Published in final edited form as:

Local Environ. 2015 February ; 20(2): 180–201. doi:10.1080/13549839.2013.839644.

Double Exposure and the Climate Gap: Changing demographics and extreme heat in Ciudad Juárez, Mexico

Sara E. Grineski,

University of Texas at El Paso

Timothy W. Collins,

University of Texas at El Paso

Yolanda J. McDonald,

Texas A & M University

Raed Aldouri,

University of Texas at El Paso

Faraj Aboargob,

University of Texas at El Paso

Abdelatif Eldeb,

University of Texas at El Paso

María de Lourdes Romo Aguilar, and

El Colegio de la Frontera Norte-Ciudad

Juárez Gilberto Velázquez-Angulo

Universidad Autónoma de Ciudad Juárez

Abstract

Scholars have recognized a climate gap, wherein poor communities face disproportionate impacts of climate change. Others have noted that climate change and economic globalization may mutually affect a region or social group, leading to double exposure. This paper investigates how current and changing patterns of neighborhood demographics are associated with extreme heat in the border city of Juárez, Mexico. Many Juárez neighborhoods are at-risk to triple exposures, in which residents suffer due to the conjoined effects of the global recession, drug war violence, and extreme heat. Due to impacts of the recession on *maquiladora* employment and the explosion of drug violence (since 2008), over 75% of neighborhoods experienced decreasing population density between 2000 and 2010 and the average neighborhood saw a 40% increase in the proportion of older adults. Neighborhoods with greater drops in population density and increases in the proportion of older residents over the decade are at significantly higher risk to extreme heat, as are neighborhoods with lower population density and lower levels of education. In this context, triple exposures are associated with a climate gap that most endangers lower socioeconomic status and increasingly older aged populations remaining in neighborhoods from which high proportions of residents have departed.

1. Introduction

Exposure to extreme heat is a serious human health concern expected to intensify due to global climate change (Intergovernmental Panel on Climate Change 2007; Patz et al. 2005). Specifically, extreme heat events can trigger human health outcomes ranging from heat stroke to preterm birth to death (Basu and Samet 2002; Basu, Malig and Ostro 2010; Curriero et al. 2002) and they are a leading cause of weather-related mortality worldwide (Luber and McGeehin 2008). The interior US-Mexican border region, including Ciudad Juárez, has been identified as a heat vulnerability ‘hot spot’ (Reid et al. 2009) due to concerns about high heat and socially vulnerable populations. In addition to concerns about rising temperatures associated with climate change, the US-Mexico border is a region simultaneously confronted by the challenges associated with economic globalization, urbanization and industrialization (Wilder et al. 2010). Ciudad Juárez is a microcosm of these processes as hot, dry summers, a drug war, and an economic recession have confronted residents over the past decade. Treating Juárez as a laboratory, this paper examines how changing economic, social, and environmental conditions have converged to create unequal risk exposures at the neighborhood level. Specifically, we consider extreme summer heat and its association with changing demographic characteristics in Juárez neighborhoods, drawing off the double exposures and climate gap literatures. Neighborhoods face situations of triple exposure, or vulnerability, related to demographic changes that we argue are related to the impacts of global economic change, drug cartel violence, and environmental change.

2. Double Exposures and the Climate Gap

The double exposures framework involves the recognition that climate change and economic globalization often confront the same regions and the same social groups simultaneously and sequentially, which shapes vulnerabilities and opportunities for individuals, households, communities and social groups (Bolin et al. 2013; Leichenko, O'Brien and Solecki 2010; O'Brien and Leichenko 2000). Double exposures provides a generalized approach for understanding the interactions between global environmental and economic changes, directing attention to the ways that the two interacting processes spread risk and vulnerability over both time and space (Leichenko, O'Brien and Solecki 2010). Despite the obvious linkages between the two, apart from the double exposures literature (Leichenko, O'Brien and Solecki 2010; Wilder et al. 2010), the relations between climate change and economic globalization have often gone unnoticed. In this case, the double exposure framework has applicability for a quantitative, spatial climate gap analysis in a US-Mexico border city. It has already been argued that the border region is a textbook case of double exposure because of rapid urbanization and industrialization alongside an arid climate and predictions of severe precipitation decreases and temperature increases in global climate models (Wilder et al. 2010).

Apart from the double exposures literature, scholars are beginning to recognize the presence of a so called climate gap, which is an emerging focus of environmental justice scholarship and activism on the environmental inequalities associated with climate change. The climate gap concept was recently developed through a series of policy reports (Kersten et al. 2012;

Morello-Frosch et al. 2009; Pastor et al. 2010) and journal articles (Shonkoff et al. 2011; Shonkoff et al. 2009) focused on California. This team of California researchers has demonstrated that poor and minority communities face disproportionate and unequal impacts of climate change in that US state. For example, poor minority communities suffer disproportionately due to heat waves, which are predicted to intensify in California under climate change scenarios (Shonkoff et al. 2011). Building off this work, a climate gap was also reported in El Paso (Texas) where lower levels of socio-economic status and reduced access to health care were significantly associated with higher summer heat in neighborhoods (Grineski et al. 2011). While not framed as a “climate gap” analysis, researchers found that Phoenix neighborhoods with the highest temperatures were also the most socioeconomically disadvantaged (Harlan et al. 2006).

In Ciudad Juárez (Mexico), a climate gap was quantified using 2000 Census data at the neighborhood level. Results of a multivariate spatial lag model demonstrated that lower proportion of children, higher population density, and lower social class were significantly associated with higher extreme heat in Juárez neighborhoods (Grineski et al. 2011). Grineski et al. (2011) concluded their examination of the climate gap in Juárez with the hypothesis that because many with the ability to leave the city (e.g., professionals, business owners) have been migrating due to safety concerns, the increasingly socially marginalized population left behind will face an acute climate gap with regards to their exposures to extreme heat and their ability to cope under climate change conditions. This paper tests that hypothesis.

3. Study Context

Ciudad Juárez, Chihuahua, Mexico is an industrial city that has recently (2008–2012) suffered through the economic recession and a drug war. It is located on the international boundary with the US, just across the Rio Grande/Bravo from El Paso, Texas. Prior to 2005, Juárez experienced decades of rapid population growth due to economic opportunities in the US-Mexico border region. With the end of the US’s *Bracero* Program (1942–1964), which legalized the movement of Mexican workers into the US during WWII to help with labor shortages, several hundred thousand Mexican workers were relocated to Mexican border cities. The Mexican government then created the Border Industrialization Program to alleviate unemployment and overcrowding in border cities like Juárez (Frey 2003; Liverman and Vilas 2006). This program was successful and there are over 3,500 *maquiladoras* in the region. These mostly US-owned transnational corporations are allowed to import needed equipment and raw materials tax-free and they employ roughly 25% of the Mexican manufacturing labor force (Frey 2003; Liverman and Vilas 2006).

The 1980s and early 1990s saw the World Bank and International Monetary Fund further liberalize Mexico’s economy, which culminated in the North American Free Trade Agreement (NAFTA) in 1994. Because it reduced tariff barriers to trade, the passage of the NAFTA enabled continued industrial growth along the Mexican side of the border, especially in Juárez (Liverman et al. 1999). After NAFTA, the Mexican agricultural sector became increasingly export oriented, forcing domestic farmers to compete globally, with prices increasingly dictated by international markets. Climate change and drought have

amplified vulnerability among Mexican agriculturalists; and concomitant political-economic and environmental push factors have expanded flows of wage labor migrants to cities like Juárez, as farmers have been driven from their increasingly marginal rural livelihoods (O'Brien and Leichenko 2000; Parenti 2011). This rural-to-urban migration is seen in statistics for Juárez: the population more than doubled between 1980 and 2005, rising from 567,365 to 1,313,338 people (Consejo Nacional de Población 2005). While most migrants are drawn by the promise of steady employment in the Juárez industrial sector, *maquiladora* workers are poorly paid. This has led many low-income migrants to reside in squatter settlements on the fringes of the city while elites and middle-class residents live in formally developed, more centrally located, urban neighborhoods. Scholars have argued that “the social and physical infrastructure of Juárez could not sustain such excessive urban growth, which created a ‘city spinning out of control’” (Morales and Bejarano 2009, p. 429). Morales and Bejarano (2009) have also reported that neoliberal policies, such as NAFTA, exacerbated social inequality along the border, which in turn has perpetuated violence.

In Juárez, and elsewhere in Mexico, shifts in the global economy have major impacts on the city due to its primarily export-oriented economy. The economic downturn in 2008 hit the city hard, resulting in a loss of more than 80,000 jobs and hampering the abilities of people to make a living in the city (Kolenc 2010). A steep rise in narco-violence began after the onset of the global economic recession. Between 2008 and 2012, over 10,000 people were killed in Juárez according to *El Diario*, a local newspaper (Alvarado 2012).

Social and economic inequalities have loomed large as underlying factors in the current epoch of violence. In reflecting on the causes of the current drug war in Juárez, Campbell (2011) argued that there have been five key contributing factors. First, the *maquiladora* model has failed to produce upward economic mobility and social development for the majority of the border population over the past decade. Second, the global economic crisis led to a rash of Juárez *maquila* closures, which left laid-off border workers with nothing to fall back on as the US militarized its southern border with fences, walls and more Border Patrol agents (Campbell 2011). Third, the neoliberal model championed by the former Mexican President Carlos Salinas and continued by the PAN administrations between 2000 and 2011 eroded the social safety net and broke down the old patronage networks that kept drug traffickers in line. Bitter political battles allowed little or no cooperation between the federal government and state/local governments to address the violence (Campbell 2011). Fourth, former President Felipe Calderón’s “drug war,” which began in 2006 and was partially sponsored by the US government, failed to curb cartel activities and has in fact spurred violence. North Americans’ demand for drugs and our liberal gun laws have also fueled Mexican drug trafficking and related violence. Fifth, since the 1990s, a “counterculture of crime” has arisen in Mexico in tandem with economic decline. A growing and desperate population of unemployed and under-employed workers, especially the youth, has emerged as an alienated labor pool ripe for recruitment by cartels, gangs and kidnapping/extortion rings (Campbell 2011).

Drug-related violence has had serious impacts on the city’s residents. Between 2009 and 2010, the drug war left more than 10,000 children in México orphaned and more than 40,000 relatives of victims affected by the violence (Paterson 2010). Survey research

demonstrated that over 95% of Juárez residents did not feel safe in 2010 (Martínez-Cabrera 2011). Over 50% of crimes in Juárez are not reported to authorities as approximately 90% of residents report that they have no or little confidence in those responsible for security in the city. In 2009 alone, 50% had been victims of robbery, and 23% had been assaulted (Velázquez Vargas 2012). 71% had been at an area where someone has been killed (Martínez-Cabrera 2011).

The insecurity has impacted not only social well-being and quality of life (Hernandez and Grineski 2012), but also economic activity and growth. The city has seen a dramatic drop in tourism (including foreigners seeking medical and dental care) and a significant rise in unemployment (to a rate that is twice that of Mexico). These factors have resulted in dramatic out-migration of residents that has been unmatched in the history of this border region (Velázquez Vargas 2012). Despite an official report from INEGI of a .3% population growth rate, Velázquez Vargas (2012) argued that this outmigration, combined with a reduction in in-migration, lower birth rates, and high death rates from homicides, resulted in negative population growth rate between 2005 and 2010. This growth rate marks a dramatic shift for a city that has had higher growth rates than the nation as a whole since at least 1930. And, 42% of residents over 18 years of age surveyed in 2009 were potential migrants, meaning that they desired to leave Juárez to avoid becoming victims of crime, but had not left (Velázquez Vargas 2012).

The impacts of this outmigration are seen in the urban landscape. Figures 1–3 present examples of residential neighborhoods that have been impacted by the outflows of people from the city. Figure 1 shows how abandoned homes are sometimes stripped of all items of value (e.g., windows, pipes, and doors) and vandalized. Figure 2–3 demonstrate the socio-environmental context of residents who remain in their homes after many neighbors move away. The children in Figure 2 walk home from school through a neighborhood with many vacant homes, while the residents of the home centered in Figure 3 live next to an abandoned home.

These socio-demographic changes occurred in a city that was already vulnerable to changing climatic conditions (Collins et al. 2013), and where exposure to increasingly extreme summer heat is of growing concern (see Table 1). Heat vulnerability in Juárez derives from characteristics of the urban environment and its residents. Many Juárez families lack air conditioning units, especially those that live on the fringes of the city without access to public infrastructure. The use of public transportation is widespread and many residents spend substantial time outdoors walking to and from bus stops and waiting for busses. While natural ecological landscapes are similar to those of the arid US Southwest, residential landscapes of Juárez (see Figures 1–3) are not nearly as densely vegetated as the water-infused landscapes in other southwestern cities, which reduces residents' abilities to cool off outside. Neighborhoods just across the border in Juárez's sister city of El Paso, Texas, for example, are 2.3 times more vegetated than average neighborhoods in Juárez. In Phoenix, Arizona, families have traditionally landscaped with shade trees native to more humid climates and many maintain private swimming pools (Wentz and Gober 2007), which is not the case in Juárez, where few refuges from the heat exist. Within a context of public insecurity, isolation inside the home is a common response, and housing units can get quite

hot during the summer in Juárez. In-depth interviews with poor parents in Juárez during the peak of the violence demonstrated that many families did not permit their children to go outside to play, even within walled patios, and that isolation in the home was more common for women and those without cars and cell-phones (Grineski, Hernandez and Ramos 2013).

Under climate change scenarios, a temperature increase of 3 to 5°C by 2100 is projected for the western US-Mexico border region, including Juárez (Intergovernmental Panel on Climate Change 2007). Not only is it hot and predicted to get hotter in Juárez, but the same forces of economic globalization that have contributed to the rapid population growth of the city have transformed landscapes in ways that have amplified extreme heat exposures in particular social spaces. The resulting socially-produced urban heat archipelago explains much of the observable variability we see in extreme heat at the neighborhood level and also underpins the exposure gaps revealed by our analyses.

Viewing this through a double exposures lens, we take the perspective that economic insecurity and drug violence interact with changing environmental conditions to shape population risk to extreme heat. The city's export-oriented economy is extremely sensitive to external forces, leading to severe local impacts from global economic trends, like the recession in 2008. The recession caused many to migrate from the city. It has also provided a ready workforce for the drug cartels because of the loss of formal sector jobs in Juárez and the difficulty in crossing the border for better livelihood options due to increases in US border security efforts (Parenti 2011). How these political-economic and demographic changes will shape people's exposure to, and ability to cope with, climate change risks is an open question. As a starting point, this paper investigates how current and changing patterns of neighborhood demographics (i.e., heat-related social vulnerability) are associated with extreme heat in the city through three research questions:

1. How have patterns of heat-related social vulnerability changed between 2000 and 2010?
2. How are changing patterns of heat-related social vulnerability between 2000 and 2010 associated with residential exposure to extreme heat in Ciudad Juárez?
3. Given these demographic changes, how is heat-related social vulnerability associated with residential exposure to extreme heat in Ciudad Juárez in 2010?

4. Data

4.1 Unit of Analysis

The unit of analysis is the *Área Geoestadística Básica* (AGEB), which is the Mexican equivalent to US Census block group. We refer to AGEBs here as “neighborhoods” because they approximately correspondent to one another (in terms of population and areal size). We excluded AGEBs from the analysis if they had fewer than 200 people in the year 2000 or fewer than 200 people in the year 2010, to be able to create stable change variables between 2000 and 2010. This was done in two steps. First, based on 2010 population counts, we removed a total of 64 populated AGEBs from the study (50 with between 1–100 people and 14 with between 101–199 people). Second, looking at the 2000 population counts, we

removed another 28 populated AGEs from the study (17 with 1–100 people and 11 with 101–199 people). This resulted in 436 neighborhoods for analysis.

4.2 Extreme Heat

To spatially represent extreme heat, we utilized a composite surface that averaged five summer daytime Landsat 7 remotely sensed images with air temperatures that exceeded 100° F with zero cloud cover centered on the year 2010. The images used were from the following days: 7/13/2009, 7/29/2009, 6/14/2010, 8/17/2010, and 9/2/2010. We considered only days that exceeded 100° F because this air temperature is a threshold just above the human body's thermoregulating temperature range (Sherwood and Huber 2010), and a temperature which is generally considered as very hot in Juárez (it is approximately 1 standard deviation hotter than the city's mean summer daytime high temperature for the years 2002–2012). 100° F also falls within NOAA's National Weather Service Heat Index category of "extreme caution" for the likelihood of heat disorders due to prolonged exposure or strenuous activity (NOAA 2010).

While we used an air temperature threshold (100° F) to select the possible days for inclusion into our composite surface, the heat surfaces used in the analysis are based on estimates of land surface temperature (LST) derived from remotely sensed images. LST is different than the air temperature readings commonly reported in weather forecasts. LST is how hot the surface of the Earth (e.g., a roof, a road, a grassy lawn) feels to the touch at a particular location.

ENVI version 4.8 and ESRI ArcGIS 10 were used for image processing. Thermal band pixel values for the images were calibrated and converted to radiance values; parameters required for the calibration like gain, offset, sun elevation and acquisition day were read from the header file attached to each image. The radiance values were then converted using the normalized emissivity function that applies the inverse of the Planck function to derive Kelvin temperature values. Then, using a band math function, Kelvin temperatures were converted to Fahrenheit in order to facilitate interpretation. Once temperature values in degrees Fahrenheit were obtained in raster format, the mean LST values for each neighborhood (i.e., AGE) in vector format were created, and then averaged across the five surfaces. Descriptive statistics for the extreme heat variable are found in Table 2 and mapped in Figure 4. Mean LST is a good choice as a neighborhood level extreme heat measure because of its demonstrated linkage to heat-related mortality; for example, Johnson, Wilson and Luber (2009) found that mean LST, constructed using Landsat data, was the most important variable for predicting extreme heat mortality risk in census tracts during an extreme heat event in Philadelphia.

4.3 Heat-related Social Vulnerability Indicators

Socio-demographic variables are used to operationalize heat-related social vulnerability in this analysis. The heat-related social vulnerability indicators correspond with a subset of variables used by Reid et al. (2009), and include a measure of socioeconomic status (mean education in years of formal schooling for the population age 16 and over), percent older adults (age ≥ 65 years), and total population density. The way these three variables were

collected by the Mexican census in 2000 and 2010 was consistent, making it possible to develop matched indicators for 2000 and 2010. In this analysis, the 2000 values serve as baselines from which to measure population changes, and the 2010 values represent the contemporary population characteristics.

Socioeconomic status (SES) is an important heat-related social vulnerability variable because higher rates of heat-related mortality have been found for people of low SES (Chan et al. 2010; Medina-Ramon et al. 2006; Portier et al. 2010), who have a relatively narrow range of choice in preparing for and responding to extreme heat exposures. Those with low SES also tend to have inadequate access to health care, which makes recovering from climate change-related illnesses more difficult (Portier et al. 2010). Mean education was used as the SES indicator as mean income was not available. It has been used in previous environmental justice studies in Juárez (Grineski et al. 2010; McDonald and Grineski 2011) and other studies have demonstrated a strong relationship between income and education (Tejedo-Balzaretti 2008).

Considerations of older populations are also important as numerous studies have shown that older adults are a particularly vulnerable group to heat-related morbidity and mortality (Naughton et al. 2002; Schifano et al. 2009; Semenza et al. 1999; Stafoggia et al. 2006). Population density is important to include because high population densities and concentrations of buildings have been associated with increased population exposure and sensitivity to heat exposure (Harlan et al. 2006; Jenerette et al. 2007; Medina-Ramon et al. 2006; Portier et al. 2010; Smoyer 1998).

In addition to creating these three variables for 2000 and 2010, we also constructed “proportion change” indicators for each neighborhood, which measure changes in the heat-related social vulnerability indicators between 2000 and 2010. This was done by subtracting the variable value in 2000 from its value in 2010 and dividing it by the value in 2000 for each neighborhood. This makes positive change values indicative of the proportional increase in the variable during the 10 years, while negative values indicate the proportional decrease on the variable over the 10-year period. In terms of how these changes relate to vulnerability, a positive change in proportion elderly maps to increased vulnerability whereby a positive change in mean education corresponds with decreased vulnerability. Descriptive statistics for these nine variables are included in Table 2 and maps are included in Figure 5–6.

5. Methods

After running descriptive statistics (Table 2), we began to explore basic relationships by examining bivariate correlations between the nine heat-related social vulnerability variables and extreme heat (see Table 3). Then, we utilized two regression models in our analysis. The first (model 1) considered the set of three baseline indicators (i.e., mean education, older adults, and population density in 2000) and the set of three change indicators (i.e., proportion change in mean education, older adults, and population density since 2000) as predictors of extreme heat in 2010. The second (model 2) included the set of three contemporary indicators (i.e., mean education, older adults, and population density in 2010)

as predictors of extreme heat in 2010. Together, these models shed light on how changes in patterns of vulnerability as well as current patterns of vulnerability are related to extreme heat.

Following Chakraborty (2009), we used the open source software, GeoDa (available at <http://geodacenter.asu.edu/>) to conduct the regression analysis. GeoDa software provides diagnostic statistics to aid model specification (Anselin 2005). We initially ran both regression models using ordinary least squares (OLS) to test model residuals for spatial autocorrelation using the Univariate Moran's I test. Spatial autocorrelation is typically caused by geographic clustering when values at nearby locations are more similar or different than would be expected for a random distribution (Kissling and Carl 2008). This phenomenon has the potential to cause spatial dependence of regression model residuals, thus violating the assumption of independence. Models 1 and 2 indicated positive spatial autocorrelation in the residuals (i.e., Moran's I values were significant at a p -value of 0.001; spatial weight: 1,000 m); this meant that our data did not meet the assumptions of OLS regression models.

We used the Lagrange Multiplier (LM) and the Robust LM diagnostic tests to determine if the spatial lag or spatial error model specification should be used (Anselin 2005). Spatial lag models assume that spatial autocorrelation is present in the dependent variable (Chakraborty 2009), while spatial error models assume that the independent variables exhibit spatial dependence (Pastor, Morello-Frosch and Sadd 2005). In this case, the LM tests suggested that the spatial error specification was appropriate for both models. Another specification diagnostic offered by GeoDa in OLS regression is the multicollinearity condition index. The condition index measures the stability of the regression results due to multicollinearity (Anselin 2005; Chakraborty 2009). Anselin (2005) suggests that a condition index of 30 is indicative of serious collinearity problems. In our case, the condition indices were 5.027 for model 1 and 1.772 for model 2, which indicate the absence of multicollinearity issues.

Spatial econometric models are supported by means of the maximum likelihood method and they require sparse spatial weights (Anselin, Syabri and Kho 2006; Chakraborty 2009), which are calculated based on a set of neighbor relationships (Pastor, Morello-Frosch and Sadd 2005). We used the distance method of defining weights, following Chakraborty (2009). This method is more appropriate for irregularly-shaped census geography than the rook or queen method (Pastor, Morello-Frosch and Sadd 2005). The process of selecting a bandwidth distance for neighbors is iterative. We began the process using 1,000 m as our distance band. In both models, the Moran's I test was significant at the $p > .001$ level, indicating that the autocorrelation had not been accounted for. We then proceeded to re-run the models adding 1,000 m to the band each time, until the spatial autocorrelation was accounted for at the $p > .001$ level, which it was at 2,000 m for both models (see Table 4–5). At this distance, all neighborhoods had at least one neighbor.

6. Results

6.1 Describing Changes in Heat-related Social Vulnerability

The most remarkable change in a city that was growing rapidly until 2005 (Velázquez Vargas 2012) was the decrease in population density in over 75% of the city's neighborhoods between 2000 and 2010 (see Table 2); only 90 neighborhoods saw increases in population density. The average neighborhood lost nearly 2,000 people per square kilometer during the decade. With these dramatic drops in density, there was an approximately 40% raw increase (raw increases not shown in Table 2) in the proportion of older adults in the average neighborhood between 2000 and 2010; only 26 neighborhoods did not register an increase in the proportion of older adults. This suggests that older adults, a hypothetically socially vulnerable group, were less likely to have migrated away from the city during the preceding years. However, the city saw an approximately one-year increase in the mean level of education across its neighborhoods (see Table 2), which may relate to the fact that younger adults (e.g., those with fewer years of education and/or incomplete educational attainment) were more likely to leave the city.

6.2 Correlations between Heat-related Social Vulnerability and Extreme Heat

In terms of the basic relationships between heat and the explanatory variables (see Table 3), higher proportions of residents over 65 (2000 and 2010) and lower levels of education (2000 and 2010) were associated with higher extreme heat (2010). This reflects a typical pattern of environmental injustice whereby increasing social vulnerability maps to increasing environmental hazard exposure. The relationship between heat and density flipped between the two time periods. While it was positive in 2000, it became negative in 2010. In terms of the proportion change variables, decreasing proportion of residents over 65, decreasing population density and decreasing mean level of education were associated with higher extreme heat in 2010.

6.3 Spatial Regression Models Predicting Extreme Heat

The first spatial lag model included the baseline (2000) and change (2000–2010) variables (see Table 4). It revealed that higher neighborhood population densities and lower levels of education in 2000 were associated with higher extreme heat ($p < .05$); higher proportions of older residents in 2000 were associated with higher extreme heat, but not significantly ($p = .12$). For the population change indicators, a decrease in population density and an increase in the proportion of older residents were associated with higher extreme heat ($p < .05$); a decrease in mean education was associated with higher extreme heat, but not significantly ($p = .33$). The second spatial lag model included the current (2010) indicators (see Table 5). Lower population density and lower levels of education were significantly associated with extreme heat while higher proportions of older residents were associated with higher heat at a level that approached statistical significance ($p = .08$).

7. Discussion

From a double exposures perspective, it is clear that global scale processes have exacerbated vulnerability to extreme heat in Juárez. In fact, some Juárez residents and neighborhoods

face situations of triple exposure, or vulnerability related to the effects of global economic change, drug cartel violence, and environmental change. This triple exposure is associated with a growing climate gap in partially abandoned neighborhoods with increasing concentrations of older residents and secondarily residents with lower levels of socio-economic status. Note that, in this context, triple exposure could exacerbate the impact of extreme heat on violent crime, although we did not investigate that here. Others have connected the impacts of climate change- such as natural disasters, sea-level rise and increasing resource scarcity- to increases in insecurity and violence (Theisen, Gleditsch and Buhaug 2013). Separately, a long line of studies have quantified the deleterious impact of hot temperatures on violent crime and riots (as reviewed by Theisen, Gleditsch and Buhaug 2013).

We summarize three key ‘climate gap’ findings in what follows. First, the relationship between population density and extreme heat reverses direction between 2000 and 2010 (models 1 and 2, and correlations). In 2000, the more typical pattern of higher density neighborhoods being hotter, such as was found in Phoenix, Arizona (Harlan et al. 2006), was present in the city of Juárez (Grineski et al. 2011). By 2010, the previously densely settled neighborhoods of the urban core had become less dense. The violence played a critical role in the movement of residents away from the city center, which was a “hot spot” for murders between 2006 and 2009 (Cervera and Fragoso 2010). Specifically, between 2007 and 2009, approximately 230,000 residents out-migrated from Juárez; 54% of them moved to the US with 55,775 residents settling across the border in El Paso, Texas. The rest mainly returned to their Mexican states of origin which for the majority of residents was Durango, Coahuila, or Veracruz (Velázquez Vargas 2012). Despite the exodus of residents, the area remained hot due to paved roads, parking lots and built-up infrastructure; this resulted in the negative association between density and extreme heat that we reported for 2010.

Second, the association between growing proportions of older residents and extreme heat, while controlling for density and mean education (Table 4), is perhaps the most troubling finding from a public health perspective due to the vulnerability of older residents to morbidity and mortality during extreme heat (Naughton et al. 2002; Schifano et al. 2009; Semenza et al. 1999; Stafoggia et al. 2006). When SES and population density are held constant, this finding emerged, which indicates a phenomenon where younger residents have migrated out of neighborhoods in relatively higher proportions, while older residents have exhibited a stronger tendency to remain. Across the city, 94% of neighborhoods have seen an increase in the proportion of older adults since 2000. The tendency for older adults to stay is most likely related to their typically decreased mobility due to difficulties with physical movement as well as their generally reduced access to resources and capacities to pursue livelihood opportunities elsewhere. Given that previous research on violence in Juárez has documented a lack of trust in institutions and the police (Velázquez Vargas 2012) and a general lack of contact between neighbors (Hernandez and Grineski 2012), many of these older residents are likely socially isolated.

An examination of an extreme weeklong heat wave in Chicago in 1995 that claimed over 700 lives revealed that isolation was a key risk factor for mortality for older adults

(Kleinenberg 2003). Specifically, risk factors for dying during the 1995 Chicago disaster were not leaving home daily; having a medical problem; being confined to bed; living alone; and lacking air conditioning, access to transportation and social contacts (Kleinenberg 2003). These characteristics are closely related to old age and in fact, 53% of those that died were over 65 (Naughton et al. 2002). At the community-level, residence in high poverty and high crime neighborhoods and a lack of vegetation were risk factors for heat-related mortality. Clearly, fears of violence and crime played a role in the social isolation experienced by elderly Chicagoans during the heat wave. Kleinenberg (2003, p. 90) stated in relation to one of his case study neighborhoods: “the dangerous ecology of abandoned buildings, open spaces, violent crime, degraded infrastructure, low population density and family dispersion undermines the viability of public life and the strength of local support systems, rendering older residents particularly vulnerable to isolation.” Despite being used to describe a poor, African-American neighborhood in Chicago which suffered many deaths in 1995, these characteristics may apply equally well to hot Juárez neighborhoods as illustrated by the photographs in Figures 1–3.

While the association between proportion of older adults and heat was positive in both 2000 and 2010 (correlations significant, regression findings approaching significance, especially in 2010), the change findings (model 1) suggest increasing risk for this already vulnerable group when accounting for the other variables in the models. In sum, results suggest that older people are at increased risk to being trapped in places where they must cope with triple exposures: extreme heat, social isolation and fear, and economic insecurity.

Third, we found a stable association between low SES (i.e., low mean education) and higher heat in 2000 and 2010 (correlations, model 1, and model 2). This aligns with work in Phoenix (Harlan et al. 2006) and demonstrates the presence of a climate gap. This is a concern because it is likely that those with low SES have reduced access to resources and will have more difficulty coping with extreme heat; poor families may lack piped water, air conditioning, electric fans and shade trees, and they may have reduced access to resources via social institutions. In terms of the change findings (model 1), a drop in neighborhood mean education between 2000 and 2010 was significantly associated with higher heat in the correlations, which may suggest increasing poverty in hot neighborhoods. However, the positive regression coefficient was not statistically significant ($p=.33$). The greater exposure of residents with low SES to extreme heat corresponds with the disproportionate exposure experienced by socially vulnerable residents to an extreme flood event that impacted Juárez in 2006 (Collins 2009; Collins 2010). The amplified exposure of Juarenses with low SES to both extreme heat and flooding points toward the existence of a gap in the context of multiple climate change-related hazards; this robust climate gap is further accentuated by the reduced capacities of those socially vulnerable residents to cope with the impacts of extreme event exposure.

7.1 Limitations

A key limitation relates to our operationalization of socioeconomic status. While mean education has been used in other environmental justice and climate change vulnerability studies relying on Mexican data (e.g., Collins et al. 2013; Grineski and Collins 2010; Lara-

Valencia et al. 2009), it is less sensitive to household-level changes in socioeconomic status between years than is a variable like mean household income. While a household's income may have dropped between 2010 and 2000 due to job loss, for example, the householder's education level would have remained constant assuming he/she did not attend additional years of schooling. The mean education variable at the neighborhood level can capture the net outmigration of people with certain levels of education between the two periods, but not changes in neighborhoods' socioeconomic status due to net gains/losses of income between the two periods. However, the Mexican census does not collect income data at the neighborhood level, and in 2010, they did not collect the poverty measure that was available in 2000, which was related to minimum wage.

A second limitation involves the use of Juárez census data more generally. While census data are a respected source of data in Mexico and elsewhere, collecting the 2010 data was demanding. The number of abandoned homes and subdivisions - the city's planning department said about 110,000 houses in Juárez were abandoned during 2010 - created an added challenge (Licón 2010). With no mail form, census workers knocked on doors numerous times to ensure houses were indeed abandoned. The 2010 Census was also difficult because *Juarenses'* distrust of the federal government grew as the violence continued which made it more difficult to keep census workers safe. However, officials believe in the accuracy of the 2010 Census because INEGI, the agency that administers the census, is a well-regarded institution among Mexicans. Additionally, staffers visited schools, organizations, and hospitals to inform people about the census. Commercials educating people about the census also appeared on the two major television networks, as well as on local radio stations and in newspapers (Licón 2010).

Third, the availability of only two data points (2000 and 2010) limits our ability to assess neighborhood changes during the intervening period of time as a result of the violence and recession. For example, Figure 6 shows net gains in population density on the fringes of the city (where the new developments are found) between 2000 and 2010, but those two data points do not capture possible decreases in density in those fringe neighborhoods that may have occurred in the second half of the decade. The fringe neighborhoods register net population density increases (see Figure 6) because of the lower levels of urban development in those areas prior to the early 2000s. The use of two data points also limits our ability to assess change on a longer time scale.

Fourth, we do not know exactly how heat-related social vulnerability relates to actual health outcomes in Juárez. Existing health surveillance data do not provide a basis to accurately summarize the impact of heat-related morbidity and mortality in Juárez. A study of daily all-cause mortality in 12 cities in low- and middle-income countries, however, concluded that urban populations in the less developed world are adversely affected by high temperatures and will be especially vulnerable in the future to the direct impacts of extreme heat under climate change (McMichael et al. 2008). The interior northern Mexican city of Monterrey, which has social and biophysical characteristics comparable to Juárez, "displayed a particularly impressive increase in mortality" in association with temperature extremes (McMichael et al. 2008, p. 1129).

8. Conclusion

In a previous study of the climate gap in Juárez using 2000 data, Grineski et al. (2011) hypothesized that because many with the ability to leave the city (e.g., professionals, business owners) migrated due to safety concerns, the increasingly socially marginalized population left behind would face an acute climate gap with regards to their ability to cope under climate change conditions. While accounting for the changes in neighborhood population density, we did not find statistically significant evidence of a growing gap with regards to changing SES; we did, however, document the presence of a stable gap based on low SES residents experiencing significantly increased heat exposure across Juárez neighborhoods for both 2000 and 2010.

We found a widening gap in regards to the association between heat and growing proportions of older adults in Juárez neighborhoods between 2000 and 2010. Older people appear to be at increased risk to being trapped in residential environments and to suffer triple exposures. This is especially the case for older residents who experience constrained access to economic, social and/or political resources. As a recent synthesis of the expanding literature on global environmental change and migration warns, trapped populations – unable to move out of situations of increasing risk (due to socio-environmental change) – face grave dangers due to the coupling of extreme hazard exposure with constrained coping capacities (Black et al. 2011; Foresight 2011). Whereas there was an exodus of wealthier and younger residents from Juárez neighborhoods as the narco-violence peaked in the late 2000s, older *Juarenses* have grown increasingly marginalized within the city's precarious socio-thermal environments.

To the best of our knowledge, Juárez does not have programs in place to operate cooling shelters during heat waves. Many residents lack access to air conditioning, a known protective factor against mortality during heat waves (Naughton et al. 2002). The city does, however, operate temporary warming shelters in spaces like community centers and government offices during the coldest winter days for residents without heat and so the social planning to operate cooling shelters in the summer months may exist. During heat waves, the city has occasionally sent water trucks into neighborhoods without access to piped water to deliver free water to residents. It stands to reason, that extreme heat has already significantly impacted human health in Juárez and that health impacts will most likely intensify due to the combination of climate change, economic globalization, and social insecurity along Mexico's northern border.

Acknowledgments

We acknowledge Bill Hargrove (Center for Environmental Resource Management [CERM] at the University of Texas at El Paso [UTEP]) and Marcelo Korc (Pan-American Health Organization) for helping assemble the research team. This work is dedicated to the late Dr. Paula Ford, a co-PI on the project. This project was supported by the Southwest Consortium for Environmental Research and Policy (SCERP) Environmental Protection Agency (EPA) Cooperative Agreement EM 83486101-01. The project was also supported by Award Number P20 MD002287-05S1 from the National Institute on Minority Health and Health Disparities (NIMHD) and Award Number CMMI-1129984 from the National Science Foundation (NSF). The content is the responsibility of the authors and does not necessarily represent the views of the CERM, UTEP, SCERP, US EPA, NIMHD or NSF.

References

- Alvarado, Emily. Texas Monthly Daily Post. Austin, TX: 2012. Juárez Death Toll Surpasses 10,000.
- Anselin, Luc. Exploring Spatial Data with GeoDa: A Workbook. Urbana, IL: University of Illinois, Urbana-Champaign; 2005. p. 1-244.
- Anselin, Luc; Syabri, Ibnu; Kho, Youngihn. GeoDa: An Introduction to Spatial Data Analysis. Geographical Analysis. 2006; 38:5–22.
- Basu R, Samet J. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. Epidemiological Review. 2002; 24:190–202.
- Basu R, Malig B, Ostro B. High Ambient Temperature and the Risk of Preterm Delivery. American Journal of Epidemiology. 2010; 172(10):1108–1117. [PubMed: 20889619]
- Black R, Bennett SRG, Thomas SM, Beddington JR. Migration as adaptation. Nature. 2011; 478:447–449. [PubMed: 22012304]
- Bolin, Bob; Declet Barreto, Juan; Hegmon, Michelle; Meierotto, Lisa; York, Abigail. Double Exposure in the Sunbelt: The Sociospatial Distribution of Vulnerability in Phoenix, Arizona. In: Christopher Boone and Michail Fragkias. , editor. Linking Urban Ecology, Environmental Justice and Global Environmental Change: A Framework for Urban Sustainability. Springer; 2013. p. 159-178.
- Campbell, Howard. No End in Sight: Violence in Ciudad Juarez. NACLA. 2011 May-Jun;:19–22.
- Cervera, Luis E.; Monárrez Fragoso, Julia E. Sistema de Información Geográfica de la Violencia en el municipio de Juárez, Chihuahua: Geo-referenciación y su comportamiento espacial en el contexto urbano y rural (SIGVIDA). Comisión nacional para prevenir y erradicar la violencia contra las mujeres. Ciudad Juárez. , editor. Chihuahua, Mexico: Secretaría de gobernación; 2010.
- Chakraborty, Jayajit. Automobiles, Air Toxics, and Adverse Health Risks: Environmental Inequities in Tampa Bay, Florida. Annals of the Association of American Geographers. 2009; 99(4):674–697.
- Chan E, Goggins W, Kim J, Griffiths S. A study of intracity variation of temperature-related mortality and socioeconomic status among the Chinese population in Hong Kong. Journal of Epidemiology and Community Health. 2010
- Collins, Timothy. The production of unequal risk in hazardscapes: An explanatory frame applied to disaster at the U.S.-Mexico border. Geoforum. 2009; 40(4):589–601.
- Collins, Timothy. Marginalization, facilitation, and the production of unequal risk: the 2006 Paso del Norte floods. Antipode. 2010; 42(2):258–288.
- Collins, Timothy W.; Grineski, Sara E.; Ford, Paula; Aldouri, Raed; Aguilar, Maria de Lourdes Romo; Velazquez-Angulo, Gilberto; Fitzgerald, Rosa; Lu, Duanjun. Mapping vulnerability to climate change-related hazards: children at risk in a US–Mexico border metropolis. Population and Environment. 2013; 34:313–337.
- Consejo Nacional de Población. Delimitación de Zonas Metropolitanas. México D.F.; 2005.
- Curriero, Frank C.; Heiner, Karlyn S.; Samet, Jonathan M.; Zeger, Scott L.; Strug, Lisa; Patz, Jonathan A. Temperature and mortality in 11 cities of the eastern United States. American Journal of Epidemiology. 2002; 155:80–87. [PubMed: 11772788]
- Foresight. Migration and Global Environmental Change. London: The Government Office for Science; 2011.
- Frey, R. Scott The Transfer of Core-Based Hazardous Production Processes to the Export Processing Zones of the Periphery: The Maquiladora Centers of Northern Mexico. Journal of World Systems Research. 2003; IX(2):317–354.
- Grineski SE, Hernandez AA, Ramos V. Raising Children in a Violent Context: An intersectionality approach to understanding parents' experiences in Ciudad Juárez. International Women Studies Review. 2013 <http://dx.doi.org/10.1016/j.wsif.2013.04.001>.
- Grineski, Sara E.; Collins, Timothy W. Environmental Injustice in Transnational Context: Urbanization and industrial hazards in El Paso/Ciudad Juárez. Environment and Planning A. 2010; 42(6):1308–1327.
- Grineski, Sara E.; Collins, Timothy W.; Romo, Lourdes; Aldouri, Raed. No Safe Place: Environmental Hazards & Injustice along Mexico's Northern Border. Social Forces. 2010; 88(5):2241–2266.

- Grineski, Sara Elizabeth; Collins, Timothy W.; Ford, Paula; Fitzgerald, Rosa M.; Aldouri, Raed; Velázquez-Angulo, Gilberto; Aguilar, Maria de Lourdes Romo; Lu, Duanjun. Climate Change And Environmental Injustice In A Bi-National Context. *Applied Geography*. 2011
- Harlan, Sharon L.; Brazel, Anthony J.; Prashad, Lela; Stefanov, William L.; Larsen, Larissa. Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine*. 2006; 63(11):2847–2863. [PubMed: 16996668]
- Hernandez AA, Grineski SE. Disrupted by violence: children's well-being and families' economic, social, and cultural capital in Ciudad Juarez, Mexico. *Revista Panamericana De Salud Publica-Pan American Journal of Public Health*. 2012; 31(5):373–379. [PubMed: 22767037]
- Intergovernmental Panel on Climate Change. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Climate change 2007: The physical science basis*. Cambridge, UK: Cambridge University Press; 2007.
- Jenerette DG, Harlan S, Brazel A, Jones N, Larsen L, Stefanov W. Regional relationships between surface temperature, vegetation, and human settlement in a rapidly urbanizing ecosystem. *Landscape Ecology*. 2007; 2:353–365.
- Jenerette GD, Harlan SL, Stefanov WL, Martin CA. Ecosystem services and urban heat riskscape moderation: water, green spaces, and social inequality in Phoenix, USA. *Ecological Applications*. 2011; 21(7):2637–2651. [PubMed: 22073649]
- Johnson D, Wilson JP, Lubert G. Socioeconomic indicators of heat-related health risk supplemented with remotely sensed data. *International Journal of Health Geographics*. 2009; 8(57):1–13. [PubMed: 19149870]
- Kersten, Ellen; Morello-Frosch, Rachel; Pastor, Manuel; Ramos, Marlene. Facing the Climate Gap: How Environmental Justice Communities are Leading the Way to a More Sustainable and Equitable California. Program for Environmental and Regional Equity. , editor. University of Southern California; 2012. p. 1-84.
- Kissling, W. Daniel; Carl, Gudrun. Spatial autocorrelation and the selection of simultaneous autoregressive models. *Global Ecology and Biogeography*. 2008; 17:59–71.
- Kleinenberg, Eric. Heat Wave: A Social Autopsy of Disaster in Chicago. Chicago: University of Illinois; 2003.
- Kolenc, Vic. El Paso Times. El Paso, TX: 2010. Maquilas dodge the violence: Juárez plants hurt more by recession than drug violence.
- Lara-Valencia, Francisco; Harlow, Siobán D.; Lemos, Maria Carmen; Denman, Catalina A. Equity dimensions of hazardous waste generation in rapidly industrialising cities along the United States-Mexico border. *Journal of Environmental Planning and Management*. 2009; 52(2):195–216.
- Leichenko RM, O'Brien KL, Solecki WD. Climate Change and the Global Financial Crisis: A Case of Double Exposure. *Annals of the Association of American Geographers*. 2010; 100(4):963–972.
- Licón, Adriana Gómez. Mexico 2010 census effort a daunting task amid drug violence. El Paso, TX: El Paso Times; 2010.
- Liverman, Diana M.; Varady, Robert G.; Chavez, Octavio; Sanchez, Roberto. Environmental Issues Along the United States-Mexico Border: Drivers of Change and Responses of Citizens and Institutions. *Annual Review of Energy and Environment*. 1999; 24:607–643.
- Liverman, Diana M.; Vilas, Silvina. Neoliberalism and the environment in Latin America. *Annual Review of Environment and Resources*. 2006; 31(1):327–363.
- Lubert G, McGeehin M. Climate change and extreme heat events. *American Journal of Preventive Medicine*. 2008; 35:429–435. [PubMed: 18929969]
- Martínez-Cabrera, Alejandro. El Paso Times. El Paso: 2011. Survey: More want US to help Juárez; p. A1
- McDonald, Yolanda J.; Grineski, Sara E. American Association of Geographers. Seattle, WA: 2011. Social determinants of health risk due to lack of plumbing: The case of El Paso-Ciudad Juárez.
- McMichael AJ, Wilkinson P, Kovats RS, Pattenden S, Hajat S, Armstrong B, Vajanapoom N, Niciu EM, Mahomed H, Kingkeow C, Kosnik M, O'Neill MS, Romieu I, Ramirez-Aguilar M, Barreto ML, Gouveia N, Nikiforov B. International study of temperature, heat and urban mortality: The 'ISOOTHERM' project. *International Journal of Epidemiology*. 2008; 37:1121–1131. [PubMed: 18522981]

- Medina-Ramon M, Zanobetti A, Cavanagh D, Schwartz J. Extreme temperatures and mortality: assessing effect modification by personal characteristics and specific cause of death in a multi-city case-only analysis. *Environmental Health Perspectives*. 2006; 114:1331–1336. [PubMed: 16966084]
- Morales, Maria Cristina; Bejarano, Cynthia. Transnational sexual and gendered violence: an application of border sexual conquest at a Mexico–US border. *Global Networks*. 2009; 9(3):420–439.
- Morello-Frosch, R.; Pastor, M.; Sadd, J.; Shonkoff, SB. The Climate Gap: Inequalities in How Climate Change Hurts Americans & How to Close the Gap. Program for Environmental and Regional Equity. , editor. University of Southern California; 2009. p. 1-32.
- Naughton, Mary P.; Henderson, Alden; Mirabelli, Maria C.; Kaiser, Reinhard; Wilhelm, John L.; Kieszak, Stephanie M.; Rubin, Carol H.; McGeehin, Michael A. Heat-Related Mortality During a 1999 Heat Wave in Chicago. *American Journal of Preventive Medicine*. 2002; 22(4):221–227. [PubMed: 11988377]
- Water Office of Climate, and Weather Services. , editor. NOAA. NOAA's National Weather Service Heat Index. Silver Springs, Maryland: National Weather Service; 2010.
- O'Brien KL, Leichenko RM. Double exposure: assessing the impacts of climate change within the context of economic globalization. *Global Environmental Change-Human and Policy Dimensions*. 2000; 10(3):221–232.
- Parenti, Christian. *Tropic of Chaos: Climate change and the new geography of violence*. New York: Nation Press; 2011.
- Pastor, Manuel; Morello-Frosch, Rachel; Sadd, James L. The air is always cleaner on the other side: Race, space, and ambient air toxics exposures in California. *Journal of Urban Affairs*. 2005; 27(2): 127–148.
- Pastor, Manuel; Morello-Frosch, Rachel; Sadd, James; Scoggins, Justin. *Minding the Climate Gap: What's at Stake if California's Climate Law isn't Done Right and Right Away*. University of Southern California; 2010. p. 1-36.
- Paterson, K. FNS: on-line. Las Cruces, NM: U.S.- México border news; 2010. Solidarity with a Besieged Sister City.
- Patz, Jonathan A.; Campbell-Lendrum, Diarmid; Holloway, Tracey; Foley, Jonathan A. Impact of regional climate change on human health. *Nature*. 2005; 438:310–317. [PubMed: 16292302]
- Portier, CJ.; Thigpen Tart, K.; Carter, SR.; Dilworth, CH.; Grambsch, AE.; Gohlke, J.; Hess, J.; Howard, SN.; Luber, G.; Lutz, JT.; Maslak, T.; Prudent, N.; Radtke, M.; Rosenthal, JP.; Rowles, T.; Sandifer, PA.; Scheraga, J.; Schramm, PJ.; Strickman, D.; Trtanj, JM.; Whung, P-Y. *A Human Health Perspective On Climate Change: A Report Outlining the Research Needs on the Human Health Effects of Climate Change*. Research Triangle Park, NC: Environmental Health Perspectives/National Institute of Environmental Health Sciences; 2010.
- Reid CE, O'Neill MS, Gronlund CJ, Brines SJ, Brown DG, Diez-Roux AV, Schwartz J. Mapping community determinants of heat vulnerability. *Environmental Health Perspectives*. 2009; 117:1730–1736. [PubMed: 20049125]
- Schifano, Patrizia; Cappai, Giovanna; De Sario, Manuela; Michelozzi, Paola; Marino, Claudia; Bargagli, Anna M.; Perucci, Carlo A. Susceptibility to heat wave-related mortality: a follow-up study of a cohort of elderly in Rome. *Environmental Health*. 2009; 8(50)
- Semenza JC, McCullough J, Flanders D, McGeehin M, Lumpkin J. Excess hospital admissions during the 1995 heat wave in Chicago. *American Journal of Preventive Medicine*. 1999; 16:269–277. [PubMed: 10493281]
- Sherwood, Steven C.; Huber, Matthew. An adaptability limit to climate change due to heat stress. *Proceedings of the National Academy of Sciences of the United States of America*. 2010; 107(21): 9552–9555. [PubMed: 20439769]
- Shonkoff SB, Morello-Frosch R, Pastor M, Sadd J. The climate gap: environmental health and equity implications of climate change and mitigation policies in California-a review of the literature. *Climatic Change*. 2011; 109:485–503.

- Shonkoff SB, Morello-Frosch Rachel, Pastor Manuel, Sadd James. Minding the Climate Gap: Implications of Environmental Health Inequities for Mitigation Policies in California. *Environmental Justice*. 2009; 2(4):173–177.
- Smoyer K. Putting risk in its place: methodological considerations for investigating extreme event health risk. *Social Science & Medicine*. 1998; 47:1809–1824. [PubMed: 9877350]
- Stafoggia M, Forastiere F, Agostini D, Biggeri A, Bisanti L, Cadum E, Caranci N, de' Donato F, De Lisio S, De Maria M, Michelozzi P, Miglio R, Pandolfi P, Picciotto S, Rognoni M, Russo A, Scarnato C, Perucci CA. Vulnerability to heat-related mortality: a multicity, population-based, case-crossover analysis. *Epidemiology*. 2006; 17(3):315–323. [PubMed: 16570026]
- Tejedo-Balzaretti M. Creating the human capital of the global cities. First step: Equal access to quality education opportunities. *Revista Panamericana de Pedagogía: Saberes y que hacer del pedagogo*. 2008; 13:29–87.
- Theisen OM, Gleditsch NP, Buhaug H. Is climate change a driver of armed conflict? *Climatic Change*. 2013; 117(3):613–625.
- Velázquez, Vargas; del Socorro, María. Desplazamientos forzados: migración e inseguridad en Ciudad Juárez, Chihuahua. *Estudios regionales en economía, población y desarrollo*. 2012; 7:4–21. (Enero/Febrero).
- Wentz, Elizabeth A.; Gober, Patricia. Determinants of Small-Area Water Consumption for the City of Phoenix, Arizona. *Water Resource Management*. 2007; 21:1829–1863.
- Wilder M, Scott CA, Pablos NP, Varady RG, Garfin GM, McEvoy J. Adapting Across Boundaries: Climate Change, Social Learning, and Resilience in the U.S.-Mexico Border Region. *Annals of the Association of American Geographers*. 2010; 100(4):917–928.

Figure 1.

A residential street in in Juárez with an abandoned home, which has been stripped of its windows and vandalized - Source: Alfredo Rodríguez

Figure 2.
Two children walking home from school through a largely abandoned neighborhood in Juárez - Source: Alfredo Rodríguez

Figure 3.
Two occupied homes right next door to an abandoned home in Juárez - Source: Alfredo Rodríguez

Figure 4.
Neighborhood distribution of summer extreme heat in Juárez

Figure 5.
Neighborhood distributions of population density, proportion older adults and mean education in Juárez, 2000 and 2010

Figure 6. Neighborhood distribution of changes in population density, proportion older adults and mean education between 2000 and 2010 in Juárez

Table 1

Summer heat in Juárez, 2002–2012

	Number of Summer days Above 100 °F	Average Summer High Temperature (°F)
2002	16	93.3
2003	1	91.8
2004	0	89.6
2005	3	90.5
2006	20	91.7
2007	10	94.0
2008	16	92.7
2009	17	95.3
2010	30	96.2
2011	44	98.4
2012	32	97.0

Notes: “Summer” refers to the period between June 1 and Sept 15.

Source: Esquivel Ceballos, Víctor H. y Adrián V. Peña López. 2013. Base de datos de temperatura máxima diaria para la estación meteorológica IIT-UACJ (2002–2012). Laboratorio de Climatología y Calidad del Aire del Departamento de Ingeniería Civil y Ambiental, Instituto de Ingeniería y Tecnología, Universidad Autónoma de Ciudad Juárez. Ciudad Juárez, Chihuahua, México.

Table 2
Descriptive statistics of the analysis variables for the 436 Juárez neighborhoods under study

	Mean	Median	SD	Min	Max	Percentiles		
						25	50	75
Population Density (2000)	7800.387	7948.960	4410.440	204.392	24047.100	4524.373	7948.960	10789.500
Proportion 65 Years+ (2000)	0.033	0.028	0.021	0.000	0.113	0.016	0.028	0.046
Mean Education (2000)	7.891	7.272	1.856	1.885	13.633	6.611	7.272	8.808
Population Density (2010)	6069.673	6052.086	3035.427	113.814	18561.494	3890.733	6052.086	8002.486
Proportion 65 Years+ (2010)	0.055	0.054	0.033	0.000	0.184	0.027	0.054	0.077
Mean Education (2010)	8.931	8.190	1.922	6.430	14.820	7.505	8.190	9.973
Proportion Change in Population Density (2000/2010)	0.190	-0.274	2.125	-0.650	25.640	-0.364	-0.274	-0.114
Proportion Change in Proportion 65 Years+ (2000/2010)	0.843	0.725	1.024	-1.000	13.291	0.456	0.725	1.046
Proportion Change in Mean Education (2000/2010)	0.151	0.113	0.302	-0.107	5.183	0.084	0.113	0.151
Mean Heat (2010), °F	104.631	104.591	1.811	97.802	108.744	103.433	104.591	105.857

Source: INEGI census data from 2000 and 2010 were used to generate the social variables. Mean heat is the average LST for five summer daytime Landsat 7 images with highs over 100° F with zero cloud cover centered on the year 2010 (7/13/2009, 7/29/2009, 6/14/2010, 8/17/2010, and 9/2/2010).

Table 3

Pearson correlation coefficients between analysis variables for the 436 Juárez neighborhoods under study

	Pop. Den. (00)	Prop 65+ (00)	Educ (00)	Pop Den (10)	Prop 65+ (10)	Educ (10)	Change Pop Den	Change 65+	Change Educ	Heat (10)
Pop. Den. (00)	1	.176**	-.145**	.759**	.284**	-.265**	-.344**	-.022	-.164**	.302**
Prop 65+ (00)	.176**	1	.295**	-.196**	.898**	.196**	-.210**	-.269**	-.171**	.364**
Educ (00)	-.145**	.295**	1	-.168**	.289**	.894**	-.055	-.007	-.292**	-.271**
Pop Den (10)	.759**	-.196**	-.168**	1	-.134**	-.198**	.050	.166**	-.016	-.066
Prop 65+ (10)	.284**	.898**	.289**	-.134**	1	.143**	-.319**	-.078	-.205**	.359**
Educ (10)	-.265**	.196**	.894**	-.198**	.143**	1	.139**	.074	.099*	-.364**
Change Pop Den	-.344**	-.210**	-.055	.050	-.319**	.139**	1	.468**	.251**	-.249**
Change 65+	-.022	-.269**	-.007	.166**	-.078	.074	.468**	1	.223**	-.0131**
Change Educ	-.164**	-.171**	-.292**	-.016	-.205**	.099*	.251**	.223**	1	-.103*
Heat (10)	.302**	.364**	-.271**	-.066	.359**	-.364**	-.249**	-.131**	-.103*	1

Notes: 00 refers to 2000 and 10 to 2010.

** Correlation is significant at the 0.01 level (2-tailed);

* Correlation is significant at the 0.05 level (2-tailed).

Table 4

Spatial error regression model predicting extreme heat in Juárez using baseline and proportion change heat-related vulnerability indicators

	Model 1: Change Model	
Neighbor Bandwidth	2000 m	
Condition Index	2.370	
Moran's I-OLS (p)	0.4050 (p = .001)	
Moran's I-Spatial Error (p)	0.022 (p = .108)	
R Square Spatial Error Model	0.669	
	Parameter	P
<i>Lambda</i>	0.892	0.001
Constant	−0.074	0.771
Population Density (2000)	0.091	0.017
Proportion 65 Years+ (2000)	0.088	0.117
Mean Education (2000)	−0.243	0.001
Proportion Change in Population Density (2000/2010)	−0.127	0.001
Proportion Change in Proportion 65 Years+ (2000/2010)	0.127	0.001
Proportion Change in Mean Education (2000/2010)	−0.033	0.325

Note: All variables are Z scores. The Moran's I statistic tests for spatial autocorrelation in the residuals; significance means that the residuals are autocorrelated and therefore not conforming to the requirements of OLS whereas insignificance indicates that the residuals are not autocorrelated. The R Square statistics suggests that the model fits quite well, explaining 67% of the variance in extreme heat

Table 5

Spatial error regression model predicting extreme heat in Juárez using heat-related vulnerability indicators (2010)

	Model 2: Current Model	
Neighbor Bandwidth	2000 m	
Moran's I-OLS (p)	0.4163 (p = .001)	
Condition Index	1.283	
Moran's I-Spatial Error (p)	-0.0145 (p = .212)	
R Square Spatial Error Model	0.659	
	Parameter	P
<i>Lambda</i>	0.893	0.001
Constant	-0.153	0.560
Population Density (2010)	-0.068	0.043
Proportion 65 Years+ (2010)	0.090	0.084
Mean Education (2010)	-0.268	0.001

Note: All variables are Z scores. The Moran's I statistic tests for spatial autocorrelation in the residuals; significance means that the residuals are autocorrelated and therefore not conforming to the requirements of OLS whereas insignificance indicates that the residuals are not autocorrelated. The R Square statistics suggests that the model fits quite well, explaining 66% of the variance in extreme heat