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# The ecology of technological risk in a Sunbelt city

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**Abstract. In this paper we examine the spatial distributions of four types of technological hazards in the Phoenix, Arizona, metropolitan area. The focus is on the locations of hazardous industrial and toxic waste sites in relation to the demographic composition of adjacent neighborhoods. Our interest is to determine whether hazardous sites, including industrial facilities in the EPA's Toxic Release Inventory, Large Quantity Generators of hazardous wastes, Treatment, Storage, and Disposal Facilities, and federally identified contamination sites, are disproportionately located in areas with lower income and minority residents. We examine patterns of environmental inequity in Phoenix, a sprawling Sunbelt city with a growing post-Fordist industrial sector. First, using 1996 EPA data for four types of technological hazards, and 1995 Special Census data for Maricopa County, we employ a GIS to map the spatial distributions of hazardous sites and to analyze the demographic characteristics of census tracts with and without point-source hazards. A second methodology is used to produce a cumulative hazard density index for census tracts, based on the number of hazard zones—one-mile-radius circles around each facility—that overlay each tract. Both methodologies disclose clear patterns of social inequities in the distribution of technological hazards. The cumulative hazard density index provides a spatially sensitive methodology that reveals the disproportionate distribution of risk burdens in urban census tracts. The findings point to a consistent pattern of environmental injustice by class and race across a range of technological hazards in the Phoenix metropolitan region.**

## Introduction

In 1999 more than 7 billion pounds of toxic chemicals were released into the environment by industrial facilities in the United States. This was the emitted component of more than 29 billion pounds of production-related waste generated by industrial firms reporting to the Toxic Release Inventory (TRI) (Environmental Defense, 2001). The monitoring and regulating of hazardous industrial emissions and waste-disposal activities are elements in a series of federal mandates to manage technological risks, protect the public, and mitigate environmental impacts. Nevertheless, the adequacy of these efforts, especially as they are implemented at the local level, has been repeatedly challenged by grassroots citizen groups concerned about health and environmental

quality (Cole and Foster, 2001; Shutkin, 2000). Since the early 1980s, local movements against the siting and expansion of hazardous industries and toxic waste disposal facilities have proliferated in the United States (Gottlieb, 1993; Harvey, 1996a). These responses reflect growing public distress over the dangers posed by hazardous technologies, and a growing distrust of federal and state agencies in their facility-siting and oversight responsibilities (Szasz, 1994; Tesh, 2000).

Environmental activists have not only articulated a critique of the growing 'toxic culture' of industrial polluters, but have also advanced claims that such technological risks are inequitably and unjustly distributed socially and geographically (Bryant and Mohai, 1992; Bullard, 1990; Faber, 1998; Hofrichter, 2000). Such claims, instantiated in the rhetoric of environmental justice, led to pioneering studies that systematically investigated the spatial distribution of hazardous facilities and the demographic composition of adjacent residential areas (UCC, 1987; see also, Goldman and Fitton, 1994; US GAO, 1984). For example, as early as 1987, the United Church of Christ (UCC) found that race was the best statistical predictor of the location of toxic waste disposal facilities in the United States. This research was instrumental in prompting a large number of subsequent cross-sectional studies examining equity issues across a variety of sites and geographic scales, and using an assortment of hazard indicators. Although space does not permit an exhaustive review, a number of recent publications offer summaries of findings and critical discussions of methodological issues, including: Been (1995), Brown (1995), CEJ (1999), Cutter (1995), Cutter and Solecki (1996), Cutter et al (1996), Krieg (1998a), Lester et al (2001), Mitchell et al (1999), Mohai (1995), Pulido (1996), Szasz and Meuser (1997), Weinberg (1998), Williams (1999).

Although these studies have enhanced understandings of inequities in the sociospatial distribution of US hazards, their findings are by no means consistent across sites and spatial scales (Lester et al, 2001; Szasz and Meuser, 1997). Further, most quantitative studies have examined spatial inequities using the distribution of one hazard type, such as TRI facilities. In general, equity studies have tended to focus on the location of a class of hazardous facilities as a source of potential risk for those residing in the same spatial unit (county, zip code, tract, block group, etc). Only a few studies have used multiple hazard indicators to assess patterns of environmental injustice in a given place (for example, Bowen et al, 1995; Cutter and Solecki, 1996; Glickman and Hersh, 1995). In addition, numerous methodological issues have been raised in the quantitative environmental equity literature. Key among these issues are the decisions of what constitutes a hazard, how to assess the magnitude of public risks, and what geographic scales to use in characterizing the at-risk populations (for example, Anderton et al, 1994; Chakraborty and Armstrong, 2001; Cutter et al, 1996; 2001; Jerret et al, 1997; Mohai, 1995; Monmonier, 1997; Pulido, 2000).

A recent addition to environmental equity research has appeared in the form of historical-geographical studies that investigate the development of sociospatial inequities over varying time periods. Hurley's rich historical treatment (1995) of the postwar formation of environmental inequities in the Fordist production center of Gary, Indiana, is one of the earliest book-length accounts. Others have deployed a variety of analytic techniques and data sets to tease out the processes of "environmental inequality formation" (Pellow, 2000). As longitudinal equity research has to contend with a variety of spatial and temporal scale issues, in addition to a myriad of data-availability problems, studies lack the relative methodological uniformity of cross-sectional research. Some authors (for example, Pulido, 2000; see also Boone and Modarres, 1999; Pastor et al, 2001) draw on quantitative cross-sectional studies, based on Environmental Protection Agency (EPA) and census data to establish extant patterns of environmental inequities in a city, and then engage in various

historical investigations into the workings of racism and capitalism in producing those inequities. These historical studies advance the understanding of the production of environmental inequality and the processes of environment racism in ways that cross-sectional studies by design cannot (Pulido et al, 1996).

Nevertheless, by describing current spatial patterns of environmental hazards, cross-sectional studies can identify locations of environmental injustice, areas that can then be studied in greater geohistorical depth. To that end, in this paper we analyze current configurations of people and toxic risks in Phoenix, Arizona, as the first step in a developing historical analysis of environmental hazards in the city. In what follows, we develop two indices to measure the distribution of environmental burdens of multiple hazard sources and apply the indices in an equity study. We contend that the distribution of one hazard type does not adequately reflect the agglomeration of environmental risk sources in urban space. Further, a single hazard can bias distributional measures and equity assessments. The focus on one hazard type and its spatial distribution may reflect a particular locational and land-use history in a given place, at the expense of neglecting the existing distribution of other, equally risky, hazard sources. For example, the siting of hazardous waste disposal facilities reflects a different set of locational requirements, zoning and permitting decisions, and economic prerequisites than the siting of large industrial polluters such as those that report to the TRI. Each may have its own specific pattern of environmental (in)equity based on the demographics of nearby residents. By examining several individual hazard distributions and their relationships to sociodemographic variables, and then aggregating the hazards into an index, we can raise several important questions that have not been systematically addressed in the environmental justice literature:

(1) Do different hazards have different spatial and/or social distributions? That is, are hazards spatially segregated by type, with certain hazards more likely to be sited near some demographic categories of residents than others?

(2) How is the evaluation of the sociospatial distributions of hazards changed by using a combined hazard measure in place of the enumeration of individual point-source hazards? When different types of hazards are summed into a cumulative hazard density index (CHDI), does the resulting index show hazards to be more concentrated in physical and social space than when using a host – nonhost methodology?

(3) How does the analysis of environmental hazards change when conventional counts of hazardous facilities are replaced with hazard density index (HDI) scores? When CHDI values are used in place of counts of hazard sites, is the relationship between sociodemographic characteristics and hazards attenuated, implying a more equitable distribution of risk, or is it strengthened, implying greater inequality in risk distributions?

We develop answers to these questions by using Phoenix as a case study. Four types of technological hazard[1] are examined: industrial facilities emitting toxic substances

[1] The annual TRI provides self-reported data on large industrial point-source polluters, including information on the volume and chemical composition of emissions, and the location of the polluting facilities. For a discussion see US GAO (1991a; 1991b); also, http://www.epa.gov/year2000/toxic.html. Large Quantity Generators (LQGs) include facilities that produce or accumulate at least 2200 lbs of Resource Conservation and Recovery Act-regulated hazardous waste on a monthly basis. Treatment, Storage, and Disposal Facilities (TSDFs) comprise a subset of LQGs that treat, store, or dispose of hazardous wastes. In our analysis we include as TSDFs only those facilities whose main function is to handle, treat, and dispose of toxic wastes generated by other firms. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) gives the legal mandates for the investigation and regulation of toxic contamination sites. CERCLIS, the Information System maintained under the act, lists heavily contaminated sites (toxic waste dumps, abandoned industrial sites, mines, severely polluted federal facilities, etc) and is the basis for selecting Superfund sites for remediation.

regulated under the EPA's TRI; manufacturing facilities that produce hazardous wastes (Large Quantity Generators or LQGs); Treatment, Storage, and Disposal Facilities (TSDFs); and toxic contamination sites listed by the federal government under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Priority List (NPL or Superfund). Our primary interest is to determine if there is a spatial concentration and compounding of potential risks, produced by the colligation of different point-source hazards in areas with racially and economically marginalized residents.

Using a geographic information system (GIS), US EPA data from 1996, and 1995 Special Census data for Maricopa County, Arizona, we first produce a composite hazard map of four key point-source hazards in the Phoenix metropolitan area. We elected to use 1996 EPA data because they closely match the date of the census data but are recent enough to reflect the expansion of criteria chemicals included in the TRI. At the time of this writing complete 2000 Census data are not available. The demographic composition of census tracts that host and do not host hazardous facilities is analyzed for each hazard. Next, we develop and test an approach that allows the assessment of the cumulative risk in census tracts, based on radius zones of one mile (1.6 km) around each hazard site for each of the four types of hazards. These multiple overlapping hazard zones are scored and summed for each census tract, and the value standardized by the total area of each tract. The resulting CHDI provides an aggregate hazard score for each tract, which is then correlated with demographic data in order to measure levels of environmental inequity. The results of the two alternative methodologies are compared and their implications for assessing spatial (in)equity are discussed.

We selected four hazard types and two alternative spatial methods to test whether a variety of facilities and sites, with diverse locational strategies and contamination histories, nevertheless concentrate disproportionately in or near low-income and minority [Latino(a) and African-American] neighborhoods. Our research provides one approach to Pulido's (2000, page 20) contention that environmental equity research should examine the broader sociospatial assemblage of hazardous facilities, not simply individual facilities, and how those industrial zones relate to the locations of minority neighborhoods and working-class areas, as well as to affluent suburbs. Investigating the spatial distributions of multiple hazard sources allows us to assess better the concentration – dispersion of different hazard sources in delimited industrialized and socioeconomically distressed areas of the city, something not possible when relying on a single hazard indicator.

**Environmental equity and technological hazards**

Environmental equity research has focused on technological hazards that residents cannot control and that pose potential health and safety risks to those living nearby. We focus on larger hazardous facilities and sites of toxic contamination that are reported in EPA databases. We recognize that there are other important sources of hazardous urban air pollution, including mobile and area sources. Mobile sources (vehicular traffic) typically account for the largest volume of hazardous emissions in cities, although ambient air pollution varies diurnally and seasonally (Ellis et al, 1999). Area source pollution may also contribute negatively to air quality as it is produced by a wide and changing variety of unregulated atmospheric emissions ranging from lawn mowers to construction equipment. However, in order to map hazardous sites in relationship to proximal residential areas, it is necessary to rely on spatially fixed hazard sources such as those discussed here.

The majority of recent environmental equity studies use EPA data or a combination of EPA and state-specific data sources of indicators of technological hazards. The most

commonly used hazard sources are TSDFs, Superfund sites, and large industrial facilities reported in the TRI (for example, Anderton et al, 1994; Boer et al, 1997; Bowen et al, 1995; Bullard et al, 2000; Daniels and Friedman, 1999; Hockman and Morris, 1998; Pastor et al, 2001; Perlin et al, 1995; Pulido, 2000; Ringquist, 1997; Sadd et al, 1999; Tiefenbacher and Hagelman, 1999; Tiefenbacher et al, 1997; Zimmerman, 1993). However, only the TRI provides information on the total tonnage and chemical composition of toxic releases to the environment by air, ground, and water (for example, Bolin et al, 2000; Cutter and Solecki, 1996; Tiefenbacher and Hagelman, 1999). With the exception of TRI reports, the EPA provides no spatially specific information on actual emissions from sites, nor does it rank industrial sites by their danger to humans and the environment or provide exposure data. Although LQG data list the total volume and content of hazardous waste generated, the EPA provides no emissions data on LQGs unless they are also TRI facilities. In the absence of comparable measures of risk for the hazard types in this analysis, we treat each as equally hazardous to those living in proximity and assume that relative hazardousness increases with the number of hazards reported in a given area.

Approximately 15% of the hazard sites with a unique address in this study host more than one hazard type. For example, 27 TRI sites are also LQGs and another 10 are listed in the Comprehensive Environmental Response, Compensation and Liability Act Information System (CERCLIS) database as having had a contamination event. In the analyses of individual hazard types, each site is counted under each applicable hazard category, as shown in table 1. However, in analyses using the sum of all hazards, each address with multiple hazard types is only counted once, in the single category that best reflects the primary hazard feature at the site. This procedure provides the most accurate representation of each type of hazard without overstating the total number of hazard sites in Phoenix.

Our approach to assessing hazards is founded on several assumptions. All of the environmental hazards considered here produce, process, and/or emit toxic substances regulated by the EPA under a variety of federal statutes. Physical proximity to such sites may increase the probability of human exposure to toxic substances in at least three ways: from acute atmospheric releases during industrial accidents (such as explosions, fires, major spills); as a result of fugitive emissions of toxic substances from minor leaks, spills, evaporation, etc that are part of routine industrial production; and from point-source air releases of toxic substances during production and disposal processes. There is a generally recognized distance-decay function of toxic substances as they disperse in the atmosphere, with risks decreasing the further one is from the point of release (for example, CEJ, 1999; Chakraborty and Armstrong, 2001;

**Table 1.** Distributions of hazards by census tract.

| Type of hazard | Number of sites | Number of tracts with at least 1 site | Number of tracts with no sites | Number of tracts with HDI sites >0 | Number of tracts with HDI score 0 |
|---|---|---|---|---|---|
| CERCLIS | 412 | 122 | 344 | 305 | 161 |
| Large Quantity Generators | 117 | 65 | 401 | 231 | 235 |
| Toxic Release Inventory | 119 | 58 | 408 | 192 | 274 |
| Treatment, Storage, and Disposal Facilities | 13 | 11 | 455 | 47 | 419 |
| Any hazard sited in tract | 661 | 156[a] | 310[a] | 361[a] | 105[a] |

[a] Numbers do not sum as a result of inclusion of facility in multiple categories.
Note: HDI—hazard density index.

Cutter et al, 2001; Glickman and Hersh, 1995; Monmonier, 1997; Phillips, 1992; Tiefenbacher et al, 1997). The spatial concentration of a variety of hazardous pollutants also raises concerns about cumulative exposures, bioaccumulation, and the human health effects of exposure to mixtures of different pollutants—issues that the EPA and others are investigating (Krewski and Thomas, 1992; Tesh, 2000). Consistent with the literature, we use proximity to hazard sources as an indicator of the potential for harm to residents from chronic and acute emissions, but no inferences can be made about actual exposures.

**Sunbelt urbanization**

The majority of US environmental equity studies have focused on the Southeast and on the older Northeastern and Midwestern industrial cities of the 'Rustbelt' (Szasz and Meuser, 2000). Sunbelt cities like Phoenix have received little attention in the literature, although they frequently exhibit a myriad of pollution, contamination, and land-degradation problems as a consequence of rapid, poorly planned growth and weak environmental regulation. Studies of Western US cities consistently demonstrate that technological hazards and other locally unwanted land uses are inequitably distributed by race and class (for example, Boer et al, 1997; Bolin et al, 2000; Boone and Modarres, 1999; Clarke and Gerlak, 1998; Davis, 1998; Laituri and Kirby, 1994; Pastor et al, 2001; Pijawka et al, 1998; Pulido, 2000; Pulido et al, 1996; Sadd et al, 1999; Szasz and Meuser, 2000). This suggests that late-developing, highly suburbanized cities of the Western US Sunbelt frequently exhibit environmental injustices, although they generally do not have significant large-scale 'smokestack industries' typical of cities like Chicago, Detroit, and Pittsburgh. The primary Western exception to this is Los Angeles, which had a significant presence of Fordist heavy industry in the period before World War 2, an industrial sector that was seriously eroded in the postwar era (Soja, 1996; 2000). As Davis (1992) suggests, the collapse of the steel, automobile, and other heavy industry in Southern California since the war has left its own legacy of environmental contamination and human socioeconomic impacts (see also Pulido, 2000).

Maricopa County, which contains Phoenix and more than 20 other self-governing cities, has experienced dramatic growth since World War 2, expanding from 331 000 inhabitants in 1950 to more than 3 million by 2000. The urbanized area grew from 108 square miles (280 $km^2$) to more than 741 square miles (1920 $km^2$) in the same period, as Phoenix became a sprawling amalgam of city and suburbs linked by an ever-expanding highway system. Much of the recent growth has been supported by and depends on the \$4 billion Central Arizona Project, which brings federally subsidized water to Phoenix and surrounding areas via a 330-mile (551 km) aqueduct from the Colorado River (Davis, 2000). Adding nearly 3% a year to its population, Phoenix is one of the fastest growing metropolitan areas in the United States, rapidly swallowing up farmland and desert on the urban fringe. Characteristic of Western Sunbelt cities like Albuquerque, Tucson, El Paso, Los Angeles, and San Diego, Phoenix's rapid expansion has been accompanied by a growing post-Fordist industrial sector that includes large electronics and semiconductor manufacturers (compare Angel, 1994; Knox and Agnew, 1994; Scott, 1996; Soja, 1996; Szasz and Meuser, 2000).

Post-Fordism is used to denote newer forms of flexibly organized 'lean and mean' industrialism (Harrison, 1994) that have displaced and replaced older vertically integrated Fordist mass-production centers and the unionized labor forces formerly employed by them. The growth of post-Fordism as a regime of flexible accumulation is generally recognized as capitalism's reflexive response to the economic crises of the 1970s, and is marked by a range of new corporate strategies including downsizing, outsourcing, subcontracting, a growing use of contingent and part-time workforces,

as well as industrial site relocation to areas of nonunion, low-cost workforces, and few or no environmental controls (Harrison, 1994; Harvey, 2000; Merrifield, 2000). As a 'right to work' state with a history of lax environmental regulation, a pro-growth, pro-business legislature, low taxes, ready availability of a low-wage workforce, and a limited union presence, Arizona's commercial interests have benefited from these recent economic transformations in the United States.

Part of the economic restructuring of the last three decades has been manifested in the development of 'specialized industrial agglomerations' driven by, among others, high-technology industries (electronics, semiconductor, telecommunications, aerospace) (Soja, 2000, page 164). It is the development of these new forms of industrial capitalism that has contributed to the shaping of Sunbelt cities, particularly through the formation of 'technopoles', high-technology industrial districts, of which the 'Silicon Valley' (Santa Clara County, California) is the archetype. As Scott shows (1996), technopoles have constituted a key element in the industrial restructuring of the Los Angeles region over the last three decades. However, contrary to the image of high-tech industries as clean and nonpolluting, semiconductor and affiliated manufacturers are sources of significant toxic air emissions and groundwater contamination (Szasz and Meuser, 2000). Indeed, the largest Superfund site in Phoenix is the result of toxic chemical releases from a Motorola semiconductor plant into the groundwater under the upscale suburb of Scottsdale.

In Phoenix, prevalent postwar industrial development trajectories coupled with rapid expansion on the urban fringe have generated a dual pattern of industrial location. Although there is a spatial convergence of both industrial plants and waste-processing facilities along major rail and highway routes in central and western Phoenix (see figure 1, over), there is also a decentralizing trend with newer large electronics-manufacturing firms locating in areas well removed from the urban core (Bolin et al, 2000; Pijawaka et al, 1998). The current distribution of hazardous industries in Phoenix is part of an aggregate riskscape that also includes sites of pronounced land and groundwater contamination from military, commercial, and municipal polluters. The majority of these polluted sites are concentrated in or near areas with significant (current or historical) commercial and industrial activity, south and west of the central city.

The spatial distribution of industrial facilities in Phoenix differs from those of older industrial cities that have been the subject of key environmental justice studies (for example, Bowen et al, 1995; Glickman and Hersh, 1995; Hersh, 1995; Krieg, 1995; 1998b). With no large-scale heavy industry as an anchor, Phoenix lacks distinct working-class neighborhoods adjacent to factories, characteristic of cities in the US industrial heartland. Apart from the now mostly dry Salt River, Phoenix has no waterways, features that were key in shaping the industrial ecology of Midwestern and Northeastern cities. There, rivers and lakes provided water for production processes, a medium for transportation of materials and products, and a convenient sink for dumping waste products (for example, Cronon, 1991; Harvey, 1996b; Hurley, 1995). Equally important, Phoenix has bypassed the pronounced deindustrialization and job loss that has wracked traditional industrial centers since 1970 as a result of corporate downsizing, capital mobility, and a shift to flexible production regimes (for example, Faber, 1998; Merrifield, 2000; Scott, 1998). To the contrary, the city has experienced steady service-sector and industrial/commercial expansion since World War 2, and currently has a burgeoning sector of high-technology facilities dispersed across the metropolitan area, creating an industrial presence in suburban locations (see figure 1).

Although Phoenix has historically been a tourist destination, with sunny skies and clean air for those seeking relief from harsh northern winters, its rapid growth is

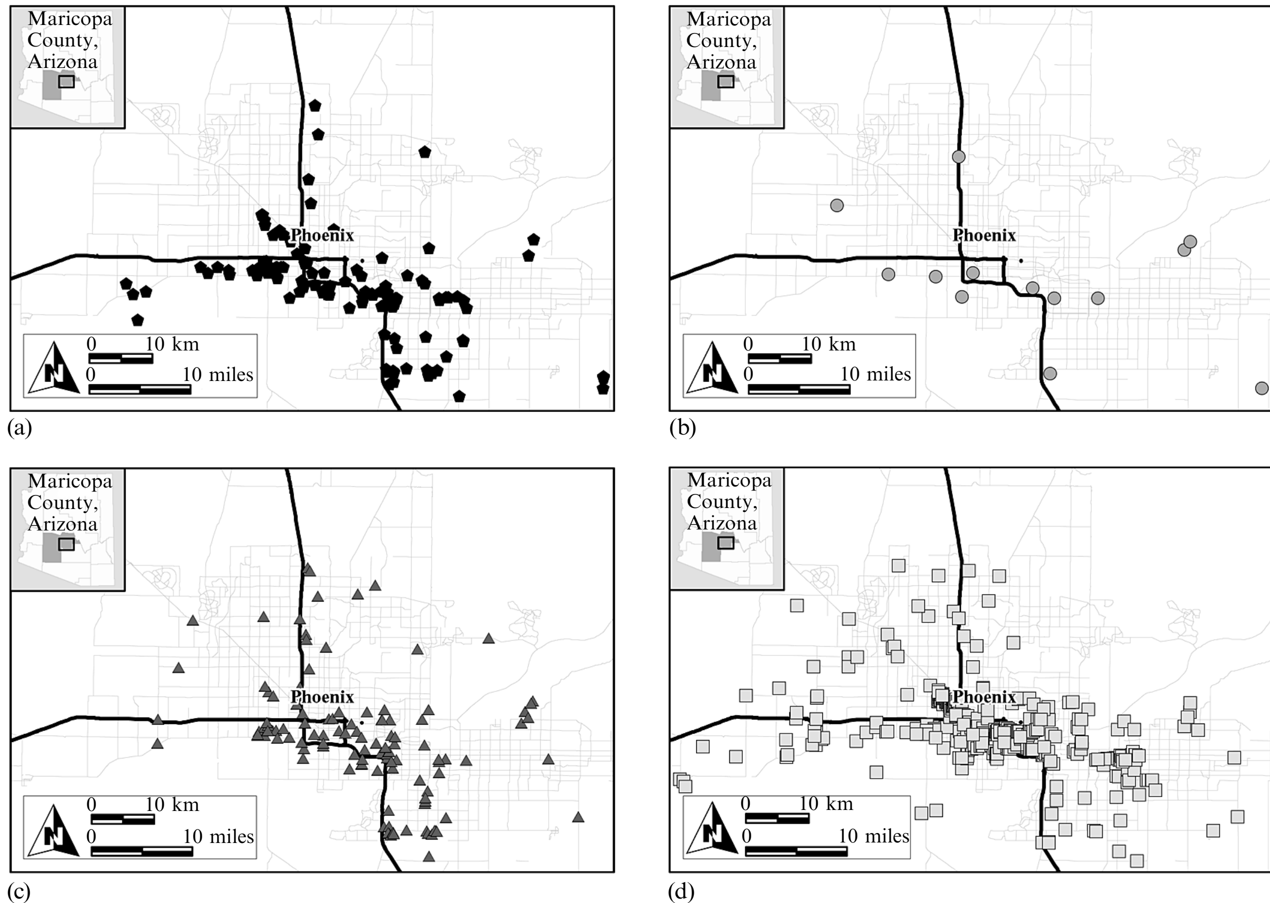



**Figure 1.** Hazardous sites in Phoenix [adapted from US EPA (Environmental Protection Agency) 1996]: (a) TRI (Toxic Release Inventory) facilities; (b) TSD (Treatment, Storage, and Disposal) facilities; (c) LQG (Large Quantity Generators) facilities; (d) CERCLIS (The Comprehensive Environmental Response, Compensation, and Liability Act Information System) sites.

undermining the very environmental conditions that tourists ostensibly have found appealing. Because of the concatenation of uncontrolled urban sprawl, industrial and vehicular emissions, a heavily used and growing freeway system, and a shallow valley location in which pollutants settle in a miasmic brown cloud, Phoenix is now host to a myriad of serious air, land, and groundwater contamination problems (Ellis et al, 1999; Pijawka et al, 1998). For most of the last decade metropolitan Phoenix has failed to meet EPA standards for atmospheric pollutants (ozone, carbon monoxide, and particulates), and the metropolitan area is rated by the EPA as 'serious' for all three pollutants (ADEQ, 1998). The spatial distributions of point-source hazards and ambient pollutants are all elements that make up Phoenix's ecology of risk. For this analysis we focus on four elements in this riskscape, comprising the distributions of hazardous industries, hazardous waste generators, waste-processing facilities, and toxic contamination sites.

**Approach**

The data for all regulated hazardous facilities in Maricopa County were extracted from the Right to Know Network (RTK) website, where we obtained a listing of all CERCLIS and Superfund sites in the county. We also accessed TSDF and LQG data from the Resource Conservation and Recovery Information Service (RCRIS), a data source that is part of the mandate of the Resource Conservation and Recovery Act (RCRA) hazardous waste program. Last, a list of all large manufacturing establishments that must comply with reporting requirements for TRI facilities was extracted from the RTK website[(2)] (see also Bolin et al, 2000).

Several studies using EPA data have raised concerns about spatial accuracy of the listed hazard locations (Been, 1995; Boer et al, 1997; Scott et al, 1997). For example, street addresses sometimes locate administrative offices rather than the actual hazardous facility, and spatial coordinates (latitude and longitude) are sometimes in error. Using a GIS, we mapped facilities, based on the published coordinates, and then checked locations against actual addresses of each facility, confirming these by cross-referencing with business and manufacturing directories, phone calls, and ground truthing. The TRI database alone listed incorrect coordinates for facilities in 40% of the cases, with errors ranging from one block to more than 10 miles (16 km). To clean the data, we geocoded and mapped each hazard site by its verified street address. Based on the information available, several listed facilities did not have adequate data to be mapped and were not listed in telephone or business directories. These were excluded from the analysis after an unsuccessful effort was made to identify their actual locations. Use of site-verification procedures has insured the accuracy of the locations of each hazard point utilized in this analysis. Figure 1 presents the locations of the 661 hazard sites by type in the Phoenix metropolitan area.

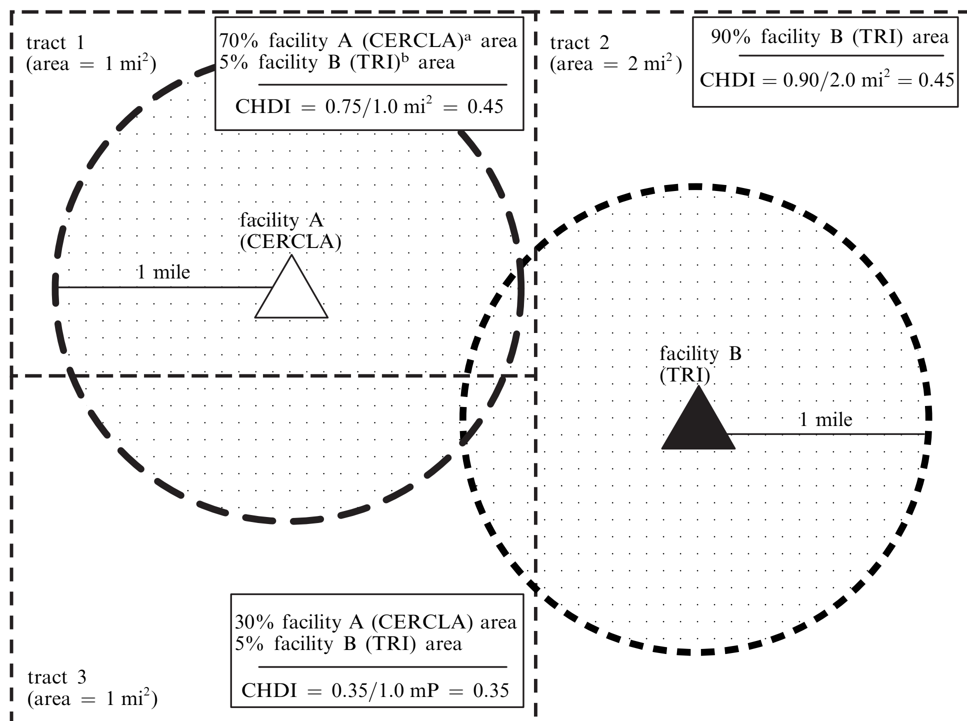
We consider this spatial verification process to be a critical step, as an error in the location of a facility by as little as one city block could place the facility in another census tract, leading to significant errors in statistical results based on a host – nonhost analysis. Although there has been significant debate in the literature on the 'best' spatial unit to use in analyses (for example, Anderton et al, 1994; Cutter et al, 1996; Daniels and Friedman, 1999; Mohai, 1996), census tracts provide an area compact enough for reasonably inferring potential risks from residential proximity to hazardous facilities. As census tracts have been used in many other equity studies, this choice also allows cross-site comparisons to be made among studies using tracts (for example,

[(2)] The URLs, respectively, for the data are: http://www.rtk.net/cerclissearch.html, http://www.rtk.net/rcrissearch.html, and http://www.rtk.net/trisearch.html.

Boer et al, 1997; Bowen et al, 1995; Glickman and Hersh, 1995; Hockman and Morris, 1998; Mitchell et al, 1999; Perlin et al, 1995; Szasz and Meuser, 2000).

Point-source hazards located on the edges of census tracts may pose greater potential risks for those in adjacent tracts than for those who reside in the hazard source's nominal host tract. Approaches that count hazard sites in each host tract do not take such edge effects into account (for example, Anderton et al, 1994; compare Pastor et al, 2001). To address this problem, we develop an alternative measure that we have labeled the hazard density index (HDI). We begin by drawing a circle with a radius of one mile (1.6 km) around each of the hazard sites, and assign the area of each circle a value of one. A GIS 'clipping' procedure is used to divided each hazard zone into fractions based on the tracts that each overlaps, then the tract is given a numerical score equal to the fraction of the circle that falls within tract boundaries (see figure 2). The scores for the hazard zone fractions are summed for each assigned tract and then divided by the tract's area in square miles to provide a density measure. This procedure yields a separate HDI value for each type of hazard. When summed across the four hazard types, the cumulative hazard density index (CHDI) measures the agglomeration of all hazard zones in a given census tract. This technique provides an indicator of the compounding of potential risk in a tract by including the proportionate contributions of all proximal hazardous sites.

This one-mile radius was selected, in part, because of precedents in the literature in equity studies concerned with proximity to industrial hazards (for example, Glickman and Hersh, 1995; compare Cutter et al, 2001). An additional factor we had to consider was the areal expanse of large industrial/commercial complexes in the city. A one-mile




[a] CERCLA—The Comprehensive Environmental Response, Compensation, and Liability Act.
[b] TRI—Toxic Release Inventory.
Note: mi$^2$—square mile.

**Figure 2.** Example of cumulative hazard density index (CHDI) methodology.

radius allowed us to include enough of the adjacent neighborhoods to determine socioeconomic characteristics. Last, the Phoenix metropolitan area is laid out on a grid pattern in which most major streets (four to six lanes wide) are one mile apart, both north – south and east – west. Much postwar industrial and commercial development has taken place along these avenues and at their intersections. Residential areas are typically bounded within these one-mile-square areas delineated by the larger streets.

An example and a schematic (figure 2) will make the hazard density procedure clearer. In this example, facility A and facility B are different categories of hazards. Facility A has a hazard zone that covers parts of two census tracts. Based on the proportion of the one-mile-radius circle that falls into each tract, that hazard area would have 0.7 assigned to tract 1 (that is, 70% of the total circle overlays tract 1), and 0.3 assigned to tract 3. The facility B hazard area has 0.9 assigned to tract 2 and 0.05 assigned to each tract 1 and tract 3. The CHDI is calculated as the sum of the two hazard scores standardized by area. Tract 1 has a hazard score of 0.75 and an area of one square mile: thus its CHDI is 0.75. Tract 2 has a hazard score of 0.9 but an area of two square miles, giving it a CHDI of 0.45. One of the criticisms leveled against the host – nonhost measure of point-source hazards is that the spatial dimension is neglected. The hazard density indices developed here offer an alternative, spatially sensitive methodology for analyzing the geographic distributions of hazardous industries and contamination sites, one that better assesses the risk burdens from sites in adjoining spatial units (for example, Glickman and Hersh, 1995).

We employ two approaches to examine the spatial distributions of hazardous industries and contamination sites in the Phoenix metropolitan area: (1) the conventional approach of recording the presence or absence of each hazard type (summed over the four types of hazards) in census tracts, and (2) the two hazard density indices (CHDI and HDI) described above. We compare demographic characteristics of tracts with and without any hazardous site, and then, separately, the demographic characteristics of host – nonhost tracts for each of the four types of hazards. We next use the HDIs to compare tracts with hazard densities of zero (meaning that no hazard zone overlaps the tract) and those with hazard densities greater than zero. Last, we examine the pattern of correlations among counts of hazardous facilities (both individually by type and summed), HDI values, and sociodemographic characteristics of tract residents. The social indicators for each tract are median household income, and percentages of the population who are White, Black (African-American), Hispanic [Latino(a)], and Native American.

Table 1 presents the frequencies for each hazard type, the number of tracts that contain at least one hazardous facility or contamination site, and the number of tracts 'touched' by a one-mile-radius hazard zone around each hazard point (columns 2 and 4). Hazardous facilities and sites are moderately concentrated, with 156 tracts (out of 466) containing at least one hazard point. When hazard zones are delineated around each point, however, the picture changes considerably: some 361 tracts are intersected by a hazard circle, leaving only 105 tracts untouched by any of the four types of hazards included here. In absolute numbers, CERCLIS sites are the most prevalent, demonstrating that even in a city as 'young' as Phoenix, past industrial and commercial activities shape the current urban riskscape. More tracts host and are touched by hazard zones of LQG than of TRI facilities, because of the spatial concentration of TRI facilities in contrast to the more dispersed LQGs.

Table 2 (see over) uses hazard counts and HDIs to examine the correlations among types of hazards. The differences in correlations among hazard types if we use the two methodologies, illustrates that each spatial approach is measuring somewhat different dimensions of hazard distribution. The upper-left portion of table 2 shows that

counts of hazardous facilities are relatively strongly correlated, indicating the likely copresence of facilities of different types within census tracts. CERCLIS sites are not so strongly correlated with hazardous industrial facilities, as might be expected given that most CERCLIS sites represent locations contaminated by past rather than by

**Table 2.** Correlations among counts of hazards and hazard density indices, by census tract.

| | Counts | | | | | HDI scores | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CERCLIS | LQG | TRI | TSDF | Sum | CERCLIS HDI | LQG HDI | TRI HDI | TSDF HDI | CHDI |
| CERCLIS | **1** | | | | | | | | | |
| LQG | **0.358** | **1** | | | | | | | | |
| TRI | **0.368** | **0.823** | **1** | | | | | | | |
| TSDF | **0.206** | **0.642** | **0.601** | **1** | | | | | | |
| Sum | **0.954** | **0.590** | **0.612** | **0.368** | **1** | | | | | |
| CERCLIS | **0.682** | **0.105** | **0.118** | 0.024 | **0.603** | **1** | | | | |
| LQG HDI | **0.195** | **0.531** | **0.357** | **0.226** | **0.292** | **0.294** | **1** | | | |
| TRI HDI | **0.259** | **0.403** | **0.485** | **0.242** | **0.352** | **0.380** | **0.719** | **1** | | |
| TSDF HDI | **0.115** | **0.259** | **0.242** | **0.447** | **0.163** | **0.128** | **0.432** | **0.454** | **1** | |
| CHDI | **0.673** | **0.191** | **0.194** | 0.064 | **0.623** | **0.985** | **0.430** | **0.511** | **0.183** | **1** |

Note: correlations with $p < 0.05$ in bold; $n = 466$. HDI—Hazard density index; CERCLIS—The Comprehensive Environmental Response, Compensation, and Liability Act Information System; LQG—Large Quantity Generators; TRI—Toxic Release Inventory; TSDF—Treatment, Storage, and Disposal Facilities; CHDI—cumulative hazard density index.

**Table 3.** Mean sociodemographic characteristics and difference of means *t*-tests for census tracts with and without hazardous facilities.

| Variable | Type of hazard | | | | |
|---|---|---|---|---|---|
| | CERCLIS | LQG | TRI | TSDF | Any hazard |
| White (%) | | | | | |
| with | 59.3 | 61.2 | 52.5 | 60.8 | 59.8 |
| without | 74.9 | 72.3 | 73.4 | 71.0 | 76.3 |
| *t* (significance) | **5.8 (0.00)** | **3.1 (0.00)** | **5.4(0.00)** | 1.3 (0.23) | **6.7 (0.00)** |
| Latino(a) (%) | | | | | |
| with | 30.5 | 29.0 | 35.9 | 26.3 | 30.2 |
| without | 18.3 | 20.3 | 19.5 | 21.4 | 17.1 |
| *t* (significance) | **5.3 (0.00)** | **2.8 (0.00)** | **4.7 (0.00)** | 0.9 (0.38) | **6.1 (0.00)** |
| Black (%) | | | | | |
| with | 4.9 | 5.3 | 5.8 | 8.7 | 4.7 |
| without | 3.3 | 3.5 | 3.4 | 3.6 | 3.2 |
| *t* (significance) | **2.2 (0.03)** | **2.0 (0.05)** | **2.1 (0.04)** | 1.3 (0.23) | **2.5 (0.01)** |
| Native (%) | | | | | |
| with | 2.9 | 1.8 | 3.4 | 1.5 | 2.7 |
| without | 1.1 | 1.5 | 1.3 | 1.6 | 1.0 |
| *t* (significance) | **2.0 (0.05)** | 0.8 (0.45) | 1.4 (0.17) | 0.3 (0.78) | **2.4 (0.02)** |
| Income ($) | | | | | |
| with | 29 019 | 30 851 | 28 713 | 28 923 | 30 247 |
| without | 39 063 | 37 305 | 37 516 | 36 594 | 39 523 |
| *t* (significance) | **6.0 (0.00)** | **2.6 (0.01)** | **3.6 (0.00)** | 1.7 (0.13) | **5.5 (0.00)** |

Note: *t*-values significant with $p < 0.05$ in bold; $n = 466$. CERCLIS—The Comprehensive Environmental Response, Compensation, and Liability Act Information System; LQG—Large Quantity Generators; TRI—Toxic Release Inventory; TSDF—Treatment, Storage, and Disposal Facilities.

current industrial, commercial, and waste-disposal activity. In addition, CERCLIS sites include leaking underground storage tanks from gasoline stations, which are widely dispersed over the metropolitan area.

Use of the HDI scores presents a similar but by no means identical picture. The correlations among specific hazard types are somewhat lower, indicating less redundancy in the measures when compared to counts of facilities. However, as in the case of using individual site counts, CERCLIS dominates in the total score. The correlation of 0.623 between the sum of all hazards and the CHDI is strong, but far from perfect, suggesting that the CHDI is providing new information not contained in the summary count of all hazards.

Tables 3 and 4 present average demographic characteristics and difference of means *t*-tests, respectively, for tracts, by using the presence–absence methodology and the HDI. Table 3 shows that for all but TSDFs, hazardous sites are inequitably distributed in Phoenix, with lower income and ethnic minorities overrepresented in tracts with at least one hazardous site. All differences of means are significant when the presence or absence of *any* hazard is considered (see the last column of table 3). If we examine each type of hazard separately some noteworthy differences are revealed. A clear pattern of association exists between socioeconomic characteristics of census tracts and the presence–absence of CERCLIS sites. The median household income in tracts without a CERCLIS site was $39 063, more than $10 000 higher than for tracts with at least one contamination site. The racial composition of host tracts versus nonhost tracts shows a similar pattern: tracts with at least one CERCLIS site had lower proportions of White residents and higher proportions of Latino, Black, and

**Table 4.** Mean sociodemograhpic characteristics and difference of means *t*-test for census tracts with zero and nonzero hazard density indices.

| Variable | Type of hazard | | | | |
|---|---|---|---|---|---|
| | CERCLIS | LQG | TRI | TSDF | CHDI |
| White (%) | | | | | |
| nonzero | 65.8 | 64.4 | 58.1 | 52.4 | 67.5 |
| zero | 80.1 | 77.1 | 79.6 | 72.8 | 81.9 |
| *t* (significance) | **6.6 (0.00)** | **5.8 (0.00)** | **9.6 (0.00)** | **4.6 (0.00)** | **6.3 (0.00)** |
| Latino(a) (%) | | | | | |
| nonzero | 25.5 | 26.2 | 30.9 | 33.1 | 24.0 |
| without | 14.0 | 16.9 | 14.9 | 20.2 | 12.9 |
| *t* (significance) | **6.3 (0.00)** | **4.9 (0.00)** | **8.1 (0.00)** | **3.4 (0.00)** | **5.7 (0.00)** |
| Black (%) | | | | | |
| nonzero | 4.1 | 4.7 | 5.6 | 7.0 | 4.1 |
| zero | 2.9 | 2.7 | 2.4 | 3.3 | 2.4 |
| *t* (significance) | **2.2 (0.03)** | **3.7 (0.00)** | **5.4 (0.00)** | **2.5 (0.02)** | **3.4 (0.00)** |
| Native (%) | | | | | |
| nonzero | 2.0 | 2.1 | 2.6 | 5.1 | 1.8 |
| zero | 0.7 | 1.0 | 0.8 | 1.2 | 0.6 |
| *t* (significance) | **3.4 (0.01)** | **2.3 (0.02)** | **3.1 (0.00)** | 1.7 (0.09) | **3.9 (0.00)** |
| Income ($) | | | | | |
| nonzero | 32 649 | 32 347 | 30 544 | 25 716 | 34 292 |
| zero | 43 444 | 40 440 | 40 473 | 37 622 | 43 616 |
| *t* (significance) | **5.8 (0.00)** | **4.9 (0.00)** | **6.1 (0.00)** | **5.6 (0.00)** | **4.5 (0.00)** |

Note: *t*-values significant with $p < 0.05$ in bold; $n = 466$. CERCLIS—The Comprehensive Environmental Response, Compensation, and Liability Act Information System; LQG—Large Quantity Generators; TRI—Toxic Release Inventory; TSDF—Treatment, Storage, and Disposal Facilities; CHDI—cumulative hazard density index.

Native American residents. The patterns of inequities for LQG and TRI facilities largely parallel those for the contamination sites: tracts with either type of industrial facility have significantly lower median household income and significantly higher proportions of Latino and Black residents. However, no significant relationship was found between the Native American population and the presence of LQG or TRI facilities.

The case of TSDFs in table 3 warrants additional comment. With only 13 TSDFs in Phoenix, the lack of statistical significance in the *t*-test is probably the result of the small number of tracts that host such facilities, and the heterogeneity of those that do not. Although tracts with TSDFs have sociodemographic characteristics similar to those with other hazardous sites—that is, they are poorer and 'less white' than tracts without—the mean differences, when compared with the standard errors of the means, are not large enough in the case of TSDFs to reach statistical significance. Nevertheless it is notable that these waste-handling facilities are spatially concentrated in 11 census tracts in south and central Phoenix. Further, the host tracts have the highest percentage of Black residents of any in the table, a product of Phoenix's long history of race-based residential segregation (for example, Roberts, 1973). To add to the potential hazardousness of such sites, the majority of these TSDFs have been operating on less stringent temporary permits for more than two decades, having been 'grandfathered' in under the far laxer environmental regulations of the 1980s (Kossan, 2000).

Table 4 presents a parallel analysis using individual HDI scores for each type of hazard, and the CHDI to summarize all hazards at once. Rather than compare tracts that do or do not host hazardous sites, tracts instead are divided into those with zero and nonzero HDIs. (Recall that tracts with an HDI score of zero are more than a mile from any hazardous facility considered in this analysis. However, a tract that contains no hazard sites may nevertheless have a nonzero HDI.) Of the 466 tracts, 105 (about 22%) have no hazardous facility within a mile of their boundaries. By comparison, 310 tracts (67%) do not contain a facility or contamination site. Despite the more inclusive nature of the CHDI measure compared with counts of sites, we again find strong, significant relationships between the proximity of a hazard and the income and race of residents. Tracts with CHDI scores greater than zero had median family incomes that averaged more than $9000 less than other tracts, and had significantly higher percentages of Latino, Black, and Native American residents (see the last column of table 4). HDIs for individual hazard types also follow this pattern. Tracts with an HDI greater than zero for all four types of hazards taken individually were significantly poorer and housed significantly higher proportions of Latino, Black, and Native American residents compared with tracts with an HDI of zero for the same hazard type.

Both spatial approaches reveal distinct differences between tracts that either host a site or are touched by a hazard zone, and those tracts with a score of zero by either measure. Affected tracts have significantly lower median household incomes and higher proportions of minority residents. Both approaches also reveal significant social inequalities in the distribution of technological hazards in Phoenix.

Table 5 presents the correlations of demographic variables with the two different hazard measures. The first five columns of data in the table show correlations based on counts of facilities or sites, whereas the last five present correlations based on HDI values. Sociodemographic variables are more strongly correlated with the CHDI than they are with the summary count of all hazards (columns 10 and 5, respectively). For example, results show that increasing numbers of sites or facilities present in a census tract are negatively related to income (−0.202) and positively related to the percentage of Latino (0.267) and Black (0.136) residents. These relationships were strengthened using the CHDI methodology (correlations of −0.353, 0.449, and 0.199, respectively).

**Table 5.** Correlations among sociodemographic variables and hazard indices, by census tract.

| | Counts | | | | |
|---|---|---|---|---|---|
| | CERCLIS | LQG | TRI | TSDF | Sum |
| Latino(a) | **0.265** | **0.101** | **0.157** | 0.031 | **0.267** |
| White | **−0.271** | **−0.118** | **−0.180** | −0.052 | **−0.281** |
| Black | **0.112** | **0.107** | **0.118** | **0.111** | **0.136** |
| Native | 0.084 | 0.008 | 0.079 | −0.006 | **0.092** |
| Income | **−0.207** | −0.075 | **−0.100** | −0.059 | **−0.202** |
| | HDI scores | | | | |
| | CERCLIS | LQG | TRI | TSDF | CHDI |
| Latino(a) | **0.412** | **0.254** | **0.371** | **0.138** | **0.449** |
| White | **−0.403** | **−0.281** | **−0.379** | **−0.182** | **−0.444** |
| Black | **0.167** | **0.211** | **0.204** | **0.238** | **0.199** |
| Native | 0.052 | 0.032 | 0.038 | 0.025 | 0.055 |
| Income | **−0.326** | **−0.217** | **−0.263** | **−0.166** | **−0.353** |

Note: correlations significant with $p < 0.05$ in bold; $n = 466$. HDI—hazard density index; CERCLIS—The Comprehensive Environmental Response, Compensation, and Liability Act; Information System; LQG—Large Quantity Generators; TRI—Toxic Release Inventory; TSDF—Treatment, Storage, and Disposal Facilities; CHDI—cumulative hazard density index.

Only the percentage of Native American residents was not significantly related to the presence of any hazard type or to the CHDI.

This is a puzzling result that deserves closer examination. It occurs in part because very few tracts house a significant proportion of Native Americans. Of 466 tracts, 4 have populations that are greater than 10% Native American, and an additional 8 tracts have as much as 5% Native American population. For 393 tracts, Native Americans make up 2% or less of the population. Further, tracts with significant Native American populations tend to be larger, so what hazards are present are distributed over a larger land area, reducing the CHDI. For example, the tract (also a reservation) with the highest fraction of Native Americans (88%), has 4 CERCLIS sites and 2 TRI facilities in an area of 150 square miles.

Considering individual hazard types in the first five columns of table 5, the counts of CERCLIS sites were significantly associated with all demographic variables, again with the exception of the percentage of Native American residents. Tracts with greater numbers of contamination sites were likely to have lower incomes (−0.207) than those with fewer sites. Tracts with greater concentrations of such sites also had higher percentages of Latino (0.265) and Black (0.112) residents. Conversely, tracts with more CERCLIS sites had significantly fewer Whites (−0.271) than less contaminated tracts. The relationship between the counts of TRI and LQG facilities and socio-economic characteristics followed a similar pattern. Median household income and the percentage of White residents were negatively related to the number of TRI facilities, whereas percentages of Latinos and Blacks were positively correlated.

As in the case of counts of hazards by type, the relationship between individual hazard types and sociodemographic variables is strengthened using HDI scores. Examining columns 6 through 9 in table 5 we see that correlation coefficients between HDIs for each hazard type and sociodemographics are consistently larger than for individual counts (with the exception of the percentage of Native American residents). That is, areas with more nearby CERCLIS, TRI, LQG, and TSDF sites are lower income and have higher percentages of Black and Latino residents. Why such strong relationships?

Counts assume that the influence of a hazard ends at the boundary of a census tract or other spatial unit, whereas the HDI methodology reduces the impact of the 'edge effect' by changing the logic of assigning risk to areas. The HDI methodology assumes that a hazard's potential range of influence extends beyond the tract, but only in proportion to the overlap of its mile-radius circle with the area of the census tract. Small overlaps with spatially large census tracts yield small measured influences.

Both spatial methodologies assume that risks are evenly distributed over the population of the tract (compare Cutter and Solecki, 1996; Cutter et al, 2001; Glickman and Hersh, 1995). This is a limitation of the HDI approach that is shared with the presence–absence methodology more typical of environment justice research. However, because the HDI is computed by multiple overlapping hazard zones, a high score suggests that larger areas of a given tract are near multiple hazard sources, even if those hazards are in adjacent tracts. This provides a better spatial measure of the concentration of hazards in and near a given tract that a host–nonhost methodology does, and it also allocates the potential effects of hazards over a more uniform area.

In sum, we found a distinct pattern of inequitable distribution of technological hazards in the Phoenix metropolitan area. Census tracts hosting point-source hazards had lower average incomes and higher proportions of minority residents than areas more distant from such hazards. These findings were even more pronounced when using the hazard density indices. Note that it could have been otherwise. That is, by using the CHDI to measure hazardousness over larger areas, class and ethnicity effects might have been attenuated by including 'whiter' and wealthier areas more removed from each point source. Instead, the relationships were strengthened. Based on the analysis presented here, we conclude that the CHDI is a more robust method for assessing the spatial relationships between point-source hazards and neighborhood characteristics as it is not subject to the arbitrariness of census-tract boundaries in mapping the distributions of hazards.

Both methodologies provide results that appear to illustrate that what Pulido (2000, page 15) calls 'white privilege' is clearly at work in Phoenix. In Pulido's usage, white privilege denotes a hegemonic form of racism, imbricated in ideologies and practices, that works to (re)produce white advantage across time and space. Conceptually, it calls attention to the relationships of different racial groupings in urban space and to the ways that 'whiteness' confers economic and social benefits to those so identified, thus linking color and class. In this context, the growth of suburbs in postwar Phoenix can be understood as a spatialized expression of white privilege that has inexorably concentrated both environmental and economic burdens on those constrained to reside in the polluted central areas of the city. White privilege in Phoenix, however, has not been manifested in patterns of 'white flight' documented in other urban areas. Rather, those privileged by race and class have historically 'avoided' the persistently lower income and minority areas of the city, rather than abandoning the central city for suburban locations as the ethnic composition of neighborhoods changes. The fact that Phoenix today remains residentially segregated reflects the 'white and middle-class' composition of its ever-expanding ring of suburbs.

**The ecology of risk**

By mapping the four technological hazards we have documented an important component of the ecology of risk in the Phoenix metropolitan area. Our analysis, using two alternative spatial methodologies, shows that there are clear and statistically significant patterns of environmental inequity in Phoenix at the census-tract level. With some variations, these inequities are consistent across a range of technological hazards, pointing to the pervasiveness of unequal environmental burdens borne by lower

income and racial minority neighborhoods. The spatial agglomeration of a variety of hazardous facilities and sites juxtaposed to disadvantaged people reflects a complex pattern of historic urban growth, industrial development, and racial exclusion. For Phoenix, the spatial effects of a century of race-based residential segregation is imbricated with the geography of industrial and commercial development to produce these environmental inequities.

Historically, early industrial development in Phoenix was promoted by military spending, with a total of nine military bases located in the area during the 1940s. The military presence, combined with a dry climate conducive to the high-technology manufacturing of the time, attracted electronics and aerospace industries, creating a small high-technology industrial sector by the 1950s (Luckingham, 1983). Until relatively recently most industrial development occurred along transportation routes (roads and railroads) which, not coincidentally, criss crossed historically low-income and minority neighborhoods in south and central Phoenix. An expanding international airport located along the Salt River just to the east of south Phoenix neighborhoods has promoted additional commercial and industrial development in the area, while subjecting these neighborhoods to the constant noise and emissions of jet traffic. Although a variety of mid-sized manufacturing concerns have continued to establish facilities along major transportation corridors in central and west Phoenix, since the 1970s a developing sector of electronics and semiconductor firms has built large industrial facilities at suburban sites, initiating a trend toward decentralization of newer TRI facilities. Smaller computer-components manufacturers that supply the larger suburban factories, including some with dubious safety records, remain in the older industrial districts (Pijawka et al, 1998). Nevertheless, the decentralization of large 'high-tech' industrial facilities into white middle-class suburbs has not been of a scale or extent to produce an 'equitable' riskscape in Phoenix, as this analysis has demonstrated. That is, irrespective of the suburbanization of some hazardous industries, Phoenix exhibits pronounced environmental inequities with disproportionate risk burdens in low-income areas and minority neighborhoods near the urban core (see Bolin et al, 2000).

The same areas of south Phoenix that now host hundreds of hazardous sites have also been home to significant portions of Phoenix's Black and Latino populations for much of the last century. Neighborhoods in what is now south Phoenix were originally settled early in the 20th century by Mexican-American and Black farmworkers employed in the cotton and citrus industries. As agriculture was displaced by commercial and industrial development over the first half of the 20th century, Blacks and Latinos were locked into these neighborhoods by strict racial segregation practices (Roberts, 1973). Chronic poverty and a lack of economic development have characterized south Phoenix virtually since settlement, in sharp contrast to the economic conditions in affluent northern and eastern suburbs that have grown rapidly since World War 2. City-led efforts at 'economic renewal' and urban development in depressed areas of south Phoenix led to the siting of a variety of hazardous industries there since 1970 (Pijawka et al, 1998). Although such industrial development was intended to provide employment for residents as part of an economic stimulus, that employment and its putative economic benefits have been largely illusory.

The toxic legacy of these historical-geographic processes is a land-use mosaic of hazardous waste management facilities, brownfields, landfills, and industrial sites in the midst of low-income and minority residential areas (Bolin et al, 2000). Although a 'which came first' approach to dating hazardous-facilities sitings and minority settlement (compare Been and Gupta, 1997; Mitchell et al, 1999; Pastor et al, 2001; Yandle and Burton, 1996) can oversimplify the complex sociospatial processes involved in the production of environmental inequities, in the case of Phoenix there is ample evidence

that Latino and black neighborhoods were established well in advance of industrial activity or toxic dumping. Further, these ancestral neighborhoods of today's south Phoenix were spatially 'contained' by a variety of racist practices, from housing and employment segregation to bank redlining that persisted over much of the 20th century. In this area, the interplay of racial segregation, low wages, unemployment, low property values, chronic underinvestment, a patchwork of zoning that produces unbuffered industrial activity in residential areas, questionable permitting decisions for hazardous facilities, and the availability of low-income housing have conspired to produce the environmental inequalities described here (Pijawka et al, 1998).

The sociospatial construction of these contaminated neighborhoods has not proceeded without popular opposition. After the efflorescence of a nationwide environmental justice movement in the late 1980s and its discourse of environmental racism, low-income neighborhoods in Phoenix have increasingly become centers of resistance and political contestation by citizen groups. The first of these environmental justice battles took place more than a decade ago as grassroots organizations coalesced in successful opposition to the proposed siting of a hazardous-waste incinerator in a predominantly Latino neighborhood in west Phoenix. During the 1990s a number of different grassroots mobilizations, protest actions, and lawsuits were filed in response to a variety of industrial accidents, toxic releases, and fires in industrial facilities in south Phoenix. A key event occurred in 1992, when a fire at a printed circuits plant located in a black neighborhood released a toxic smoke plume over the area. Lawsuits and EPA involvement followed as residents reported persistent health problems and criticized the state for a lack of adequate response to the contamination event. This event and its aftermath served both to highlight the extent of technnological hazards present in these poor neighborhoods and to raise local awareness of environmental justice issues (Pijawaka et al, 1998).

One of the central current environmental issues in south Phoenix concerns the presence of a number of TSDFs (see figure 1). Recent moves by the Arizona Department of Environmental Quality (ADEQ, 2001) to issue permits for continued operation and the expansion of one TSDF in a Latino neighborhood has engendered significant opposition from a coalition of citizen groups in the area. Although ADEQ ultimately issued an operating permit, expansion plans were denied and city zoning laws have been changed to prohibit additional sitings of hazardous facilities in the neighborhood. An environmental justice lawsuit under the US Civil Rights Act (Title VI) has recently been filed claiming that the operating permit unjustly burdens minority citizens in an area that already hosts a cluster of TSDFs (Kossan, 2000).

As this study has shown, one of the striking dimensions of the Phoenix riskscape is the concentration of multiple hazard sites in relatively few census tracts (see table 1). Four census tracts south and west of the central business district alone host more than 140 hazardous industries and toxic contamination sites—21% of the four hazard types in approximately 1% of all census tracts. To illustrate better the disproportionate burdens of risk in the metro area, figure 3 provides a three-dimensional model of the topography of hazard in Phoenix, with the vertical dimension representing CHDI scores for each tract. As the figure shows, when mapped three-dimensionally, the concentration of hazard zones in a few areas becomes clear, with a pronounced 'spiking' in west-central Phoenix and an additional high-risk zone in an extended range south of the downtown area, stretching across the older neighborhoods of south Phoenix. By portraying the cumulative hazard burden in Phoenix in this fashion we demonstrate the ecology of technological risk in Phoenix, with inequitable burdens being borne by lower income and minority residents living on the 'slopes' of these high-hazard-gradient areas.

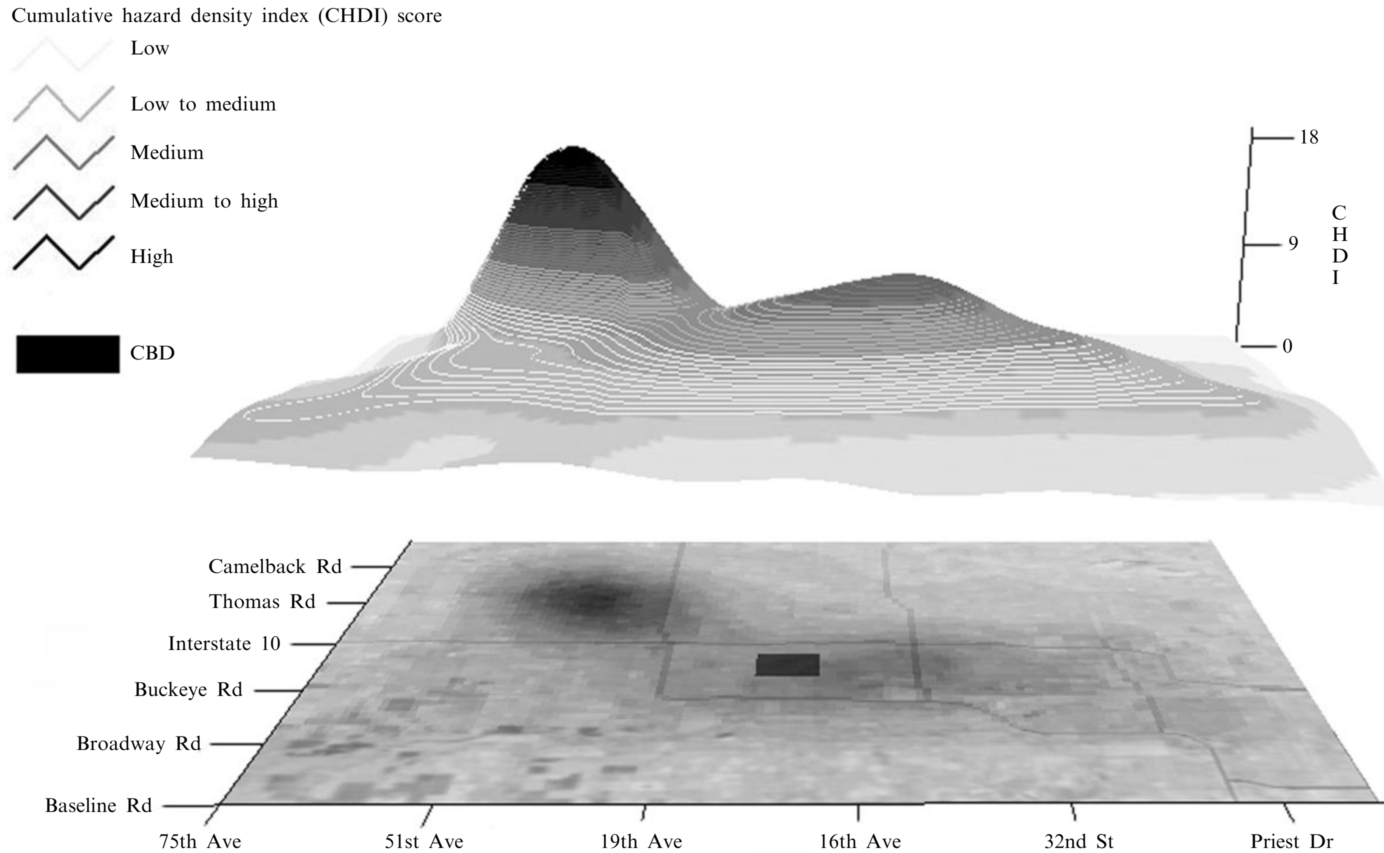



**Figure 3.** Cumulative hazard density topography in Greater Phoenix.

Methodologically, the indices developed here illustrate the importance of 'edge effects' in assessing environmental inequities in urban areas. In most instances the HDI approach strengthened findings by measuring how hazardous facilities in adjacent census tracts contributed to the hazardousness of place for those residing nearby. The HDI and CHDI provide enhanced measures of the concentration of hazards in certain areas, particularly of how risk burdens can accumulate in given census tracts. The CHDI confirms and produces stronger measures of association than use of the more conventional counts of sites in a tract. In addition, it provides a more robust and spatially sensitive measure of the distribution of hazards in census tracts by capturing the additive potential risks posed by the accumulation of hazardous sites in specific regions of the city. It provides further evidence that environmental injustices are pronounced in Sunbelt cities, although they typically lack the historical legacy of concentrated Fordist industrial centers characteristic of Midwest and Northeast cities. More importantly, from a social justice perspective, the postwar development of Phoenix's high-hazard corridors reflects a variety of recent planning and zoning decisions that have failed to protect low-income and minority residents from the presence of industrial and commercial hazards in their neighborhoods. Given the evidence presented here, multihazard studies of other Western Sunbelt cities would provide additional characterizations of the sociospatial distributions of environmental risks, and promote comparative analyses across urban sites.

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