future analyses of these data will assess information on socio-demographic characteristics of community of residence, particularly a measure of marginality. While previous studies have shown weak or no association between deprivation and temperature related mortality[73, 161, 168, 170], it is hypothesized that informal invasions and low income communities may be at a higher risk for extreme temperature associated mortality [66]. Many of the informal communities lack access to consistent electricity and water, which could be important factors in the relationship between temperature and mortality, particularly in a desert ecosystem. Address data has been collected electronically in Sonora since 2004, thus future studies may consider neighborhood effects. In a previous paper using the same mortality data from 2004 and 2005, areas of high mortality, particularly from circulatory diseases, were identified in lower income, peripheral communities [155].

The negative association between temperature and mortality was strongest for deaths caused by diseases of the circulatory, respiratory and endocrine systems. There was no significant effect of temperature on deaths due to neoplasms. The stronger effect of cold

temperature on both circulatory and respiratory deaths, when compared to other types of death, is consistent with previous studies [69, 70, 76]. The reversed relationship with external deaths has rarely been addressed in previous research, as most studies exclude external deaths from their analysis or have explored all-cause mortality. We observed an increased mortality due to external causes with higher temperatures. Further investigation of this relationship considering levels of summer alcohol consumption, dehydration and motor vehicle and pedestrian accidents will be considered for further research.

We observed no statistically significant difference in the association between colder temperatures and increased mortality between sexes. This finding is supported by previous research in the United States that reported no significant difference in mortality between genders [169]. However, in a study of 21 countries, Barnett and colleagues found that females had increased odds of a coronary event during cold weather, when compared to males[70]. A recent study of Latin American countries found increased mortality associated with heat in males in Chile and Brazil, but in females in Mexico City [164]. Hajat and colleagues found women over 65 years of age had higher mortality than men in high temperatures, but no difference at low temperatures in England and Wales [168]. This study found a non-significant increase in the cold weather effect in females, future research should consider the modification of the temperature and cause-specific mortality relationship by gender.

The overall population had a high uninsured rate (31%), but no significant difference was found between the insured and uninsured population. Few studies have included

insurance status in their study of temperature and mortality for comparison. Mexico has a nationalized health care system and in the city of study, there is a system of public clinics and a large hospital dedicated to the uninsured (SSA). The availability of health care, regardless of insurance status, appears to attenuate the differences between insured and uninsured populations.

As are most studies in this genre, this study was limited by its ecologic nature. Demographic information, at the individual level, was not available for the total population. Many recent studies of temperature and mortality have included measurements of air quality, such as ozone levels and daily particulate matter levels; both of these environmental factors are associated with temperature and have been positively associated with mortality [164, 169, 171-174]. Temperature inversions during the winter can increase the concentration of air pollutants affecting health [175]. While this data was not available for Hermosillo for this study, it could be an important confounder of the temperature and mortality relationship. Rain levels are low in Hermosillo (annual rainfall) and complaints of dust and pollution are community concerns (Vulnerability Project, Unpublished), particularly in low income or informal communities that lack paving and green space.

An additional future direction is to study the effect of unseasonal temperature variations and seasonal migration on mortality. Past studies have shown that extreme temperatures, beyond those expected for the season, are associated with increased mortality[176, 177]. In Hermosillo, cold snaps, outside normal temperature deviations, are more common than

summer heat waves, and this association will be addressed in future research. In addition, due to very hot summer temperatures, this region experiences some temporary seasonal out-migration during the hottest summer months. While the magnitude of the emigration from the city, and the difference in seasonal migration between varying socioeconomic groups is unmeasured, it could be a confounding factor of the temperature-mortality relationship and should be considered in future research[160].

In conclusion, this characterization of the temperature and mortality relationship in Northern Mexico provides an important addition to an ongoing body of research. The data presented in this paper suggests a high level of population level adaption to extreme high temperatures. Incorporation of additional information on community characteristics within the urban environment, such as the informal communities (invasions), housing construction and climate variables such as air quality and precipitation, will be important for understanding the potential impact of global climate change on urban populations in similar climates. Because climate change models predict milder winters and hotter summers, the impact of global climate change in highly heat adapted populations could differ substantially from more northern climes and warrants further research.

Table 4.1: Demographic Characteristics of Deaths in Hermosillo from 1998 to 2005

| Variable	N	%
Total	19416	100
Sex		
Male	11294	58
Female	8122	42
Age Category		
Under 5	1642	8
5 to 17	376	2
18 to 44	2578	13
45 to 64	4690	24
65 to 84	7710	40
85 +	2420	12
Site of Death		
SSA	9149	47
IMSS	6166	32
ISSTE	1336	7
Other Public Facility	322	2
Out of hospital	2147	11
Missing	296	2
Insurance Coverage		
No Insurance	6080	31
Social Security Coverage (IMSS)	8668	45
Social Security for State Employees (ISSTE)	1609	8
Other	2049	11
Ignored	1010	5
Underlying Cause of Death		
Certain infectious and parasitic diseases	653	3
Neoplasms and Diseases of the blood and blood-forming organs	3499	18
Endocrine, nutritional and metabolic diseases	2392	12
Diseases of the circulatory system	5260	27
Diseases of the respiratory system	1706	9
Injury, poisoning and external causes	1977	10
Other	3929	20
Education (adults 18 and older only)		
No Schooling	2289	12
Primary School or Less	7297	38
Secondary School or Less	5165	27
Advanced Degree	2149	11
Missing	498	3
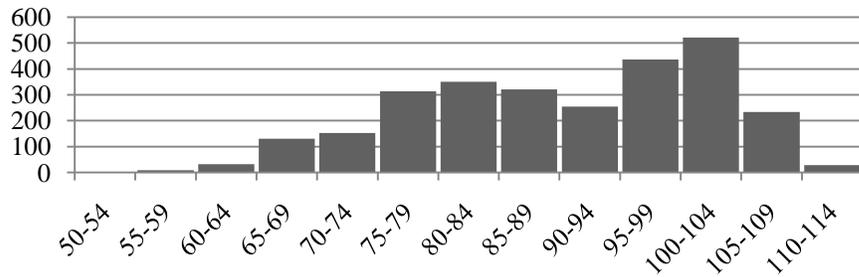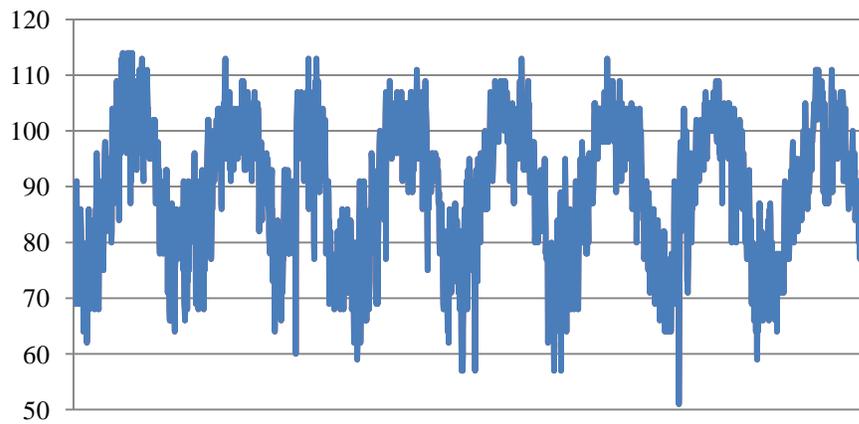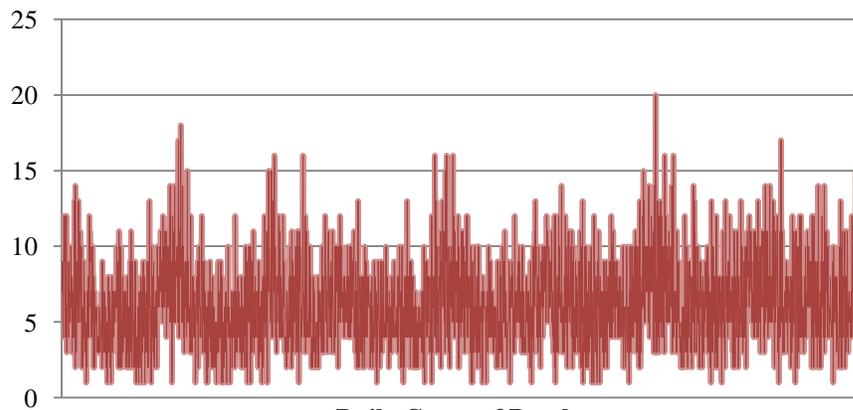
Figure 4.1: Daily Temperatures and Mortality in Hermosillo from 1998-2005
a)Histogram of maximum daily temperature in Hermosillo, Mexico b)Maximum daily
temperatures and c) daily count of deaths in Hermosillo, Mexico from 1998-2005

Table 4.2: Generalized Additive Model (GAM) and for the association between maximum daily temperature and daily count of deaths (excludes accidental death). The GAM has a linear and non-linear component. The linear component of the GAM model can be interpreted in a similar fashion: as the expected change in log daily mortality count for a one degree change in daily maximum temperature.

| | GAM[1] | | Linear – Piecewise[1] | |
| | | P | | P |
Non-Linear Components (DF)	Estimate (SE)	Value	Estimate	Value
Temperature	0.9988 (3.31)	0.0027		
Linear Components (SE)				
Temperature	-0.0072 (0.0006)	<.0001		
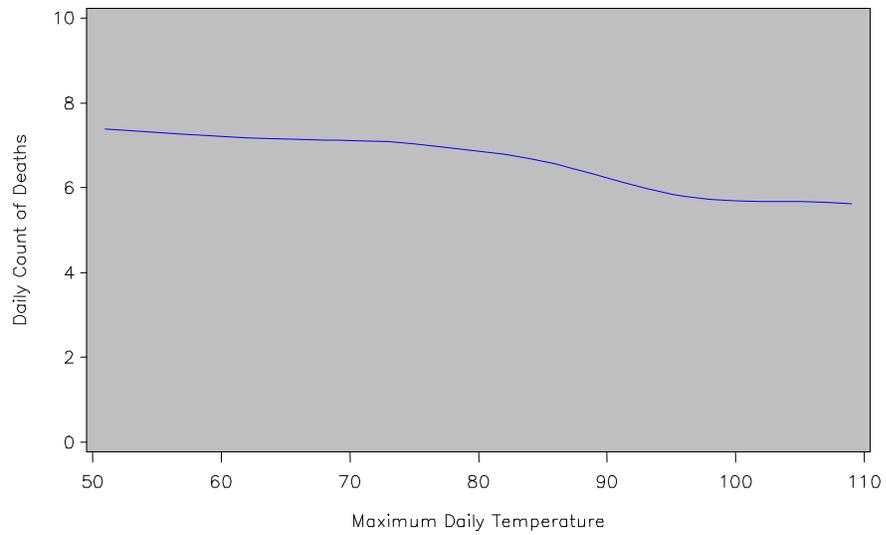
Figure 4.2: Predicted daily count of deaths at a given maximum daily temperature based on the GAM model with linear and non-linear components. External causes of death are excluded from the analysis.

Table 4.3: Demographic characteristics of the temperature and mortality relationship modeled using a GAM with a Poisson distribution. Temperature is modeled using a spline with DF based on the GCV method. Demographic parameters are modeled without splines in the GAM.

Parameter	Linear Components			Nonlinear Components		
	Estimate		Std. Error	Smoothing function		DF[1]
Age						
Intercept	1.3929	**	0.0858			
Over the age of 65	0.6418	**	0.1134			
Age and Temperature Interaction Term	-0.0046	**	0.0013			
Maximum Daily Temperature	-0.0036	**	0.0010	0.9981	**	3.8567
Education						
Intercept	1.4017	**	0.0932			
<= Primary School Education	0.6188	**	0.1197			
Education and Temperature Interaction Term	-0.0032	*	0.0013			
Maximum Daily Temperature	-0.0050	**	0.0010	0.9992	**	2.7752
Underlying Cause of Death						
Intercept	1.7027	**	0.0673			
Deaths - Circulatory and Respiratory Systems	0.2143		0.1104			
COD and Temperature Interaction Term	-0.0080	**	0.0012			
Maximum Daily Temperature	-0.0021	**	0.0007	0.9996	*	2.0950
Intercept	2.3783	**	0.0587			
Deaths- Neoplasms	-1.7375	**	0.1401			
COD and Temperature Interaction Term	0.0062	**	0.0016			
Maximum Daily Temperature	-0.0071	**	0.0007	0.9973	**	4.3588
Intercept	2.4833	**	0.0561			
Deaths- External Causes	-2.5010	**	0.1818			
COD and Temperature Interaction Term	0.0117	**	0.0020			
Maximum Daily Temperature	-0.0073	**	0.0006	0.9990	**	3.0759
Sex						
Intercept	1.7546	**	0.0840			
Male	0.0262		0.1128			
Sex and Temperature Interaction Term	0.0018		0.0013			
Maximum Daily Temperature	-0.0074	**	0.0009	0.9988	**	3.2154
Insurance Status						
	2.0085	**	0.0695			
No Health Insurance	-0.7214	**	0.1235			
Insurance and Temperature Interaction Term	0.0012		0.0014			
Maximum Daily Temperature	-0.0065	**	0.0008	0.9925	*	5.8984

* = p <0.05

** = p <0.01

1 – DF Determined by GCV method
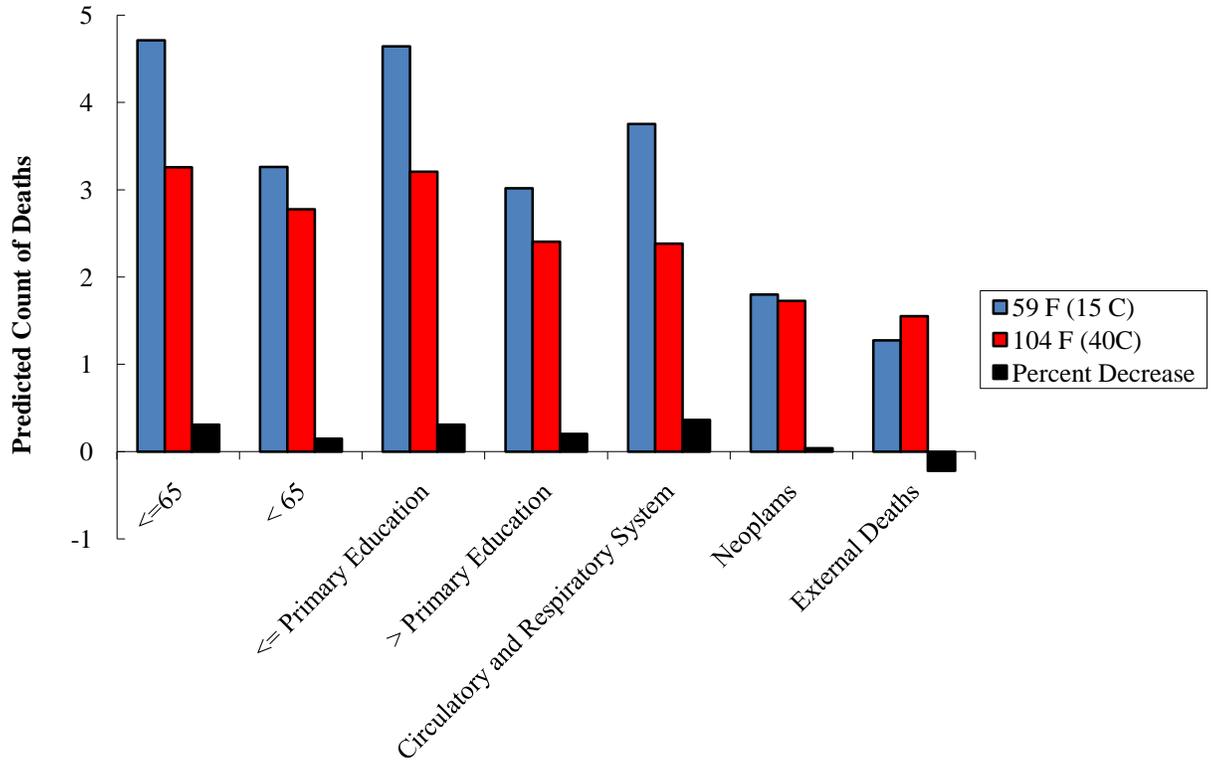
Figure 4.3: Predicted Mean Count of Deaths at 59 F (15 C) and 104 F (40 C) with predicted percent decrease in deaths between these two temperatures. Estimated are based on the GAM models in Table 4.3 with linear and non-linear components.

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CHAPTER 5

Conclusions

The impact on population health of the rapid industrialization and urbanization in the Northern Mexico Northern border region, associated with export processing factories and cross border migration, has yet to be fully understood. This dissertation used spatial mapping and advanced modeling techniques to address the intersection of health, environment and development using the vital registry data in an urban center in this area. This research aimed to fill gaps in our current knowledge regarding adult mortality patterns in Northern Mexico. Our results provided evidence regarding the quality of the vital registry mortality statistics in this region, assessed the spatial relationship between adult mortality and marginality, and the temporal relationship between temperature and mortality in this arid desert region.

Little epidemiologic research has addressed the impact of the development process found in Northern Mexico. This study established the quality of the vital registry system, the most complete health database found in the region, for use in further research. This dissertation identified areas in marginalized communities that have higher rates of

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mortality from all cause and circulatory disease mortality. Finally, the relationship between temperature and mortality in the region was described, including the populations with increased vulnerability to seasonal temperature fluctuations. These findings can be used as evidence for needed policy changes in the region, including improved vital registry statistics, distribution of preventative care for chronic diseases in marginalized communities and further research on the possible effects of global climate change on the urban desert populations of Northern Mexico.

This dissertation is the first research study to investigate the quality of adult mortality statistics of the vital registry system in the border state of Sonora, and one of only a few such studies conducted in Mexico. The northern border region has undergone rapid development in the past half century, due to political programs, such as NAFTA and US/Mexico immigration policies. The impact of this convergence of different development policies on a formerly rural, desert ecosystem has not been fully elucidated. Epidemiologic studies of mortality in this region are sparse, even though a fully digitalized vital registry dataset has been available for over a decade. This study provides novel findings on the quality of this vital registry data and the capacity of the data to be used for longitudinal and geographic analysis.

Geographic analysis is underutilized in epidemiologic research in Mexico. Mapping is a valuable tool for research and evidence based policy decisions [178]. This study overcame the challenge of geocoding mortality data in an urban setting where addresses

are not firmly established and street names are often repetitive. While requiring substantially more field work than geocoding in a country such as the United States, this process demonstrated that spatial analysis, at the census tract level, is possible in an urban environment in Northern Mexico, and that the process provides valuable information on the spatial distribution of mortality and correlates of mortality.

While temperature and mortality have been well studied in developed countries, the study presented in Chapter 3 investigated the association between mortality and temperature in a unique desert climate, in a midsized urban environment. The majority of studies in Latin America have focused on the largest megacities, generally found in tropical or subtropical climates [71, 163-165]. In addition, this study had individual level education, insurance and cause of death data for each case, which few research studies have addressed[73, 169]. Therefore, this study provides a unique perspective on the mortality and temperature from a middle income, arid desert urban ecosystem. Such information is essential when considering the future impact of climate change on global public health.

Quality of Mortality Registration

Vital registry systems are an essential data source for epidemiologic research, particularly in low and mid-income countries that lack other systematic data sources. The study presented in Chapter 2 utilized vital registry system (SEED) data from the Northern

Mexican border state of Sonora. This data source became available electronically in 1998, with availability of address data beginning in 2004. As these data have not been used previously for research purposes, in order to utilize mortality statistics in Sonora, it was essential to first demonstrate the validity and reliability of the data available from the SEED. This study focused on the reliability of the underlying cause of death a random sample of 300 adult death certificates of in-hospital deaths, residents of Hermosillo, the capital city of Sonora.

Our analysis found moderate to good overall agreement (Kappa = 0.62) between the reviewer and original COD at the ICD-10 chapter block. When comparing classification of COD at the more specific level of 2-digit ICD-10 codes, the overall agreement varied across cause of death types: excellent agreement and sensitivity was found for neoplasms, diseases of the nervous system, cerebrovascular disease and ischemic heart disease and poor agreement was found for diabetes mellitus, hypertensive disease and acute upper and lower respiratory disease. Based on these results, further analysis using these data focused on chapter level comparisons (ie neoplasms vs. circulatory disease). Given the findings of the study, caution is still warranted for analysis of causes of death within ICD-10 chapters (ie hypertension vs. ischemic heart disease).

We found a higher level of agreement than a previous study on infant mortality in the region[85]. When compared with other studies of the quality of adult mortality statistics conducted globally our results were similar to a recent study of urban vital registry

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statistics in China that reported high sensitivities for cancers and low sensitivity for diabetes mellitus and hypertensive diseases[98] but contrasted with four studies in the US and Taiwan that identified overestimation of coronary heart disease as the underlying cause of death[94, 100], and a low rate of agreement for cerebral infarction [118, 119]. This variability in findings demonstrates the need for replicating studies across a broad variety of international settings. Vital registry quality varies widely across the globe[44], and should be established at a regional or state level in order for epidemiologic research to advance our knowledge of public health statistics.

While the vital records system in Hermosillo is currently functional and provides complete mortality data, some important inaccuracies in the coding of the underlying cause of death statements exist. These inaccuracies, particularity for prevalent, costly, chronic diseases with common co-morbidites such as hypertension and diabetes mellitus, need to be addressed in order to appropriately address these important public health issues. Suggested improvements to the system include physician training, querying of ill-defined causes of death, installation of an automated classification program and strengthening of the research capacity in the region to effectively use analyze and distribute data from the vital registry system

Spatial Clustering of Mortality and Marginalization

The spatial analysis presented in Chapter 3 focused on the association between mortality and marginality in Hermosillo. The city is characterized by diverse neighborhoods

throughout the city and periphery. Older and wealthier established neighborhoods are concentrated towards the city center; new, often informally created communities, with young populations are located primarily on both the northern and southwestern peripheries of the city; areas of long standing high marginality are located in the city's northern center and newer industrial parks that house export processing factories are located in the southeast. Based on a wealth of literature in developed countries regarding the association between intra-urban socioeconomic differentials and mortality, we analyzed the spatial distribution of marginality and adult mortality by census tract for the years of 2004 and 2005.

The overall crude adult mortality rate for Hermosillo was 119 deaths per 10,000 persons. Using a linear regression, the mortality rate of a given census tract was significantly and positively associated with both an index of marginality and with the education and income reported in the 2000 census information for that census tract. Geographically, high crude mortality rates were heavily concentrated in the city center, due to the high percentage of elderly living in these census tracts. After age-standardization, higher mortality rates were observed in the northern tracts and in the periphery of the city, where the population is younger and marginality levels tend to be higher. On a global scale, no clustering of standardized mortality was observed throughout the city of Hermosillo at the census tract level, indicating that, across the city, census tracts with high mortality did not tend to cluster with other areas of high mortality, nor low with low. However, on a local scale, areas of both high and low marginality clustering were found throughout the city. For both all-cause death and death from diseases of the circulatory system,

clustering of high mortality was identified in the northern census tracts. In comparison to the informal settlements found at the periphery, these census tracts are older, established sections of the city that have long standing high marginality. For diabetes mellitus, a clustering of low mortality was found in the center of city, the area of lowest marginality. For deaths from neoplasms, no local clustering was found.

The primary findings of this analysis are consistent with previous research on marginality and mortality. While generally modest in significance, the positive association between derived or aggregate measures of neighborhood marginality and adult mortality from all cause and circulatory diseases has been demonstrated at the individual and ecologic level in developed countries[52, 53, 58-64, 134-136, 138]. Exceptions to these findings included a cluster of high marginality census tracts in the southwestern portion of the city with low mortality rates. This observation, which has not been reported in previous research, suggests a need for more detailed investigation on the marginality/mortality relationship at the neighborhood level, while taking into account factors associated with resilience.

The overall findings of this paper can be used as both a guide for future targeted research and for initial evidence for policy decisions. The clustering of high rates of death from cardiovascular disease in the marginalized communities and low rates of death from diabetes mellitus in wealthier communities, suggests a higher burden of chronic disease among economically vulnerable population. The relationship between higher rates of

mortality, particularly cardiovascular disease, and low socioeconomic status is hypothesized to be related to environmental and individual factors such as the distribution of healthcare, food availability, green space and availability of areas for physical activity, rates of cardiovascular co-morbidities and obesity, and rates of tobacco and alcohol consumption[134, 145-148].   These urban environmental risk factors have challenging, yet achievable policy interventions, such as increased distribution of urban infrastructure, disease prevention clinics, health education programs and economic programs in the marginalized communities. Further research is required to guide the appropriate placement and funding of such programs.

Mortality and Temperature

The study in Chapter 4 investigated the association between temperature and mortality in Hermosillo. The city is located in an arid desert ecosystem in Northern Mexico. The maximal temperatures in this area range from 70 to 115 degrees Fahrenheit throughout the year. Many of the informal or low income neighborhoods at the periphery of the city have substandard housing without consistent access to electricity, air conditioning, transportation and water[50]. Research, primarily in large, temperate, urban centers in developed countries, has demonstrated a positive association between extreme heat and mortality [67, 73-79]. Based on this body of research, we analyzed the association between mortality and temperature for Hermosillo for the years of 1998 through 2005.

Using generalized additive models, which allow for non-linear predictive models, the study demonstrated a statistically significant negative association between mortality and temperature. As the daily maximum temperature increased, the daily count of deaths decreased. The strongest downward trend was seen between 80 and 100 degrees Fahrenheit. This association held for most causes of death, with the exception of deaths due to external/accidental causes. This negative association was stronger in the elderly (over the age of 65), those with a primary education or less and those dying from diseases of the circulatory and respiratory systems. No relationship with temperature was found for deaths due to neoplasms, and no difference in the temperature effect was found for deaths in males compared to females and deaths among the uninsured compared to the insured.

The general relationship between temperature and mortality shown in this study is consistent with previous research showing highest mortality in the cold season[70, 73, 75, 78]. This study demonstrated a flat line relationship between temperature and mortality at hotter temperatures, with excess winter mortality that contrasts with the J shaped relationship between temperature and mortality found in most previous research in temperate climates. This flat-line hot weather and mortality relationship has been shown in previous research in climates where similarly high temperatures are the norm[68, 69, 78, 165] and has been attributed to physiologic, infrastructural and cultural adaption to the extremely high average temperatures in this region[160]. The stronger effect of cold temperature on both circulatory and respiratory deaths, when compared to other types of death, is consistent with previous studies [69, 70, 76].

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This initial investigation suggests many future directions for research. The reasons for the inverse relationship found for external causes, i.e with higher mortality at higher temperatures, should be investigated, including possible risk factors such as summer alcohol consumption, dehydration and motor vehicle and pedestrian accidents. Further research should consider neighborhood effects of mortality and temperature, particularly considering the informal communities in the periphery of the city that lack access to consistent electricity, water, green space and road paving. Further research should incorporate air pollution data, in tandem with the spatial component, as temperature inversions during the winter can increase the concentration of air pollutants affecting health [175]. Unseasonal temperature variations and seasonal migration on mortality might also be explored. While this study data is preliminary, further research on the topic will help policy makers prepare their constituents for the ongoing global and local climate changes and to develop policies on cold and hot weather shelters in the city, air pollution laws and community distribution of electricity, water, green space and road paving.

Strengths and Limitations

This dissertation used secondary data sources including the vital registry system and census information. While the reliability study allowed us to assess the validity of the underlying cause of death data, demographic data from this data source has not been validated for accuracy. We also did not achieve the targeted sample size of 300 for inter-

chapter comparisons, as 50 charts were missing in the final analysis. A larger sample size would have compensated for missing charts and allowed for more precise assessments of the agreement between the original and gold-standard coding for uncommon causes of death such as infectious diseases and maternal mortality, as well as analyses of intra-chapter causes of death, such as hypertension vs. ischemic heart disease. In addition, the study was limited to in-hospital deaths in the two largest hospital facilities in Hermosillo, future studies should assess quality of death coding in the smaller hospitals and for out-of hospital deaths. Missing data in the medical chart could have significantly impact the accuracy of the COD determined by the reviewer. Quantitative analysis of the completeness of the medical chart for review was not completed by this study. In addition, the use of area specialists, such as cardiovascular physicians for diseases of the circulatory system, may have improved accuracy of the gold-standard. While autopsy would be the best gold-standard for determining the underlying cause of death, in Mexico autopsy is not common practice[84].

For the spatial analysis, population denominators and marginality data were taken from the 2000 census, while death information was obtained for 2004 and 2005. Given population growth in Hermosillo, incidence rates may be biased upwards, particularly in the expanding peripheries of the city. A 2005 mid-census count was done in Hermosillo, but this data was not publicly available at the time of analysis. The spatial analysis was a cross-sectional, ecologic design and therefore cannot measure the temporal aspects of the relationship between neighborhood SES vulnerability and mortality, including intra and interurban migration[61, 146]. Inference is limited to the census-tract level. Chronic

diseases are determined by a life time of exposures and therefore a resident's current location may not be the sole determinant of their chronic disease status [87]. It is possible that any ecologic association found is an artifact of individual risk and not a characteristic of the neighborhood [87, 146].

This study used regional count data and is therefore susceptible to the modifiable areal unit problem, or MAUP [87, 88]. MAUP states that by limiting to census tract aggregation we may identify or fail to identify clusters of mortality that are identifiable at one level of aggregation, but not at another. It is recommended to use case-event data or to aggregate at more meaningful neighborhood jurisdictions, but this was not possible in this study due to the potential loss of confidentiality and the precision of the geographic information available.

Finally, because of limited data on confounders in the spatial analysis, associations that identified at the census tract level may be due to confounding at the contextual level. For example, residence in a particular census tract may be a proxy for similar work environments of people living in the same area and not reflect of socioeconomic vulnerability [61, 63]. Future studies that include both individual and ecologic variables in a multi-level analysis will help to distinguish the critical contextual and individual variables associated with disease risk in this community.

The temperature and mortality analysis was limited to aggregated count data, since no individual level data was available for the overall Hermosillo population. Recent work has shown that the temperature and mortality relationship can be confounded by the presence of air pollution. Future studies should incorporate environmental data.

Implications for Public Health Practice

In a region where the epidemiologic mortality profile is shifting towards that of the developed world, with moderately low infant mortality rates and increases in adult deaths to due to chronic disease, this body of research is an important addition to knowledge and suggests strategies for improving for public health practice.

Additional research on the hospital and vital registry system in Sonora will provide evidence for the extensive policy decision required to improve the system. The state of Sonora has already shown a commitment to the quality of its vital statistics through the development of an electronic vital registry system. Suggested improvements to improve the accuracy of the vital registry data include: an automated system of determining the underlying COD, such as ACME software and additional, ongoing training for physicians on underlying cause of death reporting on death certificates[132]. In addition, an electronic medical chart system could improve the quality of cause of death reporting and reduce the high percentage of missing charts found in this study. The majority of these interventions are costly and quality evidence based data is required to support their implementation.

With a transition to chronic disease as the predominant killers, considering multiple causes of death is an important next step for both research and policy. Much of the miscoding found in the study was between common co-morbidities, and understanding the overall morbidity and mortality associated with conditions such as hypertension and diabetes mellitus will require consideration of multiple conditions and emphasis in physician training of documenting these conditions on the death certificate.

The vital registry system of Sonora is the most complete health-related database available for the region's population. Understanding and improving the quality of these data are essential for the epidemiologic research. As shown by the subsequent studies included in this dissertation, the mortality statistics provide valuable insight into the distribution of mortality within the population. They also allow for identification and evaluation of the effects of potential positive and negative exposures on population health, such as climate change, air pollution, new urban infrastructure, government health initiatives, the evolution of the maquiladora industry, informal settlements and other forms of community activism or the distribution of the nationalized health care system. Many of these health exposures, particularly those dealing with the impact of export-led development, are unique to areas of the world that are underserved by epidemiologic research. The Mexican border region provides an opportunity to understand this unique development process using a well-established and complete vital registry system that is often unavailable in other similar settings globally.

We observed a global positive association between the marginality of census tract and mortality rate in that census tract. We also identified clusters of high marginality/high mortality at the peripheries of the city for all cause mortality and circulatory diseases. Further research to elucidate this relationship has been started by the larger project encompassing this dissertation. Directions for further research included the addition of future years of data to study the longitudinal fluctuations in mortality and marginality, and the mapping of urban resources such as public transportation and road quality, health care resources, industrial locations, green space, water and electricity availability, or quality food availability. It will be important for the municipal and state governments to consider measures to improve the health of these low-income populations. In particular, areas of high marginality and high mortality rates due to diseases of the circulatory system were found in the northwest periphery of the city. Public health prevention programs to address chronic conditions in low income communities should be considered by the municipality and have already been discussed at a national level[150]. Some programs that may lessen the marginality mortality effect are already in place, such new government low income housing and increased public transportation in the peripheries of the city. An important next step for research will be to evaluate the impact of these programs. The government sponsored housing project for low income families, alleviate the need for low-income housing that often spurs the invasions and provides residences constructed with standard materials that have water and electricity access and neighborhoods with paved streets and consistent transportation.

We also identified an area in the southwest of the city that had low mortality and high marginality. This area is primarily invasions, of varying stages of development and incorporation by the municipality. Qualitative and quantitative study of this community may provide important insights for new programming or services that could be provided to other communities in Hermosillo. Suggested aspects of these communities that may provide resilience to the overall impact of marginality, include access to services, such as utilities, schools, health clinics, public transportation, green spaces, non-profit organizations and the level of grassroots community activism and organization among the residents.

Most studies of temperature and mortality report increasing mortality at high temperatures. While we originally hypothesized higher mortality in the extreme temperatures of the desert summer, we instead found higher mortality during the mild temperatures of the winter months, particularly for cardiovascular and respiratory deaths. This association may be associated, in part, with winter respiratory outbreaks, including influenza[174]. While additional research is required to determine the cause of increased winter mortality in Hermosillo, research and policy should consider the public health measures taken to prevent increased mortality due to co-infections in the elderly population, such as the availability of influenza, Haemophilus *Influenzae*, S. *pneumoniae* and Meningococcocal meningitis vaccinations. Other public health measures that may reduce the public health impact from such infections include comprehensive laboratory typing of infectious agents and timely public health prophylaxis of infectious disease contacts. There is currently sparse evidence on the availability and completeness of the

public health measures for adults and elderly in Sonora, and a next step for research would be to identify and measure both the causes of winter mortality and the public health measures used to mediate the winter mortality burden.

While this study demonstrated higher mortality and lower temperatures, it was limited by aggregation of the data and lack of denominator or geographic information. A future direction of this research would be to consider whether any differences in the temperature mortality relationship exist depending on the community of residence, including access to electricity, water, transportation and cooling centers. Government sponsored cooling centers have been successfully established in most large urban areas in the United States, although the impact of these centers is not fully established[179].

While hundreds of individual researchers from a variety of fields, including sociology, anthropology, environmental and occupational health and epidemiology have contributed research to the effort to elucidate the impact of international trade agreements and export-led processing on the health of Mexico's northern border population, research remains scarce, often is not published in international journals and often focuses solely on the maquiladora industry, to the detriment of understanding the larger picture related to rapid industrial development. The parent project for this dissertation aimed to integrate many of these disparate fields of research, using quantitative and qualitative methods, to understand the global population impact of export led development. Further work of this nature is necessary to consolidate and add to existing knowledge. Qualitative data and

field research, both from this study and others like it, provided the epidemiologic researcher a better basis for identifying research needs and understanding and interpreting results. It was through interviews with community activist in neighborhood*s* in the southwest of Hermosillo, that this project identified the possibility that this area may have a unique resistance to an otherwise standard mortality-marginality relationship. It was through geocoding field work in the dusty, dry, un-electrified peripheral invasions during the height of summer that the concept for the temperature and mortality relationship was born.

In addition, new quantitative data sources need to be identified and evaluated for research utility including: medical records from the nationalized health care system, which are now being computerized; air pollution data from government and private air quality monitors; spatial mapping layers of government and private infrastructure; and improved availability, at the small area level of census data.

Conclusions

This dissertation provides valuable information to lead research on development and health in the region and that will be made available to policy makers in the border region. The overall project is anticipated to have a positive impact on policy relevant to the environment and health status of border communities and its results should have substantial relevance to other countries with policies of export-led development.

Contributions include the provision of information on the reliability of the vital registry system and possible steps for improvement; providing maps of mortality and marginality that can be used to further research and inform policy makers; and bringing together data on the association between temperature and mortality that may spark further research to elucidate the impacts of global climate change. Export processing development strategies affect over 40 million workers and an un-estimated number of communities globally. The Northern Mexico Border has undergone a half a century of growth and expansion under these strategies and provides a valuable model for research on the impact of globally driven development that can be used to inform both local and global policy. This dissertation can be used as a stepping stone towards a more comprehensive research strategy in this unique and important region of the world.

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