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GEOSPATIAL IDENTIFICATION OF POTENTIAL ENVIRONMENTAL JUSTICE CONCERNS: PROVIDENCE, RHODE ISLAND

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Geospatial Identification of Potential Environmental Justice Concerns: Providence, Rhode Island

By

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ABSTRACT

In the early 1990's social activists driven by a concern with the uneven impacts of toxic pollution drew the attention of federal policy makers, establishing an official discourse focused on the issue of *environmental justice*. The concerns of these activists were supported by a number of statistical and Geographic Information System (GIS)-based studies of demographic patterns and toxic sites (Foreman, 1998).

The concept of environmental justice is based on the premise that disadvantaged groups such as the poor and racial and ethnic minorities bear a disproportionate burden of the negative externalities associated with economic development, including toxic pollution exposure (Buzzelli et al. 2003). Over the past decade and a half, *environmental justice*, which began as a loosely organized social movement –has become institutionalized in a number of federal, state and local policies and bureaucracies (Holifield, 2001). The United States Environmental Protection Agency (EPA), requires the integration of environmental justice into "...all programs, activities, –consistent with existing environmental laws and their implementing regulations (EPA, 2001)." The implementation of environmental justice policies is intended to establish *environmental equity*, or an equitable distribution of environmental pollution, health risk, and also access to environmental amenities (Holifield, 2001).

This study examines and evaluates spatial approaches to identify, and quantify environmental justice concerns existing in the City of Providence, Rhode Island. The study applies geographic information systems (GIS) technology; making use of existing geospatial data for selected toxic sites, and socio-demographic data from the 2000 US Census. Proximity measures are used as a means of quantifying the potential risk associated with the selected hazardous/toxic sites. The distributions of risk across various socio-demographic gradients are examined to highlight disproportionate impacts, or the lack thereof.

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I would like to offer special thanks to my wife Elizabeth J. Tootoo for her continued patience and support throughout my time at the University of Rhode Island. We dedicate this project to our newborn son, Jesse Lolenese Tootoo.

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Introduction

In the early 1990's social activists driven by a concern with the uneven impacts of toxic pollution drew the attention of federal policy makers, establishing an official discourse focused on the issue of *environmental justice*. The concerns of these activists were supported by a number of statistical and Geographic Information System (GIS)-based studies of demographic patterns and toxic sites (Foreman, 1998). The concept of environmental justice is based on the premise that disadvantaged groups such as the poor and racial minorities bear a disproportionate burden of the negative externalities associated with economic development, including toxic pollution exposure (Buzzelli et al. 2003) in comparison to other groups.

The National Environmental Justice Advisory Council (NEJAC) was established in 1993 to provide independent advice, consultation and recommendations to the U.S. Environmental Protection Agency (EPA) on matters related to environmental justice. Soon after in 1994, President William Clinton signed Executive Order (EO) *12898*, "Environmental Justice in Minority Populations" requiring that all federal agencies adopt the principle of environmental justice in all policy development activities to ensure environmental justice for disadvantaged populations (EPA, 2005). With this clearly defined mandate the important question of how to identify these populations presented itself (Most et al., 2004).

Over the past decade and a half, environmental justice, which began as a loosely organized social movement -has become institutionalized in a number of federal, state and local policies and bureaucracies (Holifield, 2001). The creation and continuing evolution of significant federal, state and local environmental justice policies and programs represents a substantial commitment by these parties to address the issue. Officially, this commitment equates to the integration of environmental justice into "...all programs, activities, -consistent with existing environmental laws and their implementing regulations (EPA, 2001)."

Environmental Justice, as defined by the United States Environmental Protection Agency is the: "fair treatment for people of all races, cultures, and incomes, regarding the development of environmental laws, regulations and policies (EPA, 2005). Per the EPA's Office of Environmental Justice, environmental justice is subject to scientific measurement:

> *The goal of environmental justice is to ensure that all people, regardless of race, national origin or income, are protected from disproportionate impacts of environmental hazards. To be classified as an environmental justice community, residents must be a minority and/or low income group; excluded from the environmental policy setting and/or decision-making process; subject to a disproportionate impact from one or more environmental hazards; and experience a disparate implementation of environmental regulations, requirements, practices and activities in their communities* (EPA, 2000).

The implementation of environmental justice policies is intended to establish *environmental equity*: a concept that holds all people should bear a proportionate share of environmental pollution and health risk and also enjoy equal access to environmental amenities. Policy standards established by *Executive Order (EO) 12898* require the exploration and development of effective quantitative environmental justice measurement techniques to identify environmental justice concerns and the populations they affect, and to also inform federal, state and local policy-makers in their decision making processes (Harner et al. 2002).

This study examines and evaluates spatial approaches to both identify, and quantify environmental justice concerns existing in the City of Providence, Rhode Island. Methods utilized in this analysis make use of geographic information systems (GIS), applying existing geospatial data for selected toxic sites with socio-demographic data from the 2000 US Census. The following analyses incorporate recognized environmental justice parameters with anticipated concerns that have yet to be widely recognized within disadvantaged communities in the City of Providence. The value of these analyses is viewed to be the establishment of new parameters for spatial analysis which permit the proactive engagement of social issues related to environmental justice. The techniques utilized allow the establishment of essential baseline data, providing the means for environmental justice programmatic evaluation. Analytical tools providing quantitative measures for environmental justice concerns allow for important prioritization of scarce existing federal funding resources dedicated to addressing social concerns at the community level.

Measuring Environmental Justice

Environmental justice research has grown over the past several decades to the point that it is now a "working hypothesis" -that disadvantaged groups face "disproportionate" environmental health hazards (Buzzelli et al., 2003). Acceptance of this working hypothesis has, and will continue to shape environmental policy in the United States (Bowen et al., 1995) for some time to come.

Even with growing the growing acceptance of existing disproportionate impacts, outcome studies focusing on quantifying the extent and presence of environmental justice issues with regards to disparities in current exposure are frequently challenged. To date, environmental justice researchers have argued over: the optimal scale, spatial units for analysis, selection of socio-economic variables, statistical techniques, and definition of facilities or physical features that pose a toxic threat (Bowen, 2001; Harner et al, 2002). Adding to the clouded picture is the fact that environmental justice continues to be measured in many different ways, with often-contradictory results (Mohai, 1996; Weinburg, 1998; Williams, 1999; Holifield, 2001).

Environmental justice researchers interested in measuring risk associated with environmental hazards must deal with a scarcity of measured exposure data for toxic releases (Buzzelli et al., 2003). As a result, a number of methodologies have developed to calculate risk measurements including: correlations of social group and hazard co-location or host/non-host studies (Greenburg, 1993); buffering (Glickman, 1994; Harner et al., 2002); plume dispersal modeling (Chakraborty and Armstrong, 2001; Karkazis and Boffey, 2001); toxicity indices (Bowen et al., 1995; Harner et al., 2002); and proximity to hazards as an estimate of exposure (Bolin et al., 2002; Cutter et al., 2001).

Holifield (2001) suggests that environmental justice research has progressed to the point at which researchers should no longer be asking: whether or not patterns of disproportionate exposure to environmental hazards exist, but rather: are disproportionably burdened minority and low income communities receiving appropriate attention and resources. Arguably, an important element in assessing appropriate allocation of attention and resources is the effective quantitative measurement of environmental justice concerns. Measurement of existing environmental justice concerns provides local, state and federal policy-makers with baseline data, valuable information in their decision-making processes (Harner et al, 2002).

The City of Providence

This study will focus on the geographic areas defined by the administrative boundaries for the capital city of Rhode Island, Providence. Providence encompasses 18.47 square miles of land area and 2.06 square miles of water area (RIEDC, 2005). Providence is the most densely populated city within the state of Rhode Island, with 9,402 persons per square mile of land area. The city is the most populous of all the 39 cities and towns for the state, with a population as of April 1, 2000, of 173,618 persons. This population figure represented an 8.02% increase (12,890 persons) from the 1990 population of 160,728. (US Census, 2000). The city of Providence exhibits a high degree of racial diversity. Racial identity for those claiming one race for the city of Providence is presented in Figure 1.

City of Providence Racial Compostion:
Those Claiming One Race Only (source US Census 2000)

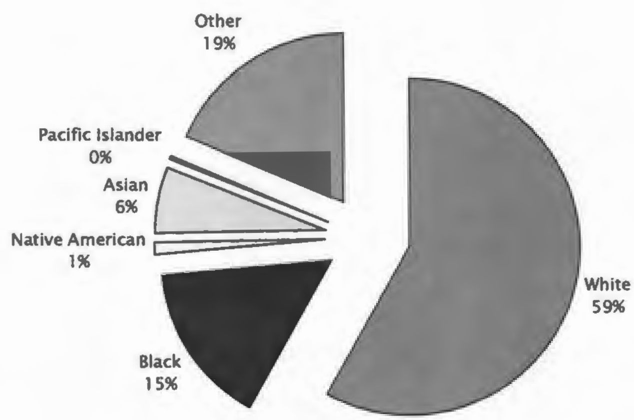


Figure 1

It should be mentioned that one of the more significant ethnic groups figuring into a net 10 year period population increase for the city of Providence are those claiming Hispanic ethnicity. In 2000, 52,146 persons of Hispanic origin lived in Providence. This population figure represented 30% of the population Capital City's total population for the 2000 reporting year; a dramatic 20 year increase of 27,164 or 108.7% from the 1980 Hispanic population of 24,982(US Census Bureau, 2000).

The City of Providence's major manufacturing industries: metals, machinery, textiles, jewelry, and silverware were established by 1830. These industries have historically played an important role in attracting international immigrants contributing to racial and ethnic diversity (RIEDC, 2005). Unfortunately, Providence's storied manufacturing and industrial heritage has also created numerous toxic and, or sites that are regulated by either, state and/or federal agencies. Toxic sites are common in the post-industrial central city context, and are typically located on former industrial or commercial sites (Miner, 2003). In

Providence, many of these sites are located in what were originally prime sites for industrial development – at the core of the city, on waterfronts and close to major transportation routes (Miner, 2003). In Rhode Island regulated toxic sites occur across a wide spectrum of neighborhoods and communities from rural and suburb to the urban core, the issues and concerns of importance in these extremes are very different. In the later contexts, they are commonly seen as community burdens because they may not contribute substantially to the tax base, possess negative aesthetic qualities and pose a possible contamination threat to the water supply; in the former they present the same burdens but are usually linked to a number of wider socio-economic problems (Solitare and Greenburg, 2002). Understanding spatial relationships between toxic sites, the risk associated with them, and those affected is key to addressing a number of socio-economic issues facing the City of Providence today.

Objectives and Methods of Study

In the context of environmental justice literature, this study is to be considered an *outcome study*– as it focuses on the extent of environmental justice concerns in terms of disparities in current exposure (Jerrett et al. 2001), for the City of Providence. Analysis will attempt to examine and highlight disproportionate burdens related to quantified measures of toxic risk in the City of Providence; specifically patterns and/or relationships between the spatial distribution of environmental hazards in the form of toxic sites, and low income and ethnic/racial minority residents.

The product of this analysis is a preliminary indicator of possible environmental justice concerns for the city of Providence; revealing inequalities in potential risk based on selected socio-economic variables.

Similar studies in the future will hopefully provide valuable guidance to public and private decision-makers, when they are faced with decisions related to the allocation of funds and resources for neighborhood scale development and/or redevelopment projects. Additionally, baseline and evaluative data provided from similar studies will allow for the monitoring and evaluation of programs and policies designed to address environmental justice issues challenging disadvantaged populations.

Methods used in this study to examine the spatial distribution of risk associated with toxic sites will draw upon recent techniques developed by environmental justice researchers in the absence of detailed data regarding the type and amount of toxic exposure associated with point sources, specifically -proximity measures. Proximity measures provide a geospatial indication and quantification of potential environmental risk and those disproportionately affected; a valuable tool in understanding and addressing environmental justice concerns at the citywide level and valuable data for comparison at the statewide and regional scale.

This study will examine several individual point source toxic site spatial distributions and their relationships to socio-demographic variables. The goals of this study are to address the following questions:

- Do different environmental hazards have differing spatial and/or social distributions in the urban context of Providence, RI?

- How does the evaluation of social and spatial distributions of environmental risk change when considering risk density measures from single point sources as opposed to a host/non-host analysis?

- How does the evaluation of the social and spatial distributions of environmental risk change when considering cumulative hazard measures: sum of toxic sites hosted (host/non-host methodology) versus cumulative hazard index (hazard density index methodology)?

Level of Analysis

The unit of analysis for this study takes place at the census block level. Assessment of risk associated with toxic sites will be analyzed at the census block group level.

The census block group is the smallest unit at which the US Census Bureau reports the desired socio-economic variables of: race and median household income. The census block group allows for aggregation and comparison at several scales including: the census tract; and the neighborhood. Additionally, Most et al. (2004), suggest the appropriateness of smaller spatial units (such as census block groups) in cross-sectionals studies such as this one.

Census block groups are analyzed in context, with reference to each of the City of Providence's 25 neighborhoods. The study area is delineated in Figure 2. Residential landuse as interpreted from 1997 aerial photography is provided as referential data, indicating the general pattern of residential development for the City of Providence (RIGIS, 2005)

STUDY AREA: THE CITY OF PROVIDENCE

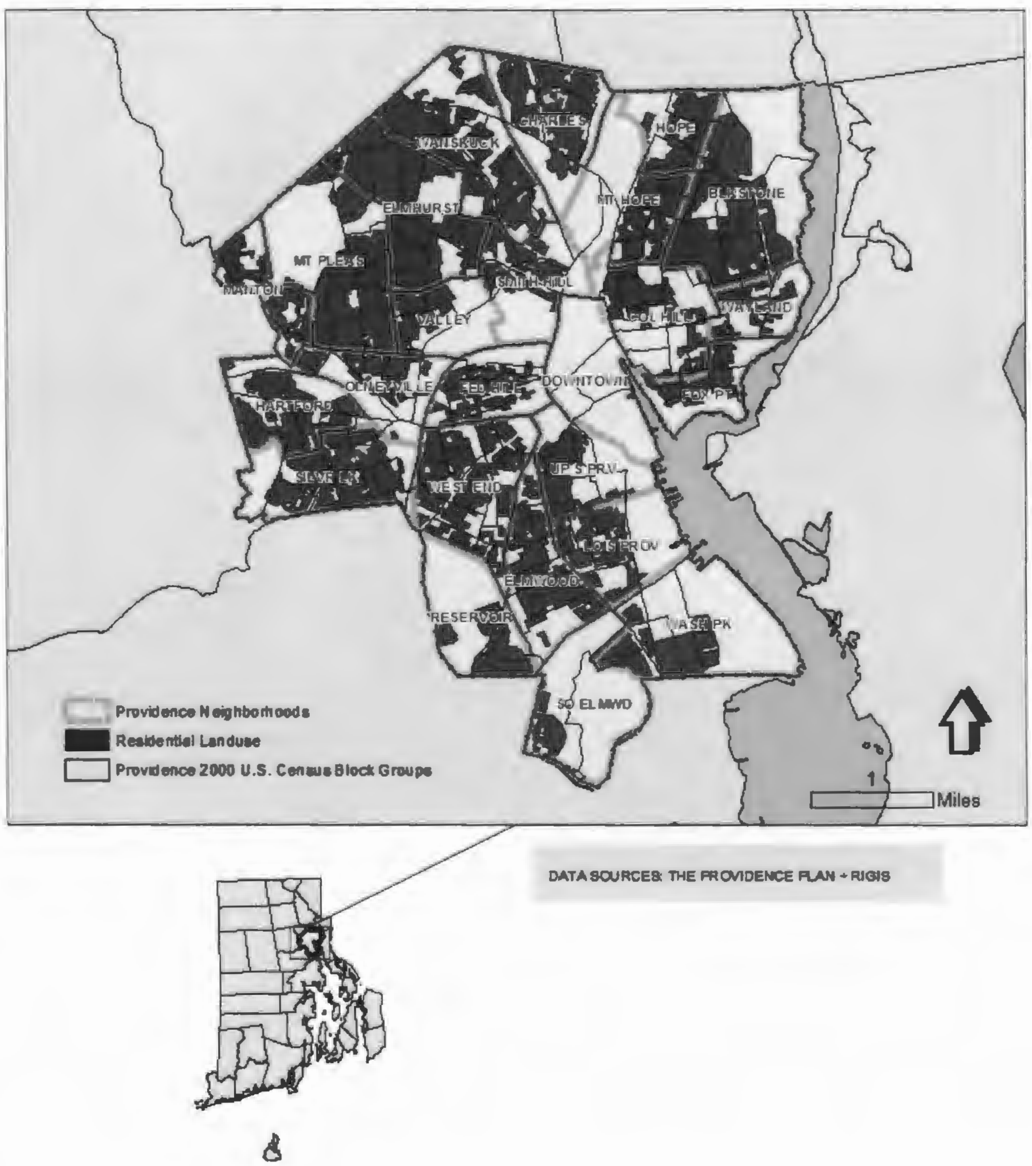


Figure 2

Definition of Toxic Sites

For the purposes of this study *toxic sites* are defined as appropriate locations included in either federal, or state of Rhode Island geographic information systems (RIGIS) -geospatial databases. All geospatial data was projected using North American Datum 1983, with a Rhode Island State Plane Feet geographic coordinate system.

Appropriate sites existing in the U.S. EPA's databases include: the reporting year 2002 Toxic Release Inventory (TRI) sites. Appropriate sites existing in the Rhode Island Geographic Information Systems (RIGIS) database to be used in this study include: Federal EPA listed Comprehensive Environmental Response Compensation and Liability Information System (CERCLIS); and hazardous material leaking underground tanks storage tanks and associated piping used for petroleum and certain hazardous substances that have experienced leaks as determined by Rhode Island Department of Environmental Management (RIDEM). Thus a total of three classes of toxic sites will be used in this study including:

- Toxic Release Inventory Sites (TRI);

- Federal EPA listed Comprehensive Environmental Response Compensation and Liability Information System (CERCLIS) sites; and

- Hazardous material leaking underground storage tanks and associated piping used for petroleum and certain hazardous substances that have experienced leaks (LUSTS).

Locations for each of the selected toxic sites were checked to insure that all of the sites used in the analysis were unique across toxic site classes – to prevent redundancy. Since TRI data are listed by chemical(s) released, each TRI point source is considered separately for each chemical released. Thus 22 unique TRI point sources yielded 70 point sources by chemical.

Evaluation and Quantification of Risk

With no comparable measures of risk among the selected toxic sites, all hazardous sites in this analysis will be treated as equally hazardous to those living in proximity. For the purposes of this study relative hazardousness -or risk will increase relative to the number of hazards in a given area. Risk will be considered a proxy measure for the burdens associated with negative environmental externalities associated with hazardous/toxic sites.

Host/Non-host Approach

Initially, risk associated with each of the three classes of toxic sites for each of census block group was analyzed by registering either the presence, or absence of each toxic site class. This host/non-host binary approach classified census blocks containing at least one of the three toxic site classes as host sites and – *at risk*, while those containing none non-hosts will be considered to be *not at risk.* Sums of all hazards hosted within the census block groups were also calculated.

Hazard Density Indices

The levels of risk associated with each of the three classes of toxic sites for each census block group were analyzed and measured using the Hazard Density Index (HDI) procedure developed by Bolin et al. (2002). HDI can be considered an indicator of potential risk for residents of affected census block groups from chronic and acute emissions. No inferences can be made from these indices regarding actual emissions from the toxic sites (Bolin et al., 2002). This density-based approach to measuring risk is based on several assumptions:

- All of the environmental hazards (toxic sites) will be considered to produce, process, and/or emit toxic substances regulated by the US EPA/RIDEM and;

- Physical proximity to the environmental hazards (toxic sites) may increase the probability of human exposure in at least 3 ways:

- Atmospheric releases during industrial accidents (explosions, fires, and major spills);

- Fugitive emissions of toxic substances from minor leaks, spills, evaporation, etc. that are part of routine industrial activity; and

- Point source air releases of toxic substances during production and disposal processes (Bolin et al., 2002).

A buffer with a radius of one mile (5,280 feet) was centered on all identified toxic sites to create a hazard zone for each site. The influential decision for a buffer radius of one mile was based on several factors: First, Glickman (1994) claimed that the radius of an area affected by a major chemical release often exceeds one mile. Secondly, since data related to the extent and chemical makeup of toxins emitted from the hazardous sites analyzed were not available in all cases, a single conservative measure was chosen (Chakraborty and Armstrong, 1997).

The hazard zones, created from the one mile buffer centered on identified point source sites were then intersected with census block groups using the *intersect analysis function* of ArcGIS 9. This function divided each hazard zone into fractions based on the census block group(s) overlapped. Each census block group was then given a numerical score based on the areal fraction of the hazard zone falling within its boundaries. The scores were summed for each toxic site class intersecting the census block group, and then divided by the census block group's area in square miles to provide a density measure (Bolin et al, 2002).

Cumulative Hazard Density Index

The HDI procedure yielded a separate HDI for each toxic site class. The separate HDIs for each of the three toxic site classes were summed to create the Cumulative Hazard Density Index (CHDI) for each census block group (Bolin et al. 2002). CHDI measures the agglomeration of all hazard zones within a given census block group; providing an indicator of the compounding risk in each census block group with the inclusion of the proportionate contributions of all proximal toxic sites (Bolin et al. 2002).

Looking for Disproportionate Impacts

To examine disproportionate impacts of the three classes of toxic sites for the city of Providence, US Census 2000 data are analyzed. Socio-demographic variables to be examined for census block group residents include: median household income, racial and ethnic composition. Since those claiming *Hispanic Ethnicity* may be included in more than one racial category disproportionate impacts affecting the Hispanic population of the City of Providence are difficult to perceive when examining those that claimed only one race. For this reason in the scope of this study; *ethnicity*-whether or not a person claims Hispanic status will be considered separately from race.

Racial and ethnic data for census block groups used in this study were derived from US Census 2000 source data for Rhode Island excerpted from Summary File 1 (SF1) of Population & Housing information including sex, race, age, household and housing unit information to the Census Block level (Rhode Island Statewide Planning, 2005). Since these data were only available at the census block level, the data were summed based on census block group identifiers and related to the larger census block group data set.

Median household income data used in this study were derived from US Census 2000 source data for Rhode Island excerpted from Summary File 3 (SF3) of Population, Housing & Economic information including sex, race, age, employment, transportation, education, income, household, family, housing unit, place of birth and language information to the Census Block Group level. SF3 data are based on a sample population but totals have been extrapolated to coincide with whole population totals (Rhode Island Statewide Planning, 2005).

To investigate disproportionate impacts of toxic sites the selected socio-demographic characteristics for census block groups containing (host) and without (non-host) any of the three toxic site classes present are compared using various statistical methods. To provide for a comparison between the host/non-host methodology and the HDI methodology HDIs (including CHDI) are used to compare the same socio-demographic characteristics for census block groups with hazard densities of zero to those with hazard densities greater than zero using the same statistical methods.

RESULTS

Results for summative findings for both the host/non-host and, the hazard density methodologies are presented in Table 1. Table 1 presents the frequencies for each hazard type, the number of block groups that contain at least one hazardous site, the number of block groups touched by at least one type of hazard zone defined by the 1-mile-radius-hazard zone around each hazard point (HDI>0), and those not touched by hazard zones (HDI=0).

Table 1 Affected and Unaffected Block Groups: Host/Non-Host and HDI

Toxic Site	# of sites	Host Block Groups	Non-Host Block Groups	Block Groups HDI >0	Block Groups HDI = 0
CERCLIS	16	7	155	152	10
LUSTS	165	81	81	162	0
TRI	70	14	148	19	143

In absolute numbers the LUSTS sites are the most common, followed by TRI sites; CERCLIS sites represent the lowest presence of all toxic sites analyzed. It must be mentioned that the number of TRI sites in this analysis, 70, reflects the total number of unique chemicals released from one of 22 TRI sites- as TRI sites were analyzed based on the type of chemical(s) released. The number of host block groups would seem to indicate that with the exception of LUSTS the hazardous sites used in this analysis are moderately concentrated in the City of Providence.

However, a consideration of block groups with HDI> zero (or those block groups that intersect with some portion of the 1-mile-radius area for each toxic site) a very different picture emerges. None of the 162 census block groups is untouched by at least one of the hazard zones created by one of the three classes toxic sites (HDI>zero).

Host/Non-Host

Census block groups for the City of Providence hosting one of the three toxic sites were identified. This methodology provided a good picture of how each of the three toxic sites analyzed are distributed throughout the city.

Each toxic site was found to have its own spatial pattern using this approach. CERCLIS sites and TRI sites were found to be concentrated in historically industrial/commercial areas, while LUSTS sites were diffusely distributed throughout the city of Providence; not limited to areas with past or present commercial/industrial and or manufacturing uses. The host/non-host methodology does not, however, take into consideration the aggregate effects of multiple adjacent toxic sites, nor the existence toxic sites located nearby- but not within census block groups.

The sum of all toxic sites hosted by each census block group provided a limited idea of the degree to which block groups are affected by the toxic sites. Analyzed in aggregation, but without data accounting for the magnitude density for toxic sites, this information does not provide detailed quantitative information relating the magnitude of toxic risk. The results of the sum of all toxic sites analyzed are shown in Figure 3.

This means of measuring risks associated with toxic sites did prove to be a valuable preliminary investigation into the spatial distributions of the examined toxic sites for the city of Providence. Patterns of overlapping concentrations for the toxic sites used in this analysis begin to emerge at this level of investigation, allowing for focus on the following hazard density index methodology. The spatial concentrations across the geographical extent of the city of Providence for each of the three toxic site classes, and the census block groups which host them are shown in Figure 4.

HOST/NON-HOST SUM OF ALL TOXIC SITES

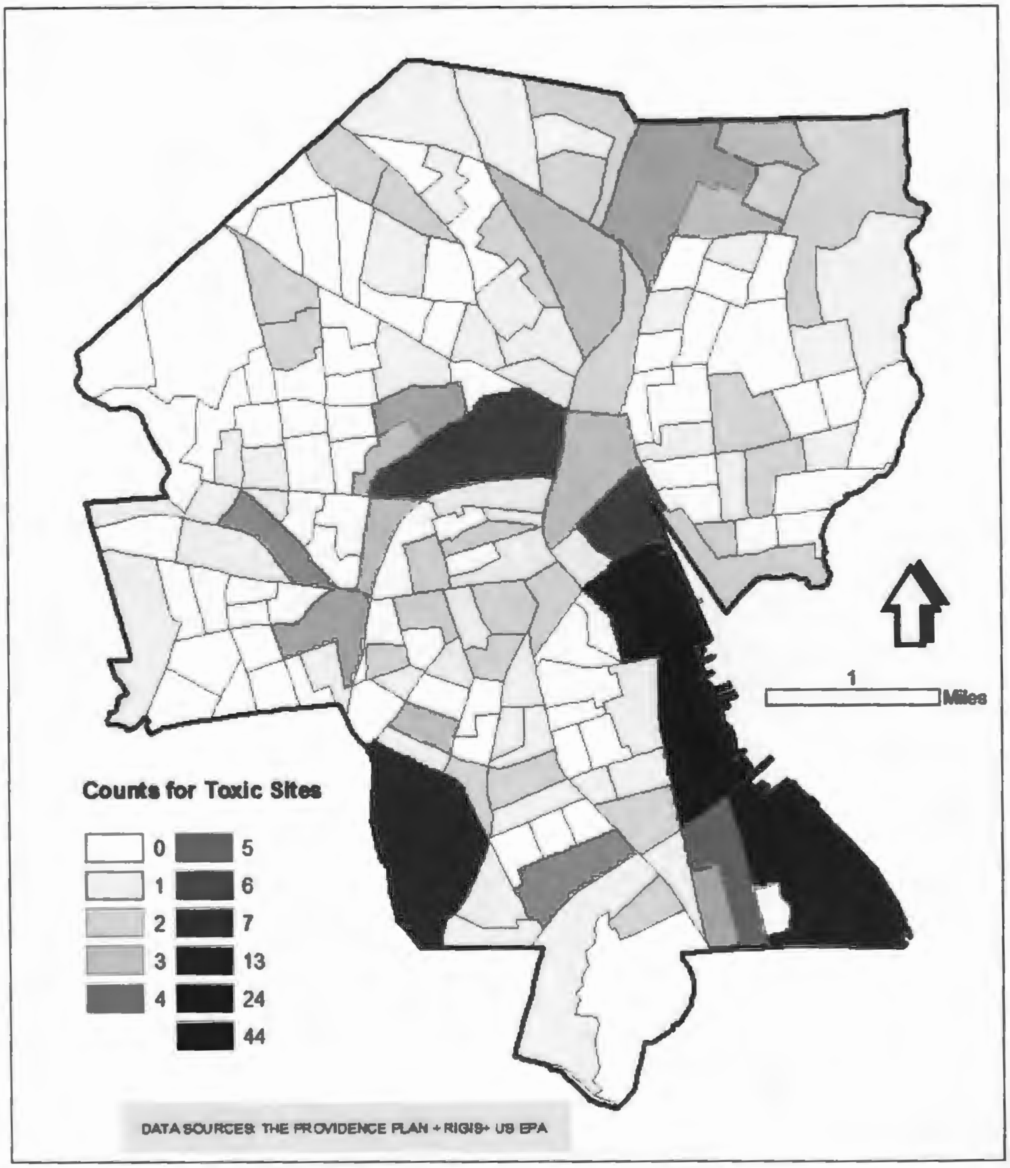
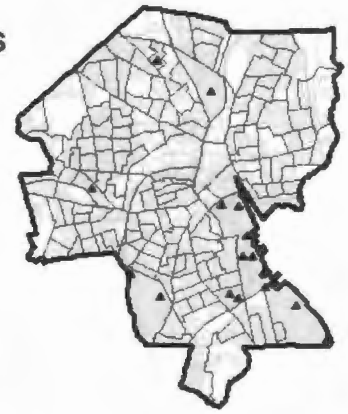


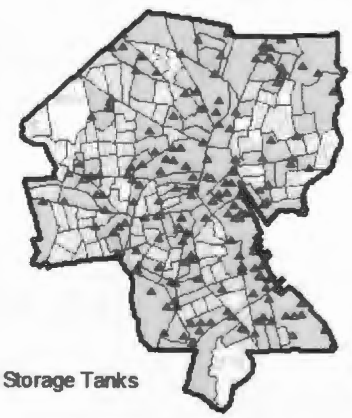
Figure 3

HOST/NON-HOST
CENSUS BLOCK GROUPS



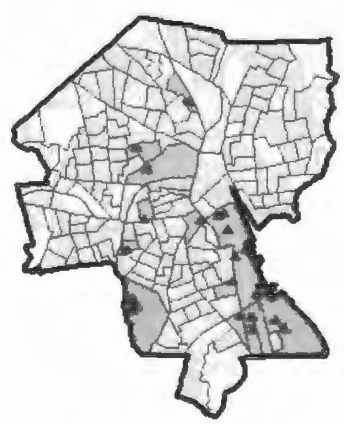
▲ CERCLIS Sites

Host Block Groups



▲ Leaking Underground Storage Tanks

Host Block Groups



▲ TRI Sites 2002

Host Block Groups

Figure 4

DATA SOURCES: THE PROVIDENCE PLAN + RIGIS+ US EPA

Hazard Density Indices

CERCLIS Hazard Density Index:

HDI values calculated for CERCLIS sites at the census block group level are shown in Figure 5; the values are presented by standard deviations.

HAZARD DENSITY INDEX: CERCLIS

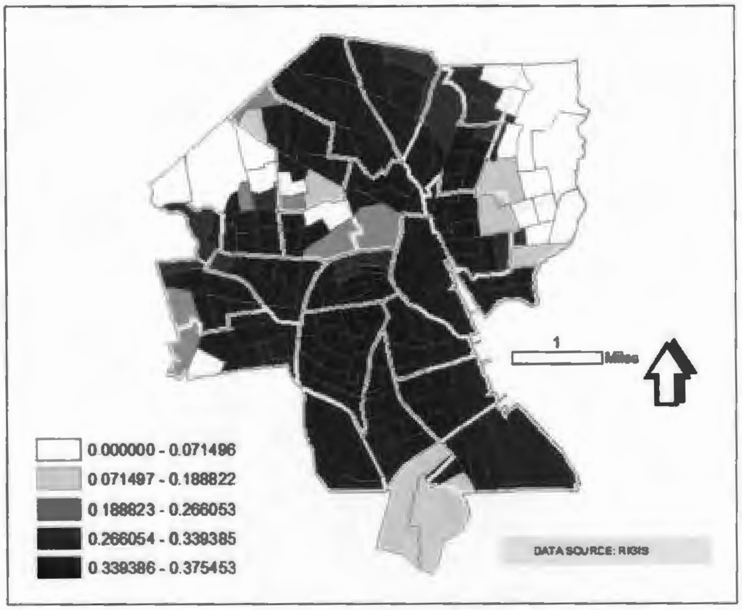


Figure 5

Spatially, the HDI calculated for CERCLIS sites presents a very different picture than the CERCLIS host/non-host approach. Using the host/non-host procedure only 4.3% of all block groups were found to host CERCLIS sites. The values of the CERCLIS HDI are fairly spread out among a greater portion of Providence's census block groups. A clearer understanding of the aggregate effects of CERCLIS sites is provide by this measure and the effects of adjacency for census block groups not containing, but spatially proximate to CERCLIS sites are perceivable.

LUSTS Hazard Density Index:

HDI values calculated for LUSTS sites are shown in Figure 6; the values are presented by standard deviations.

HAZARD DENSITY INDEX: LUSTS

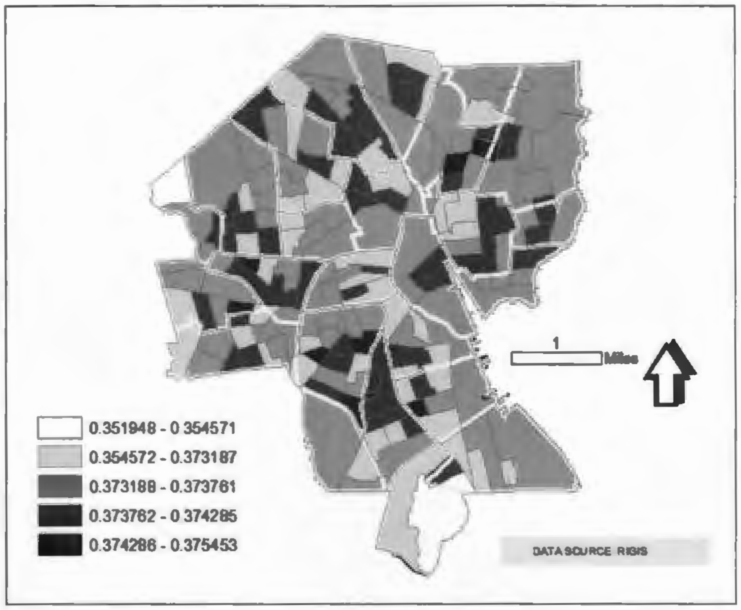


Figure 6

The HDI calculated for LUSTS sites indicates a spatially decentralized pattern of census block groups affected by existence of LUSTS, not unlike the LUSTS results of the host/non-host methodology. Definitive spatial patterns do not present themselves. The host/non-host procedure found that half of all US Census block groups in Providence host LUSTS sites. Perhaps as a result of this wide ranging distribution, calculated HDI values do not exhibit as high a degree of variation as those calculated for CERCLIS sites.

The LUSTS HDI measure does appear provide a better understanding of compounding hazard risk associated with LUSTS, as those census block groups with multiple, and/or are located within close proximity of LUSTS sites exhibit higher index values.

TRI Hazard Density Index:

HDI calculated values for TRI sites are shown in Figure 7; the values are presented by standard deviations.

HAZARD DENSITY INDEX: TRI

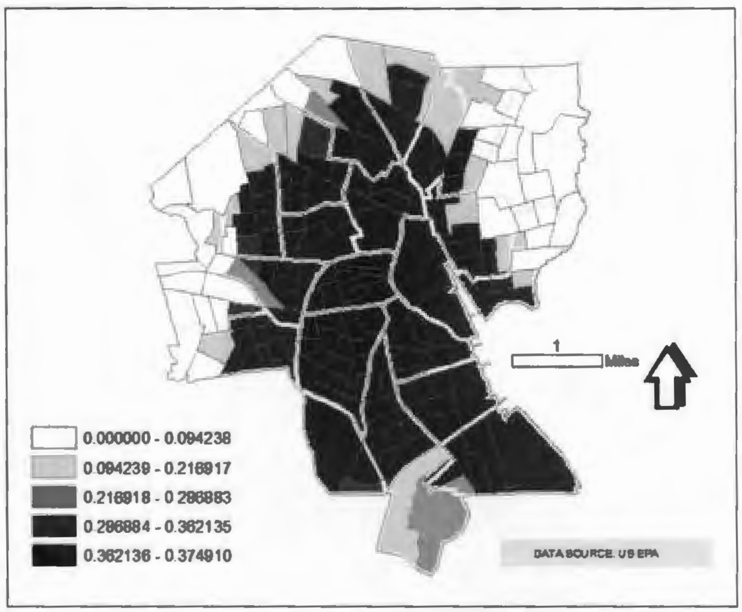


Figure 7

The HDI calculated for TRI sites provides a different perspective regarding the effects of TRI sites on census block groups throughout the city of Providence, when compared to the host/non-host methodology. More census block groups exhibit relatively high values for TRI HDI. This indicates wider reaching effects of these spatially concentrated sites, as opposed the host/non-host approach- in which, only 8% of all block groups were identified as TRI site hosts.

TRI HDI indicates a concentration of higher values in the core of the city, were commercial and industrial sites are common with decreasing risk moving out from the core on the northwestern, northeastern and southern extents of the city-where landuse transitions to residential. Perhaps, more census block groups are touched by the hazard zones of CERCLIS sites than of TRI facilities because the relative central spatial concentration of TRI hazard zones close to the urban core of Providence - as opposed to the slightly more dispersed CERCLIS hazard zones. As expected census block groups containing multiple TRI sites exhibit the higher HDI values, however these high values extend beyond the census blocks that host TRI sites. Spatial patterns of the aggregate effects of TRI sites begin to become clearer when analyzed using the HDI method for census block groups.

Cumulative Hazard Density Index:

CHDI calculated values are shown in Figure 8; values are presented by standard deviations. CHDI values were calculated by summing the separate HDI values for each of the three toxic site classes for census block groups.

CUMULATIVE HAZARD DENSITY INDEX

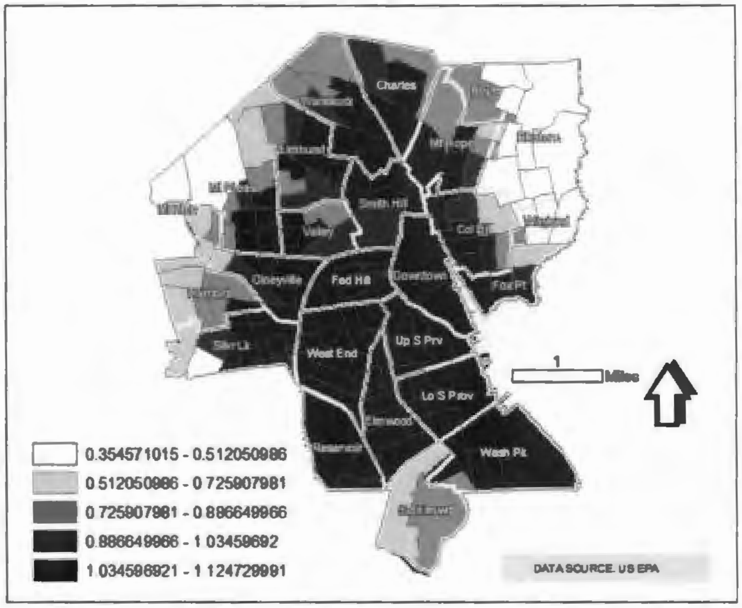


Figure 8

CHDI values provide a comprehensive picture of the spatial concentration of the toxic sites analyzed in this study. Aggregate effects of multiple hazards are reflected in higher CHDI values. At this level of analysis it was useful to consider census block groups in their neighborhood context to begin to understand their patterns of spatial distribution.

Discussion

Table 2 uses hazard counts and HDIs (including CHDI) to investigate the correlations among the different types of environmental hazards. The Pearson correlation coefficients presented in this table describe the strength of the linear association between the variables, which were all measured at the interval level. The differences in correlations among toxic sites highlight the fact that the host/non-host and hazard density index approaches are measuring different dimensions of toxic site distribution for the city of Providence.

Table 2 Correlations among counts of hazards and hazard density indices by census block groups:

	Counts				HDI Scores			
	CERCLIS	LUSTS	TRI	SUM	CERCLIS HDI	LUSTS HDI	TRI HDI	CHDI
CERCLIS	1.000							
LUSTS	***0.714***	1.000						
TRI	***0.895***	***0.719***	1.000					
SUM	***0.903***	***0.905***	***0.943***	1.000				
CERCLIS HDI	0.082	0.026	0.059	0.053	1.000			
LUSTS HDI	0.014	0.071	0.012	0.040	***0.216***	1.000		
TRI HDI	0.094	0.080	0.111	0.104	***0.620***	0.094	1.000	
CHDI	0.099	0.063	0.097	0.090	***0.877***	**0.175**	***0.921***	1.000

bold italics: correlation is significant at the 0.01 level (2-tailed)
Bold: correlation is significant at the 0.05 level (2-tailed)

Correlations among the counts of toxic sites are relatively strongly correlated, indicating the likelihood the coexistence of different toxic site classes within the city of Providence's census block groups. TRI sites and the sum of toxic sites hosted by census block groups show the strongest correlation– this strong correlation is likely due to the consideration of individual chemicals released from TRI sites. For example a TRI site releasing more than one type of regulated chemical is considered for each type of chemical released (e.g. if a census block group were to host a TRI site releasing for example three chemicals –the block group would be considered to host three TRI sites).

Analyzing correlations among HDI scores indicates an overall lower degree of correlation. This may indicate less redundancy in the HDI measures when compared to the counts of hazards by census block group. It is more likely that the HDI measures are measuring different spatial aspects of the toxic sites analyzed; particularly adjacency –or accounting for the compounding effects of multiple proximate toxic sites affecting census block groups.

Evaluating Disproportionate Impacts

The following section investigates some of the differences in the evaluation of the socio-spatial distributions for examined toxic sites when using either the host/non-host, or the hazard density methods. Specifically this section addresses the questions posed earlier in the objectives of the study:

- *Do different environmental hazards have differing spatial and/or social distributions in the urban context of Providence, RI?*

- *How does the evaluation of social and spatial distributions of environmental risk change when considering risk density measures from single point sources as opposed to a host/non-host analysis?*

- *How does the evaluation of the social and spatial distributions of environmental risk change when considering cumulative hazard measures: sum of toxic sites hosted (host/non-host methodology) versus cumulative hazard index (hazard density index methodology)?*

Host/Non-Host Methodology

Presence/Absence

Table 3 presents average socio-demographic characteristics and difference of means t-tests results for census block groups by using the host/non-host methodology. Do significant differences in the racial/ethnic composition and median household income for block groups exist when evaluated using the presence/absence of hazardous sites?

Table 3 Mean socio-demographic characteristics and difference of means t-tests census block groups: host/non-host toxic sites:

Variable	Type of Hazard		
	CERCLIS	LUSTS	TRI
Percent Asian			
Host	4.2	5.4	6.90
Non-Host	4.5	5.6	4.20
t	-0.088	1.750	1.340
significance	0.930	0.082	0.181
Percent Black			
Host	14.3	13.2	19.20
Non-Host	12.5	12	12.00
t	0.426	0.732	2.360
significance	0.671	0.465	0.019
Percent Hispanic			
Host	28.6	27.3	32.20
Non-Host	28.600	30.000	28.300
t	-0.009	-0.807	0.643
significance	1.0	0.421	0.52
Percent White			
Host	44.3	46.5	33.10
Non-Host	47.0	47.2	48.10
t	-0.245	-0.139	-1.850
significance	0.801	0.890	0.067
Median HH Income ($)			
Host	$22,709	$20,604	$7,350
Non-Host	$31,145	$17,004	$19,505
t	-1.157	-0.847	-1.200
significance	0.249	0.398	0.232

Table 3 suggests that toxic sites are not distributed inequitably in the city of Providence, when analyzed using the host/non-host method. CERCLIS and TRI sites are highly spatially concentrated and most common in the southern core areas of the city of Providence. Nearly 96% of all census block groups do not host CERCLIS sites, 92% do not host TRI site. LUSTS sites in contrast are common throughout the city of Providence and exhibit a diffused spatial pattern; it is worth mentioning here that only 50% of all census block groups do not host LUSTS sites.

Under the lens of the host/non-host methodology lower income and racial/ethnic minorities do not appear to be overrepresented in census block groups hosting at least one of the toxic sites analyzed. No differences in means are significant using the host/non-host methodology. It should be pointed out that because of the relatively few CERCLIS (16) and TRI (22) sites, the lack of statistical significance in the t-test may be a result of the small number of census block groups that host these facilities. Lack of statistical significance in the t-test for LUSTS is more likely due to the fairly well distributed nature of these sites across the city of Providence.

Summed Toxic Sites Hosted

How does this evaluation change when considering the absolute numbers of toxic sites hosted by census block groups? The summary measure created by adding the total number of toxic sites hosted by each census block group did not appear to provide any detectable strong linear relationships to any of the socio-demographic variables examined.

Table 4 presents the correlations of socio-demographic variables and the host/non-host methodology or counts of each toxic site class within each census block group. Even when considering the absolute sum of all toxic sites hosted by a census block group no significant correlations exist between the selected socio-demographic variables and the counts of toxic sites by census block groups.

Table 4 Correlations among socio-demographic variables and absolute counts of hazards by census block groups

	Counts			
	CERCLIS	LUSTS	TRI	SUM
Asian	-0.038	-0.011	0.003	-0.009
Black	-0.034	-0.030	-0.001	-0.019
Hispanic	-0.080	-0.085	-0.063	-0.081
White	-0.087	-0.043	-0.079	-0.071
Income	-0.069	-0.046	-0.050	-0.055

HDI Methodology

How does the evaluation of the relationships between the distribution of hazards and the selected socio-demographic characteristics associated with toxic sites change when using the proximity measure HDI? Of particular interest is how this measure, which considers spatial adjacency, detects disproportionate impacts resulting from multiple point source toxic sites.

Table 5 presents average socio-demographic characteristics and difference of means t-tests results for census block groups by using the HDI methodology. Racial/ethnic categories including percent: Asian; Black, Hispanic and White were included in this analysis. Median household income is included to provide an economic measure for each census block group.

Individual block group hazard density scores were not considered in these t-tests, but rather: whether or not block groups scored a HDI greater than zero. Do significant differences in the racial/ethnic composition and median household income for block groups exist when evaluated using the HDI methodology that were not apparent using the host/non-host methodology?

Table 5 Mean socio-demographic characteristics and difference of means t-tests census block groups non-zero/zero hazard density indices:

Variable		Type of Hazard		
		CERCLIS	LUSTS	TRI
Percent Asian				
	Non-Zero Value	4.6	n/a	7.01
	Zero Value	2.0	n/a	4.20
	t	1.190	n/a	1.650
	significance	0.236	n/a	0.101
Percent Black				
	Non-Zero Value	**13.4**	n/a	**13.70**
	Zero Value	**1.0**	n/a	**4.20**
	t	**3.660**	n/a	**3.773**
	significance	**0.000**	n/a	**0.000**
Percent Hispanic				
	Non-Zero Value	**30.3**	n/a	**31.00**
	Zero Value	**1.0**	n/a	**11.00**
	t	**4.440**	n/a	**3.990**
	significance	**0.000**	n/a	**0.000**
Percent White				
	Non-Zero Value	**44.2**	n/a	**43.00**
	Zero Value	**88.0**	n/a	**75.80**
	t	**-5.100**	n/a	**-5.109**
	significance	**0.000**	n/a	**0.000**
Median HH Income ($)				
	Non-Zero Value	**$28,248**	n/a	**$27,290**
	Zero Value	**$69,530**	n/a	**$57,050**
	t	**-7.830**	n/a	**-7.470**
	significance	**0.000**	n/a	**0.000**

Bold: t-values significant with $p<0.05$; $n=162$

* n/a: not applicable since all of Providence's Census Block Groups exhibit LUST HDI > 0.

** CHDI not analyzed since all of Providence's Census Block Groups have CHDI Scores > 0.

Table 5 shows that toxic sites are distributed inequitably in the city of Providence. Lower income and racial/ethnic minorities, with the exception of *Asian;* appear to be overrepresented in census block groups with HDIs greater than zero. All differences in means (with the exception of percent Asian) were significant using the HDI methodology.

With the HDI methodology, associations begin to emerge between the selected socio-demographic characteristics of census block groups and a HDI score greater than zero. Census block groups with HDIs for both CERCLIS and TRI >0 appear to be less white and exhibit lower median household income. All significant differences between means of racial/ethnic composition of census block groups with non-zero and zero HDI scores indicate larger mean minority presences. Median household income, mean differences are notable. The average household income for census block groups with CERCLIS HDI >0 as opposed to equal to zero are $28,248 and $69,530 respectively. The average household income for census block groups with TRI HDI >0 as opposed to equal to zero are $27,290 and $57,050 respectively.

Table 6 presents the correlations of socio-demographic variables and all raw hazard density index scores for each census block group. The cumulative hazard density index scores show the strongest correlations to the selected socio-demographic variables. The strongest of these correlations indicates a negative relationship between median household income and the summary hazard density index measure: cumulative hazard density index.

Table 6 Correlations among socio-demographic variables and hazard density index score by census block groups

	HDI			
	CERCLIS	LUSTS	TRI	CHDI
Asian	0.152	0.179	**0.179**	**0.186**
Black	***0.389***	-0.063	***0.375***	***0.422***
Hispanic	***0.405***	0.030	**0.357**	***0.419***
White	***-0.354***	-0.068	-0.390	***-0.415***
Income	***-0.598***	-0.005	***-0.518***	***-0.614***

bold italics: correlation is significant at the 0.01 level (2-tailed)
Bold: correlation is significant at the 0.05 level (2-tailed)

With significant correlations at either the 0.01, or 0.05 levels to all of the socio-demographic variables analyzed CHDI shows promise as a summary measure of risk associated with toxic sites and its disproportionate effects on minority racial/ethnic groups and low median income households.

Data Interpolation

To further understand the patterns of risk associated with calculated CHDI scores data interpolation methods were employed. The calculated CHDI values for each census block group were converted to point data. Each point was assigned to the center of gravity of each census block group, or centroid. Three data interpolation methods were used to examine spatial trends in the CHDI calculated dataset including: an inverse distance weighting function; a Krig prediction map and a triangular irregular network (TIN) generated grid.

The inverse distance weighting function was used to create a risk surface based on the CHDI score for each census block group. The extrapolated risk surface is presented in Figure 9. Neighborhood boundaries are included for spatial and community reference.

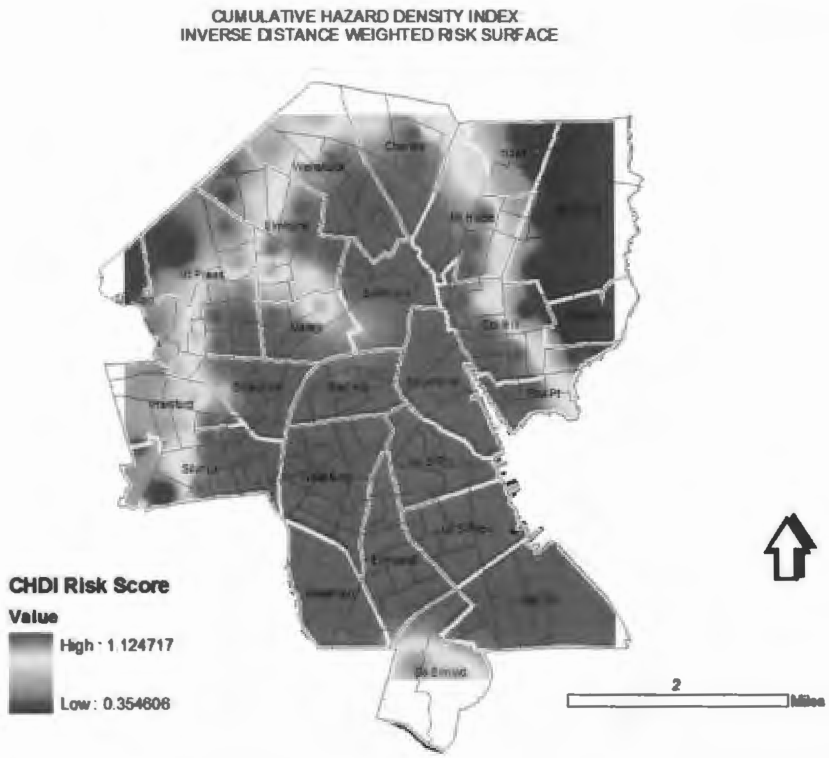


Figure 9

The second method used to examine the CHDI data was a Krig prediction surface to create a risk surface based on the CHDI score for each census block group. The extrapolated risk surface is presented in Figure 10. Neighborhood boundaries are included for spatial and community reference.

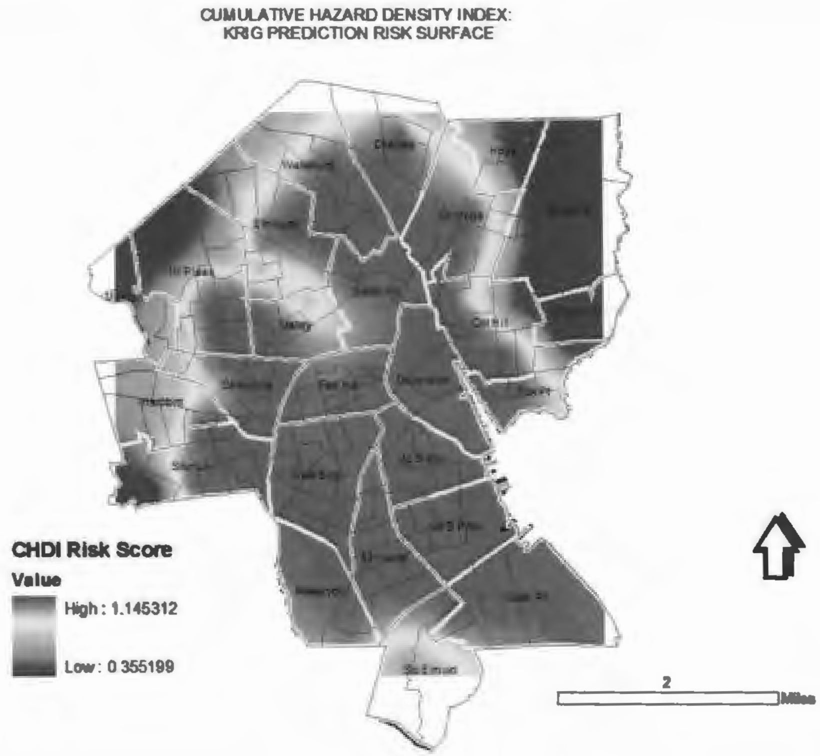


Figure 10

The final method used to examine the CHDI data was a Triangular Irregular Network (TIN) generated grid. To create a risk surface based on the CHDI score for each census block group. The extrapolated risk surface is presented in Figure 11. Neighborhood boundaries are included for spatial and community reference.

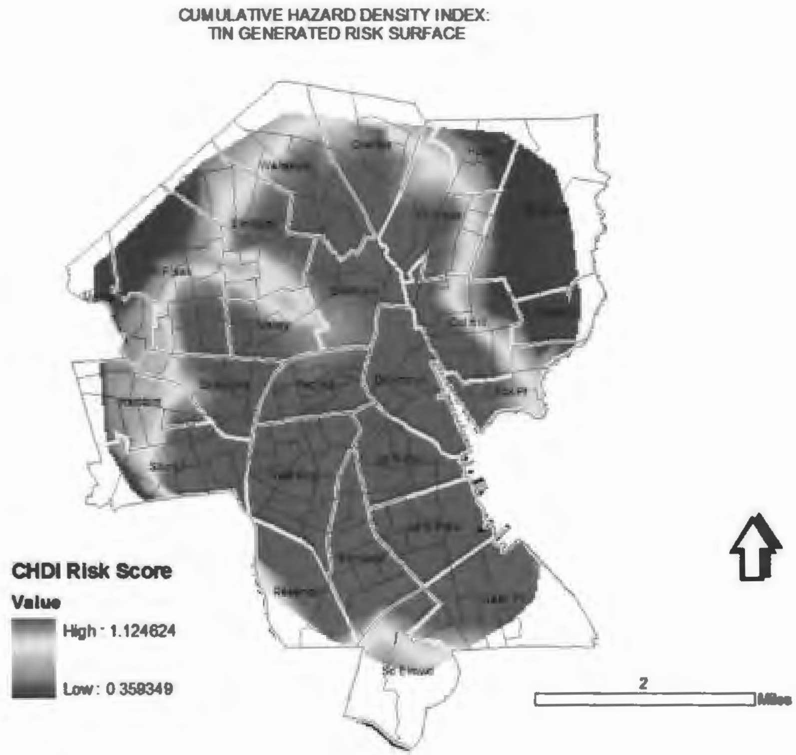


Figure 11

All interpolated CHDI surfaces provide an indication of potential risk and environmental justice concerns for the City of Providence. This measure revealed inequalities in potential risk based on selected socio-economic variables of: race, ethnicity and median household income. Based on independent means t-tests, neighborhoods with higher CHDI scores are more likely to have higher numbers of ethnic and racial minorities and exhibit lower median household incomes.

All interpolation methods used in this analysis are in consensus with their indication neighborhoods containing areas with the highest levels for interpolated CHDI risk score. These neighborhoods include:

- Charles
- College Hill
- Downtown

- Elmhurst
- Elmwood
- Federal Hill
- Fox Point
- Lower South Providence
- Mount Hope
- Mount Pleasant
- Olneyille
- Upper South Providence
- Reservoir
- Silver Lake
- Smith Hill
- Valley
- Washington Park
- West End

This information is useful when examined in conjunction with census block group data. Since the unit of analysis (the census block group) may be considered in aggregate at the neighborhood level gradients for calculated CHDI values are perceivable.

Conclusion

Findings of this study point to the existence of potential environmental justice concerns for the city of Providence when evaluated using the hazard density index method developed by Bolin et al. (2002). The HDI method produced results that pointed to significant differences related to the racial/ethnic composition (with the exception of Asian) and median household income and census block groups with HDI values greater than zero for all toxic sites analyzed. The summary measure, Cumulative Hazard Density Index was not included in this statistical test since all of Providence's census block groups exhibited a CHDI score greater than zero.

The cumulative hazard density index did exhibit correlations to all of the socio-demographic variables examined. CHDI score for all block groups was significantly positively correlated to the number of racial and ethnic minorities living in a block group, and significantly negatively correlated to the number of whites and increasing median household income for census block groups.

The host/non-host methodology identified no differences among the selected socio-demographic variables and the existence of toxic sites within the census block group. This method did provide a general and preliminary understanding of the spatial distributions of the toxic sites across the extent of the City of Providence examined in this study.

The findings of this and related studies can provide useful data on several levels: First, with incorporation of recognized environmental justice parameters allow for the preliminary identification of environmental justice concerns for disadvantaged communities in the City of Providence. Secondly, the data generated provide baseline information regarding the status of environmental justice concerns for the city of Providence. This baseline data, derived from recent and/or existing conditions permits comparison and evaluative reference for individuals and/or agencies hoping to address environmental justice concerns for the city. Finally, the quantitative measure CHDI, allows for important prioritization of scarce existing federal funding resources dedicated to addressing social concerns at the community level for the City of Providence.

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