Criteria Air Pollution and Marginalized Populations: Environmental Inequity in Metropolitan Phoenix, Arizona*

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Objectives. Our objective is to examine spatial relationships between modeled criteria air pollutants (i.e., nitrous oxides, carbon monoxide, and ozone) and sociodemographics in metropolitan Phoenix, Arizona. Modeled air pollution offers environmental justice researchers a new and robust data source for representing chronic environmental hazards. *Methods.* We used multiple regression equations to predict criteria pollution levels using sociodemographic variables at the Census block group level. *Results.* We find that Census block groups with lower neighborhood socioeconomic status, higher proportions of Latino immigrants, and higher proportions of renters are exposed to higher levels of criteria air pollutants. Proportion African American, however, is not a significant predictor of criteria air pollution in the Phoenix metro area. *Conclusions.* These findings demonstrate clear social-class and ethnic-based environmental injustices in the distribution of air pollution. We attribute these patterns to the role of white privilege in the historical and contemporary development of industrial and transportation corridors in Phoenix in relation to racially segregated neighborhoods. Although all people are implicated in the production of criteria pollutants, lower-income and ethnic-minority residents are disproportionately exposed in metropolitan Phoenix.

This article examines the environmental justice implications of spatial relationships between modeled criteria air pollutants (nitrous oxides, carbon monoxide, and ozone) and sociodemographics in metropolitan Phoenix (Maricopa County). The use of modeled air pollution data offers environ-

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mental justice researchers an important data source for representing chronic urban environmental hazards. Conceptually, we argue that the formation of environmental inequities is a process embedded in racial/ethnic and class-based systems of stratification. We find that dominant groups influence patterns of development that are beneficial for their group (e.g., freeways are necessary, just not in my backyard) while burdening others with environmental dis-amenities, resulting in environmental inequity.

Environmental justice research centers on concerns over the societal distribution of environmental risks and hazards and their disproportionate distribution and impacts on low-income groups, racial minorities, and other marginalized groups. A quantitative branch of the field rests firmly on geographic information system (GIS) technologies and the development of complex techniques for representing hazards, marginalized groups, and their relations in space (Cutter, Scott, and Hill, 2002; Mennis and Jordan, 2005). This body of research has demonstrated that many minority and lower-class urban neighborhoods suffer from unequal distribution of hazards at various sites across the United States (Brown, 1995; Szasz and Meuser, 1997), from New Jersey (Mennis and Jordan, 2005) to Los Angeles (Pastor, Sadd, and Morello-Frosch, 2004). Environmental injustices are also found in Phoenix, where low-income and minority populations have been consistently found to face disproportionate burdens from a variety of point-source technological hazards (Bolin et al., 2000, 2002).

After a proliferation of spatial studies depicting patterns of environmental inequalities across the United States in the 1990s, researchers began to develop detailed examinations into how such patterns developed over different temporal scales (e.g., Cutter, 1995). In one of the pioneering historical studies of "environmental inequality formation" (Pellow, 2000), Hurley (1988) studied the historical formation of environmental injustices in Gary, Indiana, but the field was slow to follow. Since then, a small but growing number of qualitative historical studies have examined the production of environmental inequalities through time, including Pulido, Sidawi, and Vos (1996), Boone and Modarres (1999), Pulido (2000), Boone (2002), and Bolin, Grineski, and Collins (2005). These historical studies place contemporary environmental inequalities within a framework of environmental racism and uneven development, calling into question the ways "race" and "space" are constructed in quantitative environmental justice research (Pulido, 2000).

In environmental justice research, the concept of environmental racism has been the subject of some debate. It has been frequently conceptualized as appropriate only when referring to intentional discriminatory acts, for example, siting decisions that place industrial facilities in neighborhoods specifically because residents are African American or Latino (Pulido, 2000). Restricting the definition of racism to intentional acts of discrimination in facility siting ostensibly provides an avenue for answering the "racism question" by examining longitudinal data on the demographic composition of neighborhoods in relation to dates when facilities were sited (Been and Gupta, 1997; Been, 1994; Mitchell, Thomas, and Cutter, 1999). That is, if minorities moved into the area after a facility was sited, then environmental racism cannot be involved since the facility predates the demographic shift. Others discount intentionality as a necessary element in defining environmental racism, instead focusing on the variety of race-based institutional practices that produce racialized environmental inequalities. Proponents of this approach argue that institutional racism, in all its diverse ideological and political-economic manifestations, operating at a variety of spatial and temporal scales, must be seen as the key in environmental racism, whether intentional racist acts are involved or not (Pulido, 2000; Pulido, Sidawi, and Vos, 1996).

Offered as alternative framing to the conventional understanding of environmental racism as intentional acts, Pulido (2000:13) introduces the notion of "white privilege." In her usage, white privilege denotes a hegemonic form of racism, deeply embedded in ideologies and practices, which works to (re)produce white advantages across time and space. Conceptually, it calls attention to the relationships of different racial groupings in urban space and the ways that "whiteness" confers economic and social benefits to those so identified, thus linking race and social class. It offers a fuller understanding of environmental racism in the development of urban geographies than focusing solely on facility siting dates and demographic change. It recognizes that privileged groups do not necessarily *intend* to hurt, but that they accrue benefits by maintaining the status quo, continually unaware of an ensemble of social privileges they are advantaged by (Pulido, 2000). "As an unmarked category against which difference is measured," writes historian George Lipsitz (1995:369), "whiteness never has to speak its name, never has to acknowledge its role as an organizing principle in social and cultural relations." In the United States, Pulido argues that whites' ignorance and lack of reflection on racial categories has produced and maintained a system that would not be allowed to thrive in more racially egalitarian societies (Pulido, 2000). Although we do not engage a detailed historical analysis of environmental racism here, we do adopt Pulido's framing of environmental injustices in our discussion of environmental discrimination in Phoenix. We extend her discussion of white privilege beyond point-source hazard and minority neighborhood locations to analyze the distribution of ambient air pollution in relation to marginalized populations.

In addition to questions of race, the environmental justice literature is replete with studies refining techniques for representing technological hazards and their risks (e.g., Cutter, Hodgson, and Dow, 2001). Two common sources of data are typically employed in mapping hazards and assessing environmental risks: Toxic Release Inventory (TRI) data (e.g., Bolin et al., 2002; Cutter, Hodgson, and Dow, 2001) and municipal air pollution monitoring stations (e.g., Buzzelli and Jerrett, 2004; Jerrett et al., 2001). Although the former provides an important source of point-source toxic emissions data, the latter provide data on air pollutants typically, but not exclusively, associated with mobile sources. TRI was established under the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) and expanded by the Pollution Prevention Act of 1990 (EPA, 2006). Right-to-know legislation serves to provide people with public access information on chemical and industrial hazards in their neighborhoods. EPCRA requires industries to provide the locations and quantities of chemicals stored onsite to state and local governments. Facilities are asked to report their environmental releases (air, land, water, underground, offsite) if they have 10 or more full-time employees and manufacture/processes over 25,000 pounds of the approximately 600 designated chemicals, or use more than 10,000 pounds of any designated chemical or category. The information is then made public in the TRI (EPA, 2006). Conducting environmental justice research using only TRI data is limited by the fact the TRI does not contain information about nonindustrial sources of pollution, like automobiles. It is, however, the only publicly available source of industrial air emissions and chemical toxicity data and is used effectively in research studies (e.g., Perlin, Sexton, and Wong, 1999).

Researchers generally use TRI data in two types of studies: presence/absence and buffering. The presence/absence approach involves identifying the number of TRI facilities hosted by each spatial unit of analysis (e.g., Census tract). Buffering techniques were introduced to address the limitations of this approach. Buffering involves using GIS to draw a circle around each TRI facility (usually with a radius of one kilometer or one mile) to represent that the impacts of each facility extend beyond the point where it is located. Using buffers is based on the assumption that TRI facilities influence people living around them, as opposed to, for example, only the people living in the same Census tract as a TRI facility. For a more complete discussion of these two approaches, see Bolin et al. (2002).

To move from point-source air pollution hazards to mobile-source air pollutants, some researchers use data from municipal pollution monitoring stations in their environmental justice analyses. They map the stations and then use average levels of criteria pollutants at each site to interpolate an air pollution surface in a GIS (e.g., Jerrett et al., 2001). Interpolation involves estimating values of points that are between sampling points (e.g., air pollution monitoring stations) using spatial autocorrelation. Municipal monitoring networks rarely conform to the assumptions that the data points used in interpolation are liberally and equally distributed across the spatial extent of analysis. This results in large standard errors (Jerrett et al., 2003). Environmental justice studies use interpolated data to suggest relationships between people and hazards, but are limited by the quality of the data. Collaborating with scientists in other fields who spatially and temporally model pollution, as we do in this analysis, is one way to improve the quality of the pollution data used in environmental justice studies.

In other fields, scientists, such as engineers, computer scientists, and toxicologists, are refining techniques for modeling air pollution over time and space (e.g., Lee, Fernando, and Grossman-Clarke, 2007). These techniques have been developed to inform pollution reduction strategies and determine nonattainment areas for regulated air pollutants. With current GIS capabilities, these pollution models can be paired with other types of data and used in sociospatial environmental justice studies. They overcome limitations associated with interpolated surfaces as they take into account how pollution moves through space by considering population and housing density, roads, water sources, land use, and meteorology.

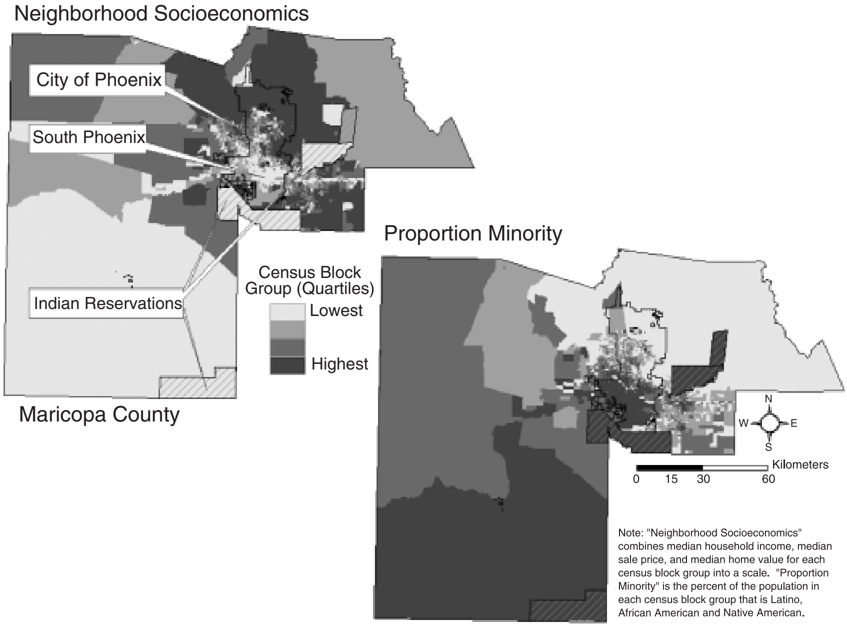
Urban Development in Metropolitan Phoenix

Maricopa County, which contains Phoenix and more than 20 other self-governing cities, serves as our case study location for exploring the relationships between sociodemographics and modeled criteria air pollutants. Phoenix, like other western Sunbelt cities (e.g., Albuquerque, Tucson, El Paso, Los Angeles, and San Diego), has experienced dramatic growth since World War II. Its population has expanded from 331,000 inhabitants in 1950 to more than 3 million by the 2000 Census. The urbanized area grew from 108 square miles (280 square kilometers) to more than 741 square miles (1,920 square kilometers) in the same period, as Phoenix and its suburbs became a sprawling metropolis connected by an ever-expanding highway system (Bolin et al., 2002). Adding close to 4 percent per year to its population, Phoenix is one of the fastest growing metropolitan areas in the United States and recently replaced Philadelphia as the fifth largest metropolitan area in the country.

In spite of its reputation as a late developing and highly suburbanized Sunbelt metropolis, Phoenix has a segregated urban geography with the majority of the poor and racial/ethnic minority populations concentrated in relatively confined regions in southern and western Phoenix (Gober, 2006). The Native-American population comprises about 3 percent of the total population and resides on several Indian reservations east and south of Phoenix and in central and north-central Phoenix neighborhoods. The majority of the Latinos and African Americans reside in South Phoenix. The term "South Phoenix" refers to an expanding region south of the central business district (CBD) defined as much by its racial and class composition as by specific geographical coordinates. The historic boundaries of South Phoenix are constantly in flux, adjusting to the Latinization of previously Anglo neighborhoods as well as the displacement of historic barrios by highways and development (Bolin, Grineski, and Collins, 2005). Currently in Phoenix, Latinos comprise 34 percent and African Americans 5 percent of the population, with disproportionate numbers located in South Phoenix, loosely defined as the southern one-third of the city (Bureau of the U.S. Census, 2000) (Figure 1).

FIGURE 1

Spatial Pattern of Socioeconomic and Racial/Ethnic Segregation in Maricopa County, 2000



Note: "Neighborhood Socioeconomics" combines median household income, median sale price, and median home value for each census block group into a scale. "Proportion Minority" is the percent of the population in each census block group that is Latino, African American and Native American.

South Phoenix has expanded south and west from the historic downtown over the last century, but the characteristics of the place have remained relatively constant: a variety of environmental hazards, degraded housing stock, and low-income and minority populations. In the 1890s, two large floods along the Salt River started the city on its north-south segregated trajectory, as Anglos fled north of the downtown out of the flood plain, abandoning the southern reaches of the city to Mexicans, Mexican Americans, and African Americans. The absence of an urban sewer system prior to 1920, combined with growth north of the CBD, created a crisis of wastewater from the north running in open ditches through South Phoenix and into the Salt River. Industrial land uses also clustered in the southern zone, aligning themselves along an east-west rail corridor first established in 1887, which historically functioned as the dividing line between Anglo Phoenix to the north and minority Phoenix to the south (Bolin, Grineski, and Collins, 2005). The coming of the transcontinental railroad through the same corridor in the late 1920s further cemented early industrial patterns and fashioned land use in the district toward industry, stockyards, land fills, and sewage plants (Myrick, 1980) in the midst of Latino and black neighborhoods. Minority populations of South Phoenix were spatially isolated and legally confined to their contaminated neighborhoods, well separated from the expanding "white-only" neighborhoods to the north (Dimas, 1999). A "system of segregation, as inflexible as any in the South, was a dirty little secret of life in Phoenix for many years" (McCoy, 2000:217). A variety of laws and strict social rules of deference to whites in public spaces produced nearly complete residential, employment, health-care, and educational segregation for decades (Bolin, Grineski, and Collins, 2005). Public expenditures on water lines, sewage, paved roads, and urban services were directed toward neighborhoods north of the downtown, while those south of the rail corridor did without, in some areas well into the 1960s (Russell, 1986).

In 1935, the City of Phoenix purchased land in South Phoenix for construction of the municipal airport. Now the nation's fifth busiest airport, Sky Harbor has long been a magnet for industry in the city. Primary flight paths at the airport put virtually all commercial flights directly over neighborhoods of South Phoenix during takeoffs and landings, with attendant noise and air pollution (Sobotta, 2002). During World War II, industrial development accelerated as a variety of high-technology defense and aerospace factories relocated to Phoenix because its inland geography made it ostensibly safer for war production than California locations. Since that time, Phoenix has aggressively recruited electronics and aerospace firms, beginning with Motorola in 1948, which practiced a "whites-only" hiring policy into the 1960s (Bolin, Grineski, and Collins, 2005). Urban renewal in the 1960s led to a familiar pattern of leapfrog development on the fringe and the disruption and displacement of minority communities near the core. New freeways were constructed through South Phoenix beginning in the 1960s to connect new peripheral developments to employment in the CBD, cleaving in two the historically African-American neighborhood of Eastlake. Subsequent development in the 1980s placed freeways through historic barrios east of the downtown, providing employment access to the central city for suburbanites, while simultaneously increasing air quality issues in the urban core.

South Phoenix continues to host a complex mix of environmental disamenities (e.g., landfills, freeways, an airport, warehouses, railroads, power plants, and industrial facilities), but the city's urban periphery has been rapidly suburbanizing with "resort-style" growth and gated communities. In the last few years, metro Phoenix has led the nation in new home construction (Bernstein, 2004). Indeed, no other major U.S. city depends as heavily on the housing industry for its economic well-being (Burrough and Creno, 2004), an economic distortion that shows no signs of moderating in the current housing boom. Besides adding to traffic woes, the scale of construction has disturbed the desert crust and created serious air quality problems in metro Phoenix. Because of the concatenation of uncontrolled urban sprawl, emissions from industrial facilities and vehicles, a heavily trafficked and expanding freeway system, and a shallow, relatively calm valley location in which pollutants settle and concentrate, Phoenix is host to serious air, land, and groundwater contamination problems (Bolin et al., 2002; Ellis et al., 2000).

For more than a decade, metropolitan Phoenix has failed to meet Environmental Protection Agency (EPA) standards for atmospheric pollutants. Metropolitan Phoenix was an EPA nonattainment area for carbon monoxide from 1990 to 2003 and has been a nonattainment area for particulate matter greater than 10 microns in diameter (PM 10) and ozone since 1990 and 1991, respectively (Arizona Department of Environmental Quality, 2004). These pollutants are tied to respiratory disease (EPA, 2000a; McConnell et al., 2003; Zhu, Carlin, and Gelfand, 2003). Given the history of uneven urban development and residential segregation in Phoenix, we hypothesize that neighborhoods with low incomes and higher proportions of racial/ethnic minority groups will exhibit higher levels of modeled criteria air pollutants in Phoenix than will other neighborhoods.

Data and Methods

Testing this hypothesis involves combining criteria pollution and sociodemographic data in a multiple regression analysis. The EPA sets legal limits for six common or criteria air pollutants: ozone, nitrogen oxides, sulfur dioxide, carbon monoxide, particulate matter, and lead. In this analysis, we focus on three criteria pollutants that are associated with industrial activities and vehicular traffic, including the airport: nitrous oxides, ozone, and carbon monoxide. Nitrous oxides (NO_X) are a group of reactive gases that includes nitrous dioxide (NO_2). NO_X is an important precursor to ground-level ozone and is implicated in respiratory and cardiovascular health (EPA, 2000b). Although most NO_X is colorless, NO_2 is part of the brown haze visible over large cities like Phoenix. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are major sources of NO_X (EPA, 2000b). Ozone (O_3) forms in the presence of NO_X, volatile organic carbons, and sunlight. As a result, the highest levels of ozone occur in summer. Ozone can irritate lungs and airways even at relatively low levels. Carbon monoxide (CO) results from the incomplete combustion of fuel, and almost all urban CO can be attributed to motor vehicle exhaust. CO is associated with illnesses of the cardiovascular system, central nervous system, and respiratory tract (EPA, 2005).

We use modeled pollution surfaces for nitrous oxides, carbon monoxide, and ozone as our dependent variables. These data were obtained from the Environmental Engineering Department at Arizona State University. Engineers manipulate Environmental Protection Agency (EPA) National Emissions Inventory (NEI) estimates in a spatiotemporal model that accounts for population and housing density, roads, water sources, land use, meteorological factors, and chemical interactions between pollutants. Yu-Jin Choi, a postdoctoral research assistant in the Fluid Dynamics Laboratory at

Arizona State University (ASU), used a series of pollution modeling steps, culminating in the running of the CMAQ (Community Multiscale Air Quality) model to create this data set.

First, EPA NEI estimates for CO, NO_X, and volatile organic carbons (VOCs) are gathered. Second, tons of pollution per year at the county level, as per NEI, is imputed into the SMOKE (Sparse Matrix Operator Kernel Emissions) model. SMOKE is an emissions processing system designed to create gridded, speciated, hourly emissions for input into a variety of air quality models (Center for Environmental Modeling for Policy Development, 2005). It processes area, mobile, point-source, and biogenic emissions (Lee, Grossman-Clarke, and Fernando, 2002). In this case, emissions were allocated to a four-kilometer grid. SMOKE uses spatial and temporal profiles to convert the tons per year into hourly totals for each grid cell (Yu-Jin Choi, postdoctoral research assistant, Fluid Dynamics Lab, ASU, personal communication, 2005). To inform the allocation, population and housing density, roads, water sources, and land use are used in the model. Third, the MM5 Model, which includes temperature and wind speed as meteorological factors, is also used to create input for the CMAQ model. For more information about the modeling procedure, see Lee, Fernando, and Grossman-Clarke (2007).

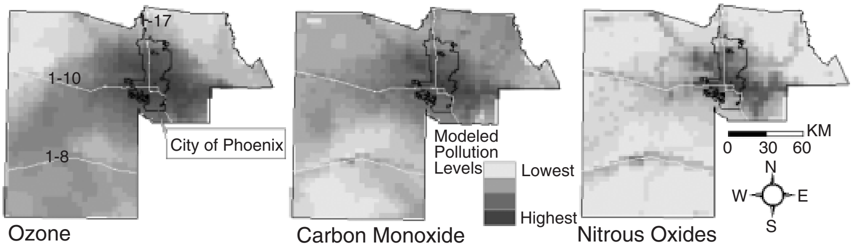
CMAQ models are used to develop emission control strategies. They consider interactions of multiple pollutants, which is important as pollutants chemically interact in the atmosphere. These emissions models were developed in the 1970s, catalyzed by the promulgation of new U.S. air quality regulations. The CMAQ integrates meteorological variables and outputs from emissions models and then performs chemical transport modeling for multiple pollutants at multiple scales (EPA, 1999).

CMAQ models are spatial and temporal; they allocate pollution scores to each grid cell during each hour of the time period under study. We use the CMAQ allocation for 4 PM on August 27, 1999 in this analysis. We used August 27, 1999 because our engineering colleague created a CMAQ model for that day because it was a high-ozone event. She created these surfaces as part of a study conducted for local policymakers that culminated in the drawing of the 2002 ozone nonattainment boundary for Maricopa County. We selected 4 PM because it was at the start of the evening rush hour, a time when people would be returning from work, and a time of day with high ozone levels. Although, ideally, we would have liked to have used a yearly average, summer average, or winter average, that was not possible due to a lack of available models. However, we assume that the models from August 27, 1999 at 4 PM are representative of summer pollution, in general. Although the levels of pollution might change, the pattern is relatively stable through time (Yu-Jin Choi, personal communication, 2005).

We received the data as text files, which were imported into ARC GIS 9.0 as a raster (grid) file with four-square-kilometer cells, each with a pollution value in parts per million (Figure 2). The freeways (shown in Figure 2) are

FIGURE 2

Raw Pollution Model Data for Maricopa County, August 1999



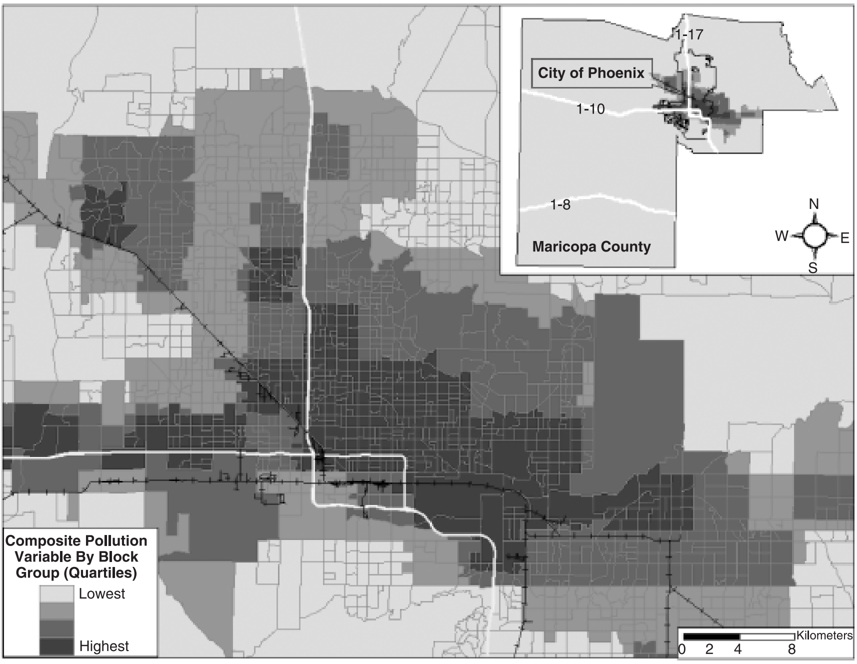
visible as areas with higher levels of pollution. The pattern is especially distinct in the nitrous oxides model.

We assigned a pollution level (for each of the three pollutants and a summed value) to each Census block group in Maricopa County by converting the raster layer to polygons and overlaying (unioning) the grid polygons with the Census block group boundaries. If a Census block group fell completely within a pollution grid cell, it received that pollution value. If a Census block group straddled more than one pollution cell, an areally weighted pollution value was calculated. For example, if a Census block group overlapped two pollution grid cells and 20 percent of the area of a Census block group fell within one pollution grid cell, that grid cell's pollution value would be multiplied by 0.2 and the pollution value of the other grid cell would be multiplied by 0.8. The sum of the two values provides the areally weighted pollution value (Figure 3).

We used 11 Census variables to create factors in SPSS that represent sociodemographics at the Census block group level. We created factors, instead of using individual Census variables, because of multicollinearity between closely related Census variables (e.g., percent Latino and percent in poverty). After creating the factors, we ran an alpha test on each factor to confirm its reliability. Our choices of variables for inclusion into each factor were based on previous environmental justice research findings. Others have found that race, ethnicity, immigration status, and SES were correlated with environmental hazards, as measured by TRI and interpolated pollution surfaces (Brown, 1995; Bullard, 1999; Hunter, 2000; Jerrett et al., 2001; Morello-Frosch, Pastor, and Sadd, 2002; Pastor, Sadd, and Morello-Frosch, 2004; Szasz and Meuser, 1997). Although other studies have not specifically looked at housing tenure, we added it as another social class variable because our experiences interacting with Phoenix residents living in polluted areas during other projects (e.g., Grineski, 2006a, 2006b) led us to believe it might be important. Specifically, we created a neighborhood socioeconomic status (SES) factor by combining median home value, median sale price of homes, and median household income for each block group (alpha = 0.78).

FIGURE 3

Spatial Pattern of Pollution (CO, NO_X, and Ozone) in Maricopa County, 1999



We also used a related SES variable—housing tenure—in our analysis (i.e., proportion of households in each Census block group that rent). We formed a Latino immigrant factor by combing the highly correlated percent Latino, percent foreign born, percent not a citizen of the United States, percent in poverty, and percent speaking Spanish (alpha = 0.94). To represent race, we used proportion African American and proportion Native American. Descriptive statistics are provided in Table 1.

Results

Using stepwise multiple regression models, we examined the independent effect of SES, the effect of SES, race, and ethnicity, and then the impacts of SES, race, ethnicity, and housing tenure on each of the three pollutants and then on the composite pollution variable, resulting in a total of 12 regression equations. Table 2 displays model fit statistics and results from the regression analysis.

We find sociospatial patterns in the relationships between sociodemographics and criteria pollutants in metropolitan Phoenix. When predicting

TABLE 1

Descriptive Statistics

Variables	*N*	Range	Min.	Max.	Mean	*SD*	Vari.
Neighborhood SES (alpha = 0.78)	2113	10.50	− 1.59	8.90	0.00	1.00	1.00
Median home value	2113	1000001	0	1000001	122807	92235	8507321047
Median home sale price	2113	1000001	0	1000001	61423	113880	12968755541
Median household income	2113	200001	0	200001	47804	23909	571629272
Latino Immigrant (alpha = 0.94)	2088	5.39	− 1.03	4.36	0.00	1.00	1.00
% Latino	2090	1.00	0.00	1.00	0.25	0.25	0.06
% Foreign born	2090	0.92	0.00	0.92	0.15	0.14	0.02
% Not a citizen	2090	0.92	0.00	0.92	0.11	0.13	0.02
% Speak Spanish	2090	1.00	0.00	1.00	0.20	0.22	0.05
% Poverty	2088	1.00	0.00	1.00	0.12	0.13	0.02
Race							
% Black	2090	0.82	0.00	0.82	0.04	0.05	0.00
% Native American	2090	1.00	0.00	1.00	0.02	0.05	0.00
Housing Tenure							
% Rent	2088	1.00	0.00	1.00	0.32	0.29	0.08
Composite Pollution	2113	4.45	− 1.87	2.58	0.00	1.00	1.00
CO	2113	1.28	0.13	1.42	0.63	0.29	0.08
NO_X	2113	0.10	0.00	0.10	0.03	0.02	0.00
Ozone	2113	0.12	0.01	0.13	0.09	0.02	0.00

TABLE 2

Regression Results

Dependent Variables	Model #	F*	Adj. R2	Neighborhood SES		African American		Native American		Latino Immigrant		Tenure	
				BETA	SIG.	BETA	SIG.	BETA	SIG.	BETA	SIG.	BETA	SIG.
CO	1	156.2	0.07	−**0.264**	0.000								
	2	76.5	0.13	−**0.132**	0.000	0.005	0.800	**0.042**	0.043	**0.266**	0.000		
	3	87.5	0.17	−**0.063**	0.008	−0.027	0.200	0.007	0.717	**0.182**	0.000	**0.262**	0.000
NO_2	4	193.8	0.08	−**0.293**	0.000								
	5	113.1	0.18	−**0.127**	0.000	0.012	0.564	0.033	0.106	**0.340**	0.000		
	6	105.3	0.20	−**0.076**	0.001	−0.012	0.573	0.007	0.713	**0.279**	0.000	**0.191**	0.000
Ozone	7	187.9	0.08	−**0.287**	0.000								
	8	80.4	0.13	−**0.177**	0.000	0.023	0.275	−**0.052**	0.013	**0.246**	0.000		
	9	80.9	0.16	−**0.122**	0.000	−0.003	0.904	−**0.079**	0.000	**0.180**	0.000	**0.209**	0.000
Composite Pollution	10	169.8	0.07	−**0.274**	0.000								
	11	84.2	0.14	−**0.137**	0.000	0.007	0.727	**0.036**	0.080	**0.279**	0.000		
	12	92.9	0.18	−**0.070**	0.003	−0.024	0.249	0.003	0.902	**0.198**	0.000	**0.255**	0.000

*All F Scores are significant at $p < 0.000$

Bold BETAs are significant at $p < 0.000$

CO with only neighborhood SES (Model 1), neighborhood SES is a significant and negative predictor, meaning that Census block groups with lower neighborhood SES have higher levels of CO. When we add the race and ethnicity variables (Model 2), proportion Native American and Latino immigrant are both significant and positive, meaning that areas with higher proportions of Native Americans and Latino immigrants have higher levels of CO, independent of neighborhood SES, which also remains significant. When we add housing tenure to the equation (Model 3), we find the proportion of the population that rents explains away the significant Native-American finding, but not the Latino immigrant or the neighborhood SES findings. Housing tenure itself is a significant and positive predictor, meaning that areas with higher proportion of renters have higher levels of CO.

Neighborhood SES is also a significant predictor of NO_X (Model 4), and it remains significant with the addition of the race/ethnicity (Model 5) and housing tenure (i.e., proportion renting) (Model 6) variables. Unlike in the case of CO, proportion Native American is not a significant predictor of NO_X, although the Latino immigrant factor is significant and positive (Model 5). Tenure is again significant, while neighborhood SES and the Latino immigrant factor retain their independent and significant effects (Model 6). Again for ozone, neighborhood SES is a significant predictor when considered alone (Model 7). The findings for ozone differ from CO and NO_X in terms of the effect of proportion Native American. Whereas for CO and NO_X, the effect of Native American was positive, for ozone it is negative, meaning that areas with higher proportions of Native Americans have significantly lower levels of ozone (Models 8 and 9). The effect of Latino immigrant is the same for ozone as it is for CO and NO_X: positive and significant (Models 8 and 9). Housing tenure is also a significant and positive predictor (Model 9) and the positive effect of Latino immigrant and negative effect of Native American are retained, even with its addition to the model.

When predicting the composite pollution variable (which combines the three criteria pollution variables), neighborhood SES is significant as a sole predictor (Model 10). Neighborhood SES, proportion Native American, and the Latino immigrant factor are significant when considered in the same model (Model 11). The effect of neighborhood SES is negative, while the effects of proportion Native American and Latino immigrant are positive. When housing tenure is added (Model 12), the effects of neighborhood SES and Latino immigrant remain significant; housing tenure is also significant.

This analysis demonstrates clear environmental justices along ethnic and class lines. Neighborhoods with lower SES, higher percentages of Latino immigrants, and higher percentages of renters generally experience higher levels of criteria air pollution. Proportion African American is not a significant predictor in any of the models, but the Latino immigrant factor is robust. However, other analyses have found percent African American to be significantly associated with point-source hazards (Bolin et al., 2002). The Latino immigrant factor is consistently a significant predictor of pollution levels, independent of neighborhood SES. Although beyond the scope and design of this article, future research should address the issue of spatial nonstationarity, where the relationship between the independent and dependent variables can vary over space. New methods, such as geographically weighted regression, offer tools to address such methodological approaches (Longley and Tobon, 2004; Mennis and Jordan, 2005).

Discussion and Conclusion

These findings complement and expand on previous quantitative environmental justice studies of the metro area (Bolin et al., 2000, 2002) by illustrating that lower-income and minority Phoenix neighborhoods are burdened, not only by industrial facilities and their air emissions, but also by disproportionate levels of traffic-related criteria pollutants (e.g., CO, NO_X, and ozone). The strong relationships between housing tenure and traffic pollution is worth nothing because housing tenure is not a variable that is always used in environmental justice studies, in contrast to race, ethnicity, and income. The relationship between renters and traffic pollution, independent of race, ethnicity, and neighborhood SES, may reflect the current undesirability of polluted areas to home buyers as well as historical patterns of transportation planning. In this study, freeways and the airport were important sources of pollution and these are likely environmental dis-amenities to home buyers. Those considering making a long-term commitment to a neighborhood (i.e., buying a home there) may be choosing not to buy in these undesirable places, abandoning them to renters, who are likely people with low incomes, or those not planning to permanently settle in the neighborhood. Additionally, homes are less expensive in these undesirable areas and may be purchased by investors as rental properties. Historically, dis-amenities like freeways and airports were placed in areas lacking political power instead of in neighborhoods that would organize to resist transportation-related development (Hayden, 2003; Rose, 1979).

Explaining the development of these patterns involves looking at the production of space in metropolitan Phoenix; that is, at the sources of these pollutants and the forces that have shaped their prevalence in transient, low-income, and minority neighborhoods. We argue that white privilege, as conceptualized by Pulido, is a useful theoretical construct to describe racialized patterns of Phoenix's dominant growth trajectory. As we have sketched here, an important part of that trajectory has been the disproportionate environmental burdens that residents of South Phoenix have borne as a result of urban growth, while the socioeconomic benefits of that growth have flowed to others (Bolin, Grineski, and Collins, 2005). In Phoenix, white privilege has driven urban development since the late 19th century and is reflected in urban settlement patterns, residential and job segregation, social exclusion of minorities, industrial location, and the emplacement of urban infrastructure, including highways, railways, and the airport (Bolin, Grineski, and Collins, 2005; Brunk, 1996; Burns and Gober, 1998; Grineski, 2006c; Horton, 1941; Kotlanger, 1983; Luckingham, 1989; McCoy, 2000; Roberts, 1973; Zachary, 2001).

The continuing exposure of poor and minority residents to higher levels of criteria pollutants is a contemporary consequence of these racialized development patterns and the city's devotion to laissez faire growth. Although exponential growth of the city, both in terms of population and area, has added significant employment opportunities, in the central city, few of the jobs created actually benefit the low-income and minority communities in the area. As research has demonstrated, there is a significant spatial mismatch in the central city between where people work and live: in 1995, only 15 percent of employees of large downtown Phoenix businesses lived in proximity to their places of employment (Burns and Gober, 1998). Thus, the air pollution generated by suburban commuters to the CBD is largely borne by those who live in South Phoenix, residents who do not materially benefit from that industrial and commercial activity.

Environmental injustices have not gone unnoticed. In tandem with the nationwide growth of the environmental justice movement since the 1980s, several Phoenix neighborhoods have become centers for struggle as citizens contest acute toxics. The first struggle took place in the late 1980s when citizens successfully halted the citing of a hazardous-waste incinerator in a predominantly Latino neighborhood. Since then, several mobilizations, protests, and lawsuits have occurred in response to industrial accidents, toxic releases, and fires in South Phoenix (Bolin et al., 2002; Grineski, 2006a; Sicotte, 2003). A common characteristic of these mobilizations has been the acute and spatially specific nature of the environmental injustice. Mobilizations against chronic ambient hazards, such as those studied in this article, are much less common in Phoenix and elsewhere. Phoenicians seem cognizant of air pollution and its health effects—local officials publicize levels on "bad air" days—but the action on the part of citizenry has been largely individual at best (e.g., drive less), and not activist and collective in orientation. In this sense, it is easier for citizens to mobilize against specific point-source hazards (e.g., power plants, industrial facilities, hazardous-waste handlers) than ambient pollution, which is generally perceived as diffuse and chronic.

In-depth interviews with 53 Phoenix parents of children with asthma revealed that nearly all parents were very concerned about air pollution, but felt powerless to reduce its prevalence and negative impact on their children (Grineski, 2006b). Although nearly every Phoenician is involved in the generation of criteria air pollution by driving or riding in automobiles, this study demonstrates that the poor and minority residents are exposed to higher levels of these pollutants than are others. Unlike point-source hazards associated with particular facilities, air pollution from vehicles is seldom the focused target of environmental justice movements. However, the location of major traffic corridors is not accidental, and a close look at the development of the metro areas freeway system reveals that key portions of freeways were inserted through some of the lowest-income minority neighborhoods in the city (Bolin et al., 2002). This has had the dual effect of concentrating several criteria air pollutants in the central city as well as attracting additional industrial activity into the same area. In this sense, the location and concentration of freeways in the city over the last four decades has added to pollution burdens of low-income and minority neighborhoods already historically burdened with polluting commercial and industrial sites (Bolin, Grineski, and Collins, 2005). The historic ability of white and middle-class neighborhoods to use zoning to keep polluting industry out has also worked to prevent major incursions of freeways through most existing residential areas.

This analysis demonstrates clear patterns of environmental inequity when using a new method for representing environmental hazards. This article shows that pollution models, in addition to TRI and interpolated pollution surfaces, can be combined with sociodemographics in a GIS to understand patterns of environmental injustice. Pollution models, like the ones used in the study, are complex and must be acquired through partnerships with other scientists. By interacting with others from outside the social sciences, environmental justice researchers can gain access to data that can further our ability to investigate injustice.

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