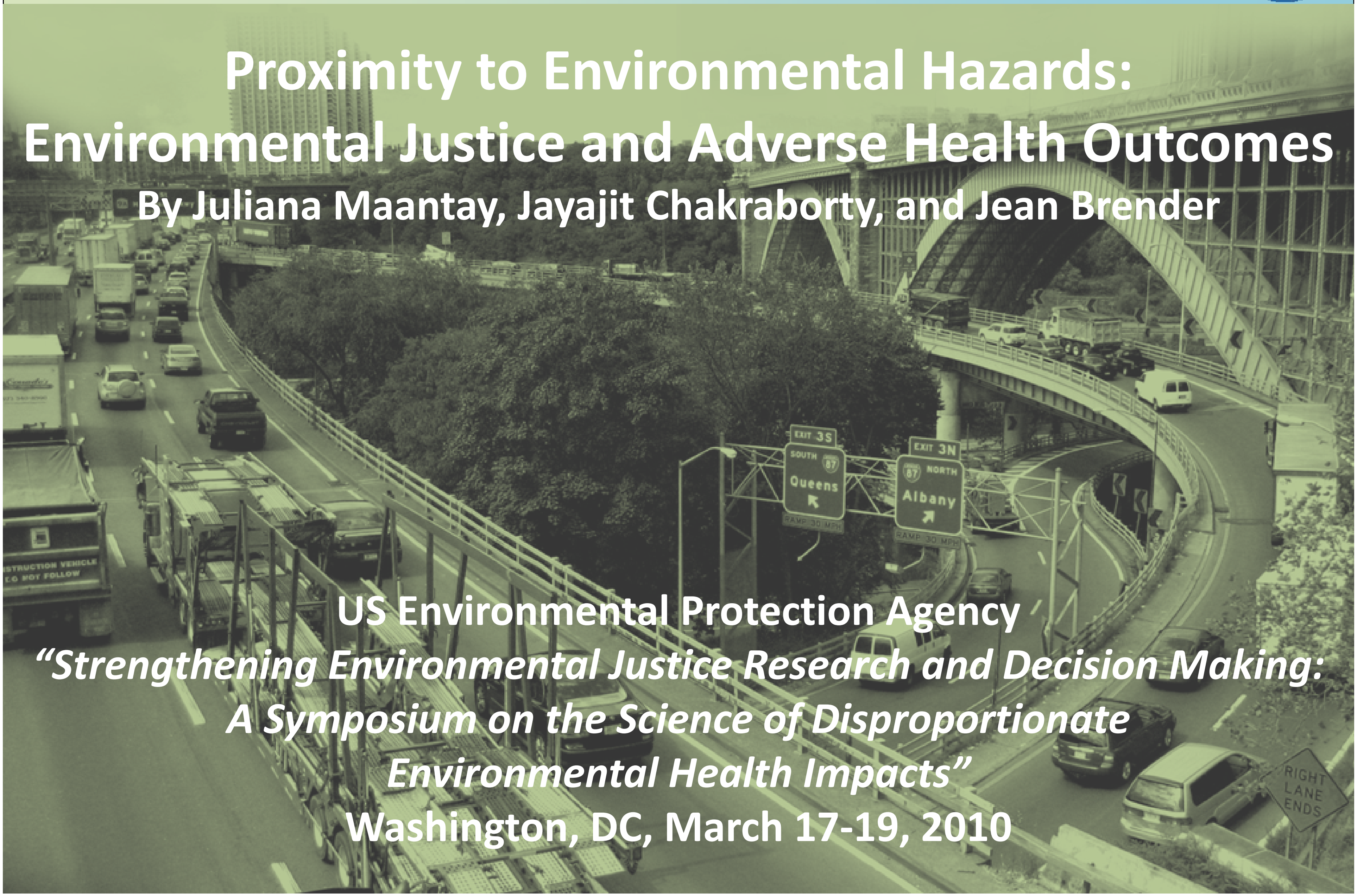
Proximity to Environmental Hazards: Environmental Justice and Adverse Health Outcomes

By Juliana Maantay, Jayajit Chakraborty, and Jean Brender



US Environmental Protection Agency

"Strengthening Environmental Justice Research and Decision Making: A Symposium on the Science of Disproportionate Environmental Health Impacts"

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Source of title slide photo: Brian Morgan, Urban GISc Lab, Lehman College, CUNY, ***Urban Geography***, cover, January 2009, "Yesterday's 'Cities of Tomorrow,' Today."

I. Introduction

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I. Introduction

Research Question:

Does proximity to environmental hazards result in adverse health outcomes and account for health disparities, and if so, *how* does proximity contribute to disproportionate environmental health impacts?

To answer this question, we reviewed and evaluated more than 150 peer-reviewed journal articles published over a span of two decades in several distinct bodies of literature, including

- environmental justice,
- health disparities,
- medical geography/health GISc, and
- epidemiology.

These papers examined residential proximity to environmental hazards in relation to

- environmental justice,
- health disparities,
- adverse reproductive outcomes,
- childhood cancer,
- respiratory and cardiovascular conditions, and
- other adverse health outcomes.

Proximity to hazards, adverse health outcomes, and disproportionate impacts

Much of the published literature has supported the hypothesis that proximity to environmental hazards translates to higher risks, including adverse health risks.

Proximity to environmental hazards increases burdens such as:

- poor air quality,
- noise,
- use and storage of hazardous materials,
- emissions of hazardous and toxic substances,
- contaminated soil and water,
- diminished traffic safety,
- illegal dumping,
- poor enforcement of environmental regulations,
- inadequate response to environmental complaints,
- quality-of-life impacts,e.g., inferior housing and fewer amenities (parks, etc.)

Proximity to hazards, adverse health outcomes, and disproportionate impacts

These health and quality-of-life impacts are visited disproportionately on the most vulnerable populations, those least likely to be able to effectively combat them. Not only are these populations more likely to be exposed to these burdens, but due to material deprivation and social stress, they may be more susceptible to the resultant health effects.

Environmental Health Justice

"Environmental Justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. EPA has this goal for all communities and persons across this Nation. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work," (U.S. EPA, 2009).

"The EJ movement has sought to redefine environmentalism as much more integrated with the social needs of human populations, and, in contrast with the more eco-centric environmental movement, its fundamental goals include challenging the capitalist growth economy, as well," (Pellow and Brulle, 2005:3).

Environmental Health Justice

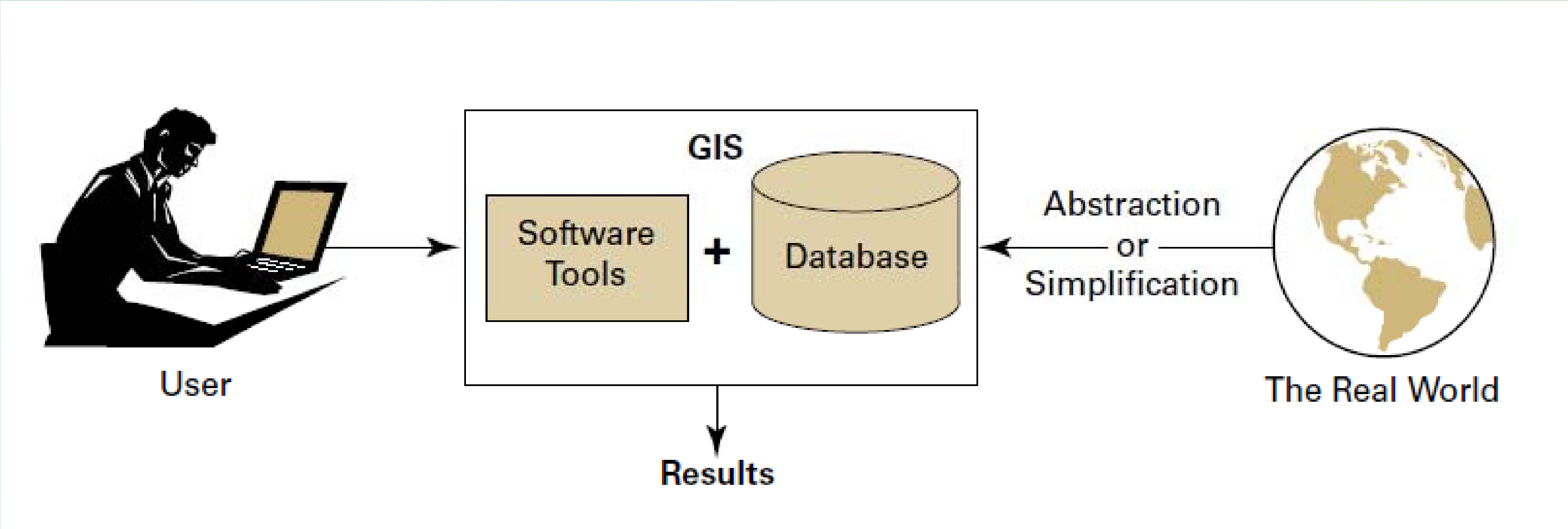
Researchers and Community Scientists have expanded the definition to include:

❑Other vulnerable groups:
- Children
- Elderly
- Pregnant women
- Disabled
- Immune-compromised
- Future generations

❑Other unsustainable activities:
- rampant population growth,
- industrialization,
- pollution,
- consumption patterns,
- energy use,
- industrialized food production, and
- resource depletion

The Role of Geographic Information Science (GISc) in Environmental Health Justice Research

GISc is an integrated system of hardware, software, spatial and attribute databases, and expert judgment of GISc analyst.



Source: Maantay, J.A., and Ziegler, J., 2006, ***GIS for the Urban Environment***, ESRI Press, Redlands,CA

The Role of Geographic Information Science (GISc) in Environmental Health Justice Research

Since the late 1980's, GISc has been used in EJ research to:

- Analyze the spatial relationship between sources of pollution and socio-demographic characteristics of potentially affected populations;
- Allow for integration of multiple data sources, representation of spatial data in map form, and application of spatial analytical techniques;
- Bridge the disciplines of environmental justice and health disparities by showing correspondence amongst proximity to environmental hazards, adverse health outcomes, disproportionate exposure and risk, and health disparities.

Environmental Justice Research Studies

Independent variables:

- Race/Ethnicity (% NHW, NHB, Hispanic, etc.)
- Income (median, mean, household, per capita, etc.)
- % Below Poverty
- % without a high school diploma
- Segregation measures (Dissimilarity Index, for instance)
- Population density
- Homeownership status
- % Single-parent households
- Employment status/employment category (i.e., "blue collar")

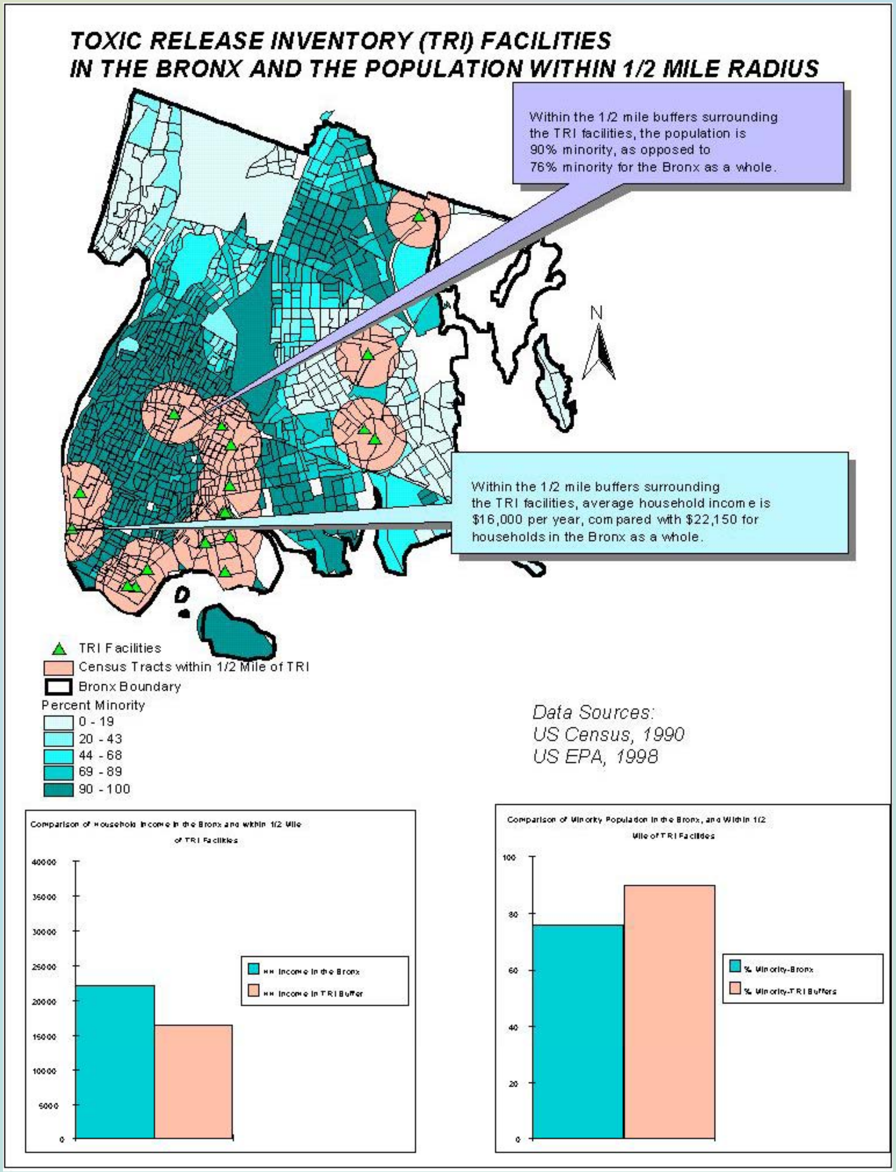
Dependent variables/environmental hazard and proximity to hazard:

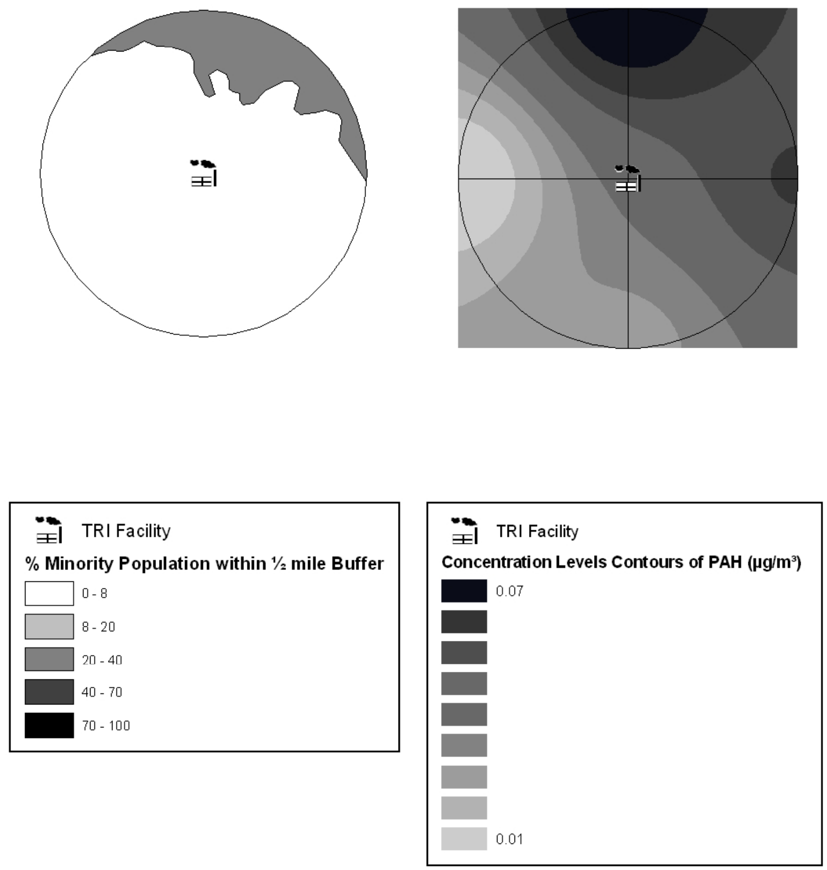
- Pollution sources (power plants, TRI facilities, high-volume roads, Superfund sites, hazardous waste TDSFs, landfills, solid waste transfer)
- Presence of hazards; number or density of hazards; distance to hazards; measure of pollution's magnitude (quantity, toxicity, or health risk).

Study Reference	Study Parameters (Study Extent / Unit of Analysis / Independent Variables)	Environmental Indicators (Category of Environmental Indicator / What's Being Measured)	Methods (Determination of vulnerable population or exposure risk/Evaluation of disproportion)	Findings
Ash and Fetter, 2004	*Extent:* Census designated urbanized areas in the U.S. *Unit:* Block group *Independent Variables:* Race, ethnicity, income, population density, education, housing	*Indicator:* Toxic Release Inventory (TRI) facilities and emissions, based on EPA's RSEI model *Measuring:* Inequities in cumulative risk from TRI emissions, based on toxicity and atmospheric dispersion	*Population:* Tract level chronic risk estimates based on pollution plume and exposure modeling *Disproportion:* Multivariate tobit regression and linear probability models	African Americans tend to live both in more polluted cities and in more polluted areas within cities. Hispanics live in less polluted cities on average, but in more polluted areas within cities.
Baden et al., 2007	*Extent:* Three scales: National (U.S.), state (California), county (Los Angeles). *Unit:* County, ZIP code, census tract, block group *Independent Variables:* Race, ethnicity, income, percent urban, MSA	*Indicator:* Superfund sites on the National Priorities List (NPL) *Measuring:* Disparities associated with NPL site location at county, ZIP code, tract, and block group levels.	*Population:* Spatial coincidence using four different units of analysis. *Disproportion:* Multivariate logistic regression using presence of NPL site as a dependent variable.	Different results for different scales and units, but strong evidence of injustice for Blacks and Hispanics at national and state level with tract and block group data.
Boer et al., 1997	*Extent:* Los Angeles County, California *Unit:* Census tracts *Independent Variables:* Race, ethnicity, SES, residential land, industrial land, population density, registered voters.	*Indicator:* Hazardous waste treatment, storage, disposal facilities(TSDFs) *Measuring:* Inequities in the distribution of all TSDFs and large-capacity TSDFs (processing more than 50 tons annually)	*Population:* Spatial coincidence to select tracts hosting any TSDF, large-capacity TSDFs, and those within a mile of large-capacity TSDFs. *Disproportion:* Univariate comparison of host and non-host tracts; multvariate logit regression.	Both race and ethnicity significantly associated with TSDF location. Working class minority communities located near industrial areas most affected.
Bolin et al., 2002	*Extent:* Phoenix metropolitan area, Arizona *Unit:* Census tract *Independent Variables:* Race, ethnicity, income	*Indicator:* Four types of hazardous industrial and toxic waste sites *Measuring:* Inequities based on the number of hazards and hazard density indices for each tract	*Population:* Combination of spatial coincidence and circular buffer analysis to measure hazard density index for each tract and type of hazard *Disproportion:* Bivariate correlation with hazard counts and hazard density indices	A consistent pattern of environmental injustice by class and race across a range of hazards in the Phoenix metropolitan region

Proximity to Environmental Hazards:
Environmental Justice and Adverse Health Outcomes

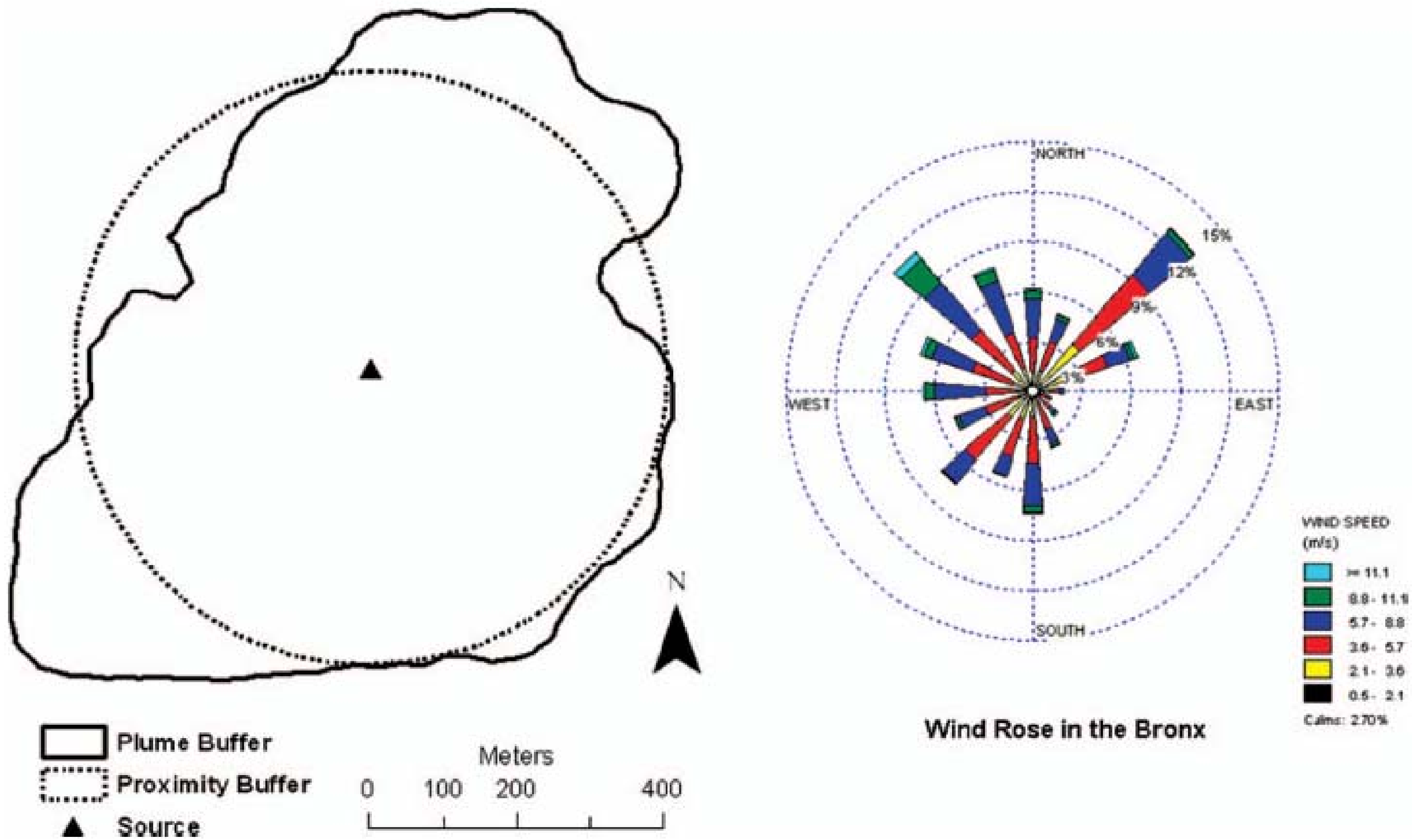
Maantay, Chakraborty, and Brender





Source: Maantay, J.A., 2007, Asthma and air pollution in the Bronx: Methodological and data considerations in using GIS for environmental justice and health research. ***Health and Place***, *13:32-56.*

Comparison of a Plume Buffer and a Proximity Buffer for an Air Pollution Source



Source: Maantay, J.A., Tu, J., Maroko. A.R., 2009. Loose-coupling an air dispersion model and a geographic information system (GIS) for studying air pollution and asthma in the Bronx, New York City. ***International Journal of Environmental Health Research***, 19(1):59-79.

Summary of Findings of Environmental Justice Studies

- Both race and SES predict a disproportionate spatial distribution of environmental burdens (e.g., McMaster et al., 1997; Apelberg, 2005; Grineski, 2007; Morello-Frosch et al., 2001; Pastor et al., 2005; Chakraborty, 2009) .

- Studies focusing on air pollutants (TRI facilities, mobile sources, etc.) dominated the literature, and most consistently predicted disproportionate burdens (e.g., Apelberg et al., 2005; Ash and Fetter, 2004; Buzzelli et al., 2003; Dolinoy and Miranda, 2004; Downey, 2006; Mohai, et al., 2009; Pastor, et al., 2004; Perlin et al, 1999).

- Positive spatial correspondence was found between minority/SES status and proximity to hazards such as Superfund sites (Baden et al., 2007); hazardous waste TSDFs (Boer et al., 1997; Bolin, 2002; Fricker and Hengartner, 2001; Goldman and Fitton, 1994); solid waste landfills (Been and Gupta, 1996; Higgs and Langford, 2009; Mohai and Saha, 2007; Norton, 2007); and noise pollution from airports (Most et al., 2004). A large proportion of minority and impoverished populations reside in areas exposed to multiple worst-case EHS (extremely hazardous substances) releases (Chakraborty, 2001).

- Some early studies were inconclusive or did not show disproportionate burdens, but this might be due to the coarse level of data aggregation used, or the limitations of the methods used to approximate exposure (Anderton, et al., 1994; Cutter et al., 1996).

Summary of Findings of Environmental Justice Studies (continued)

- The siting of public facilities was not disproportionate by race, but the siting of privately-owned facilities was (Norton, 2007).

- Studies that included qualitative assessments found instances of disproportionate distribution of environmental factors that were not revealed through geostatistical analyses (Maantay, 2001; Maroko and Maantay, 2009; McMaster et al., 1997).

- Some studies reported mixed results in the relationship between TRI density and socio-demographic explanatory factors, which, although mostly a positive correspondence, varied significantly over space (Mennis and Jordan, 2005), or could be explained by a pattern of residential and occupational segregation (Boone, 2001).

- Some studies found inverse or non-linear relationships between income and proximity to noxious facilities, termed the “halo” effect (Higgs and Langford, 2009).

- Studies focusing on methodological issues indicate that some methods in common usage likely underestimate the disproportionate impacts borne by disadvantaged populations (Chakraborty, 1997; Morello-Frosch and Jesdale, 2006).

II.
Methods and Models for Measuring Disproportionate Proximity and Exposure to Environmental Hazards

Methods and Models for Measuring Disproportionate Proximity and Exposure to Environmental Hazards

- Spatial Definition of Proximity and Potential Exposure to Hazards
- Estimating Characteristics of Proximate Populations
- Emerging Geostatistical Techniques

Spatial Definition of Proximity and Potential Exposure to Hazards

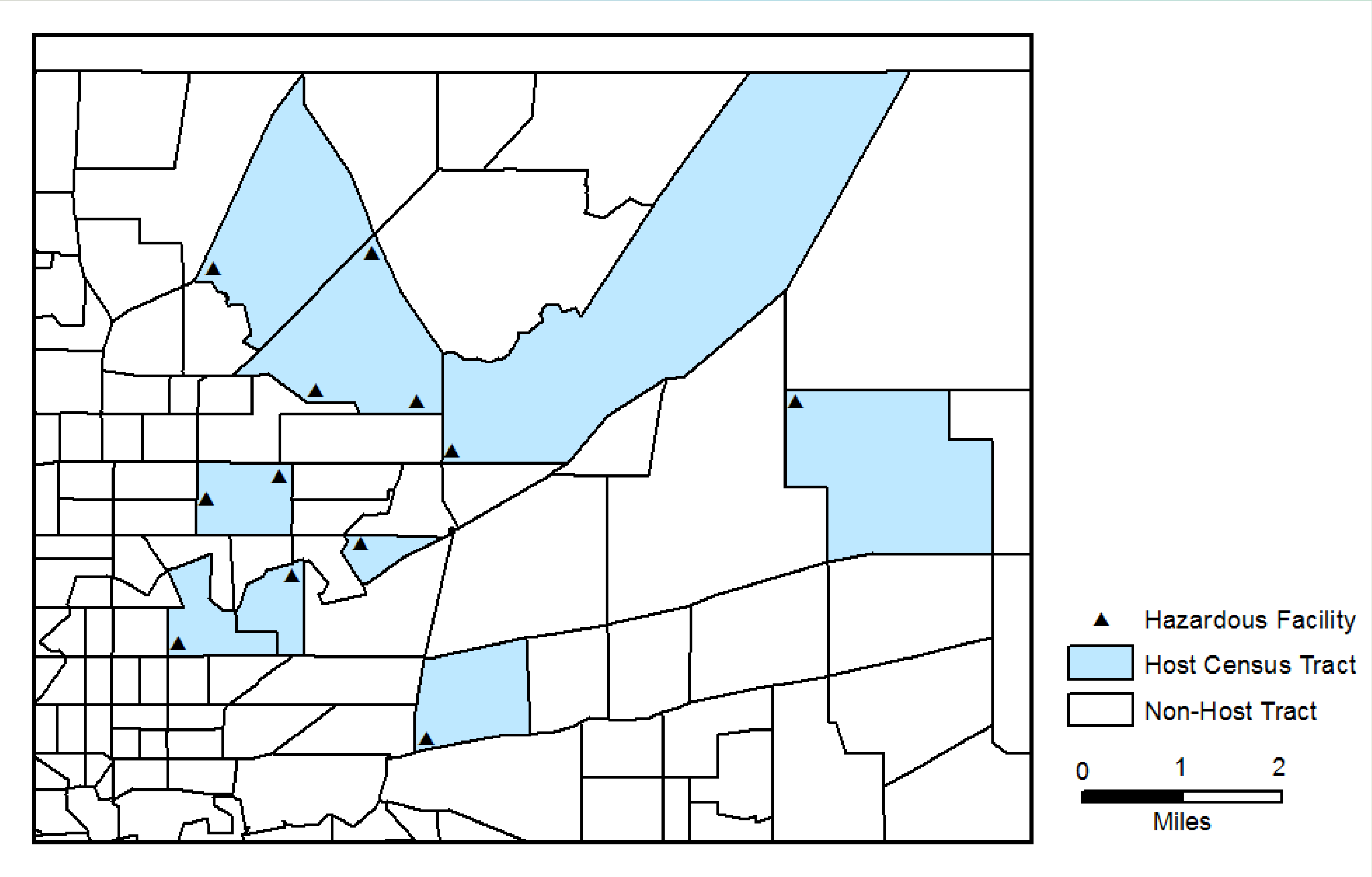
Approaches utilized in previous studies can be classified into three categories:

1. Spatial Coincidence Analysis
2. Distance-Based Analysis
3. Pollution Plume Modeling

1. Spatial Coincidence Analysis

- Proximity to environmental hazards defined spatially by boundaries of pre-defined geographic entities or census units (e.g., ZIP codes, census tracts, block groups) containing a hazard.
- Most widely used method referred to as **unit-hazard coincidence:**
  - Identify locations of environmental hazards on a map.
  - Classify spatial units based on presence/absence of a hazard.
  - Compare socio-demographic characteristics of spatial units containing a hazard (host units) to those that do not contain a hazard (non-host units).
- Examples from EJ research literature:
  - United Church of Christ 1987; Burke 1993; Hird 1993; Anderton et al. 1994; Goldman & Fitton 1994; Been 1995; Been & Gupta 1996; Cutter et al. 1996; Boer et al. 1997; Daniels & Friedman 1999; Fricker & Hengartner 2001; Boone 2002; Taquino et al. 2002; Walker et al. 2006; Baden et al. 2007.

Unit-Hazard Coincidence Analysis: Example Using Census Tracts

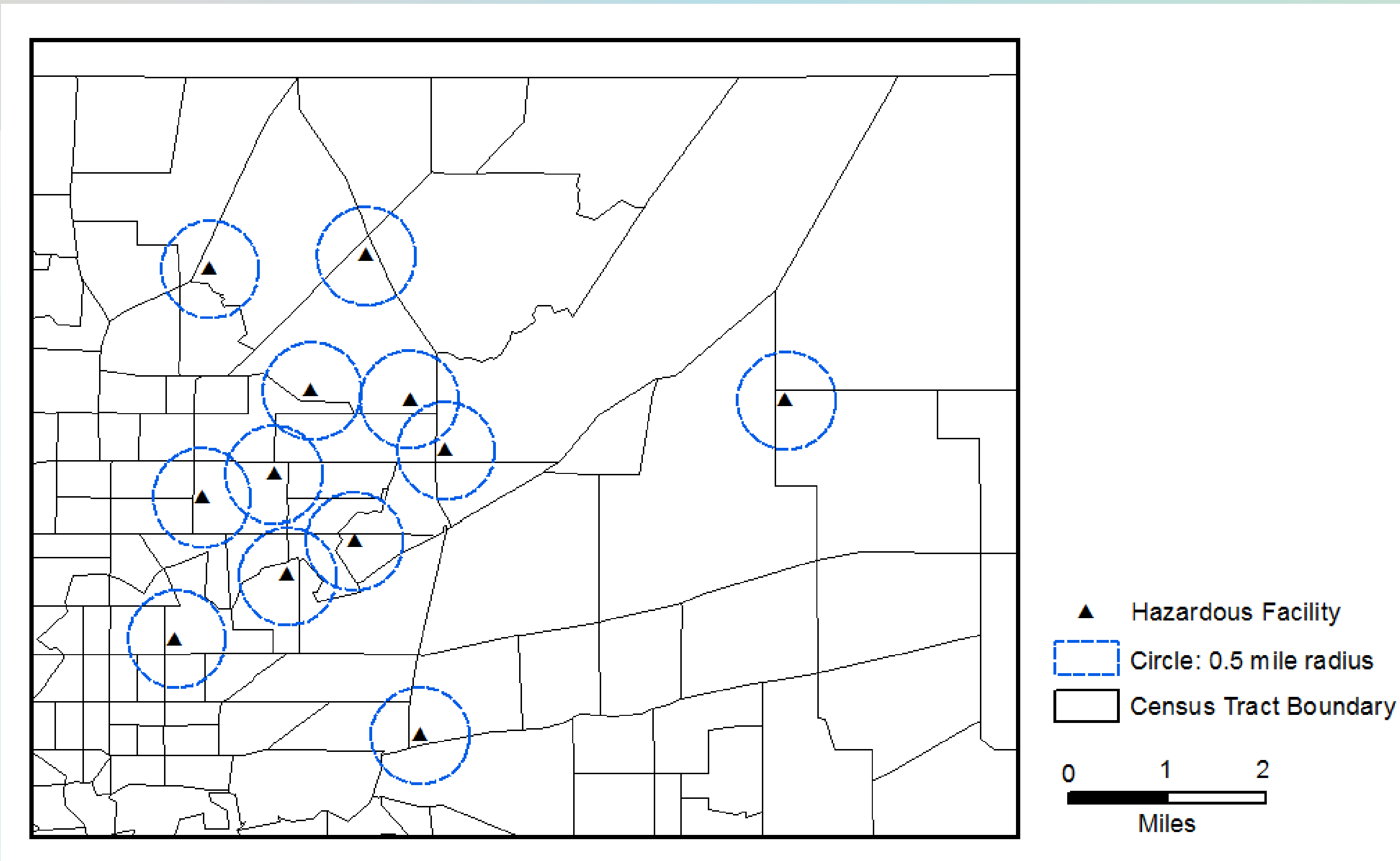


1. Spatial Coincidence Analysis: Extending Unit-Hazard Coincidence

- Instead of treating all host spatial units equally, several EJ studies have extended the basic approach by estimating:
  - **Total number or density of hazards**: Burke 1993; Cutter & Solecki 1996; Ringquist 1997; Tiefenbacher & Hagelman 1999; Fricker & Hengartner 2001; Mennis & Jordan 2005.
  - **Total quantity of emitted pollutants**: Bowen et al. 1995; Krisel et al. 1996; Boer et al. 1997; Tiefenbacher & Hagelman 1999; Daniels & Friedman 1999; Bolin et al. 2000.
  - **Toxicity-weighted quantity of pollutants**: Bowen et al. 1995; Perlin et al. 1995; McMaster et al. 1997; Brooks & Sethi 1997; Bolin et al. 2000; Sicotte & Swanson 2007.
- Key assumptions and limitations of the general approach:
  - All individuals in a host spatial unit are equally proximate to the hazard.
  - Only individuals in the host unit are proximate to the hazard.
  - Exact location of hazard within the host unit not considered.
  - Potential exposure to hazards is distributed uniformly within and confined only to the boundary of the host unit.

2. Distance-Based Analysis: Discrete Buffer

- **Circular buffer analysis:** address limitations of spatial coincidence approach by constructing buffers of uniform radius around hazard sources.



2. Distance-Based Analysis: Buffer Radius

- Buffer radii in EJ studies have ranged from 100 yards to 3 miles, but distances of 0.5 and 1.0 mile used most frequently:
  - Glickman 1994; Zimmerman 1994; U.S. GAO 1995; Chakraborty and Armstrong 1997; Neumann et al. 1998; Bolin et al. 2000; Baden and Coursey 2002; Boone 2002; Harner et al. 2002; Mohai and Saha 2006; Maantay 2007; Kearney and Kiros 2009; Mohai et al. 2009.
- Several studies have used multiple circular rings at increasing distances from hazard sources:
  - Neumann et al. 1998; Perlin et al. 1999; Sheppard et al. 1999; Atlas et al. 2002; Perlin et al. 2002; Pastor et al. 2004; Walker et al. 2006.

2. Distance-Based Analysis: Discrete Buffer

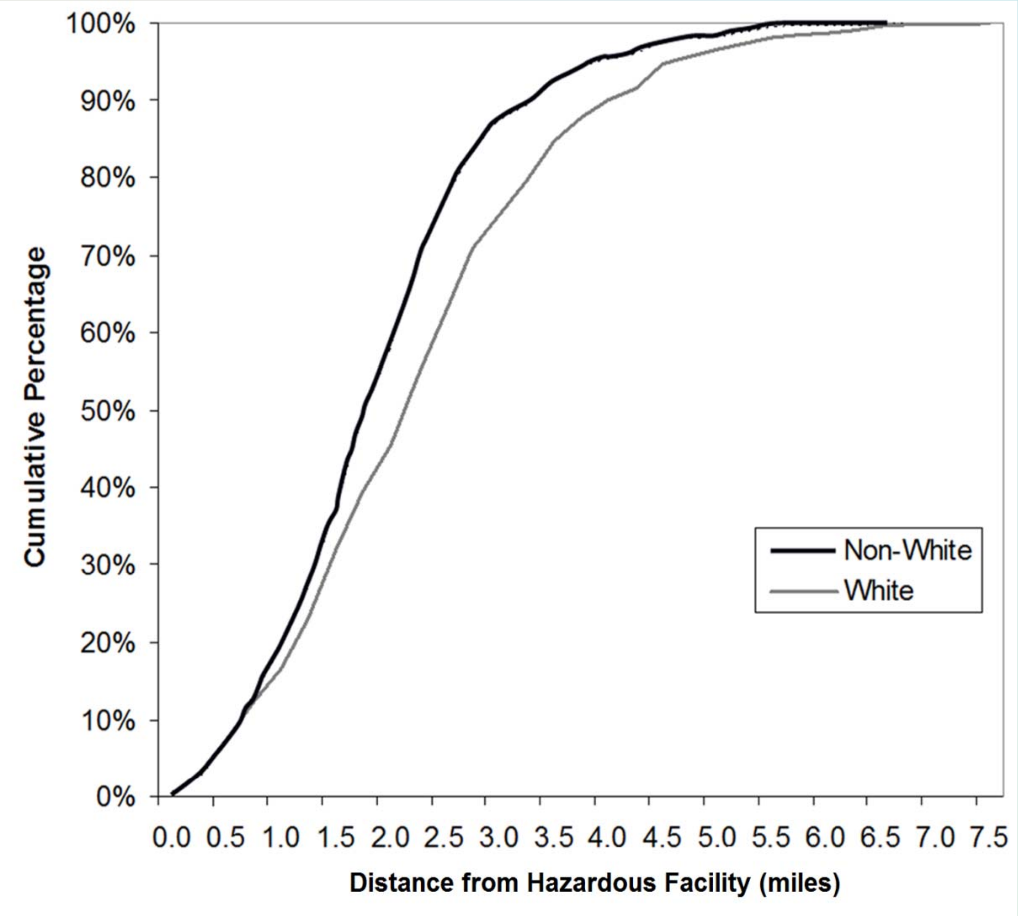
- **Advantages:**
  - Does not assume that the adverse effects are restricted solely to the boundaries of spatial units hosting the hazard.
  - Easily implemented and visually represented using GIS software.
  - Makes statistical comparisons between potentially exposed (inside circle) and non-exposed (outside circle) areas convenient.
- **Limitations:**
  - Buffer radius is selected arbitrarily and identical for all hazards.
  - Assumes adverse effects of a hazard are limited only to the specified circular area or distance.
  - Properties, quantities, and operational parameters of toxic emissions rarely considered.
  - Adverse effects are equal and uniform in all directions (isotropic) from the hazard.

2. Distance-Based Analysis: Continuous Distance

Based on computing the exact distance between locations of hazards and potentially exposed populations:

- Use distance from the centroid of each census unit to their nearest hazard source to estimate potential exposure:
  - Pollock & Vittas 1995; Gragg et al. 1995; Stretesky & Lynch 1999; Margai 2001; Mennis 2002; Downey 2006.
- Cumulative distribution function (CDF) approach: plot distance to hazard source vs. proportion of the population to compare exposure patterns of various sub-groups.
  - Waller et al. 1997; 1999; Perlin et al. 1999; Downey 2006; Chakraborty & Zandbergen 2007; Fitos & Chakraborty 2010.

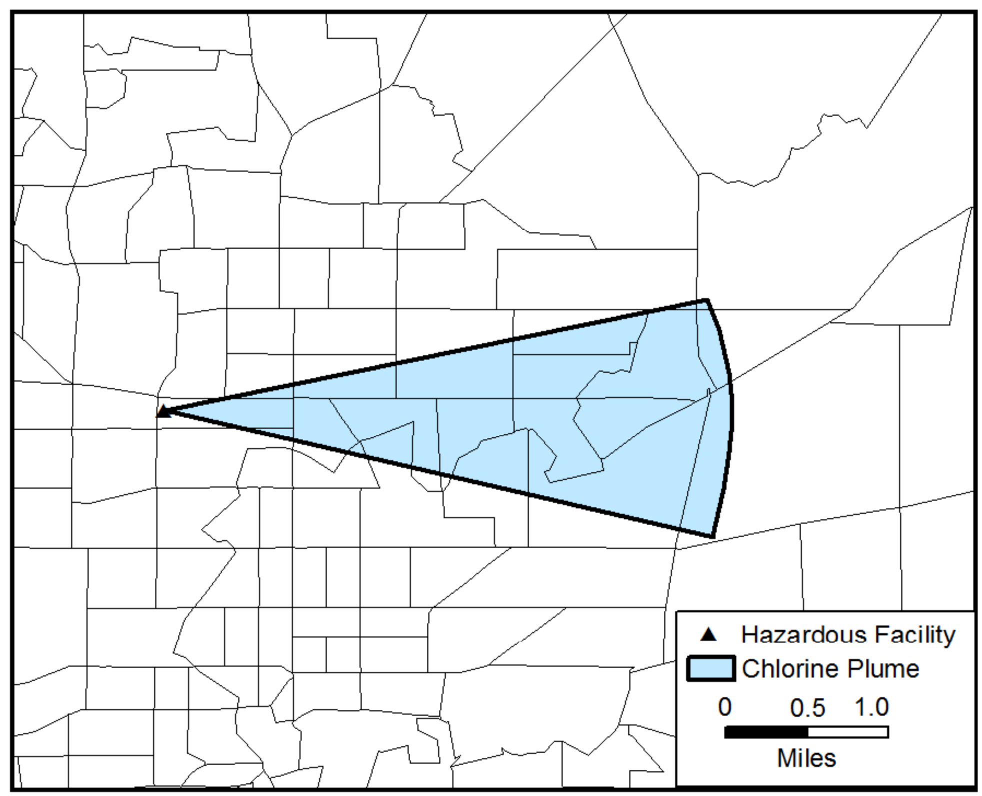
2. Distance-Based Analysis: Cumulative Distribution Function (CDF) Approach



Distance (miles)	Cumulative Percentage		
	Non-White	White	Difference
0.5	2.5%	2.9%	-0.4%
1.0	12.9%	12.4%	0.5%
1.5	27.0%	22.9%	4.1%
2.0	49.2%	39.4%	9.8%
2.5	69.1%	54.4%	14.7%
3.0	83.6%	70.8%	12.8%
4.0	94.4%	87.8%	6.6%

3. Pollution Plume Modeling: Geographic Plume Analysis

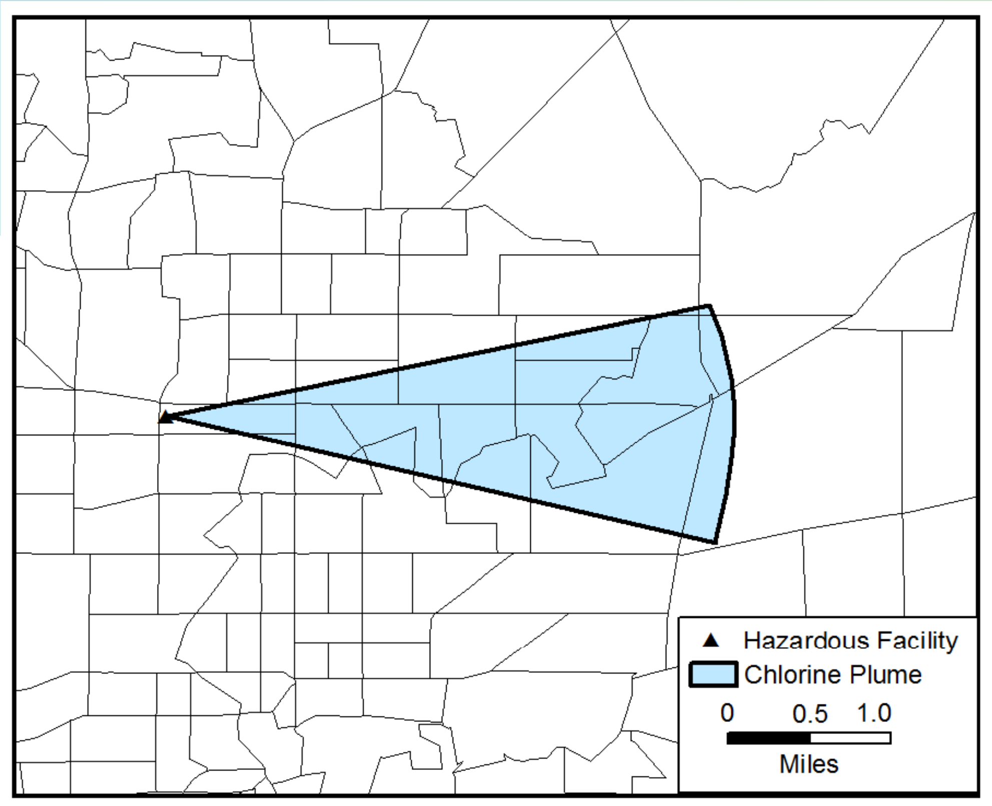
- Integrate air dispersion modeling with GIS to accurately estimate areas and populations exposed to air releases of toxic substances.
- Dispersion models combine data on the quantity and physical properties of a chemical with information on circumstances of release and local meteorological conditions to estimate pollutant concentrations downwind from an emission source and delineate a **plume footprint**.



3. Pollution Plume Modeling: Geographic Plume Analysis

Various pollutant fate-and-transport models used in EJ studies:

- **Areal Locations of Hazardous Atmospheres (ALOHA):** Chakraborty & Armstrong 1997, 2001, 2004; Chakraborty 2001; Margai 2001.
- **Industrial Source Complex Short Term (ISC-ST) model:** Dolinoy & Miranda 2004; Fisher et al. 2006; Maantay 2007; Maantay et al. 2009.
- **Ash deposition model:** Bevc et al. 2007.
- **Noise pollution model:** Chakraborty et al. 1999; Most et al. 2004.



3. Pollution Plume Modeling: Geographic Plume Analysis

- **Advantages:**
  - Allows concentration of toxic pollutants released from a hazard source and their health risks to: (a) vary according to compass direction; and (b) decline continuously with increasing distance from the emitting source.
  - Addresses problems of assuming that residing either within a spatial unit containing a hazard (spatial coincidence) or a specific distance from a hazard (distance-based) results in potential exposure and health risks.
- **Limitations:**
  - Dispersion models typically required large volumes of data on emission parameters, as well as site-specific and facility-specific information.
  - Some models assume topography is flat and do not provide accurate concentration estimates when atmosphere stable or wind speeds are low.
  - Creation of plume modeling data to include all toxic facilities and chemical emissions in a large area is a time-consuming and expensive process.

3. Pollution Plume Modeling: EPA's National Scale Databases for Exposure and Risk Assessment

- Risk-Screening Environmental Indicators (RSEI) model:
  - Chronic health risks and ambient concentrations of air pollutants based on quantity, toxicity, and atmospheric dispersion of chemicals emitted by TRI facilities (up to 101 km from each facility, for each 1 sq. km. grid cell)
    - Bowes et al. 2001; Ash & Fetter 2004; Sicotte & Swanson 2007; Abel 2009; Williams 2010.
- National-Scale Air Toxics Assessment (NATA):
  - Estimates of exposure concentration and public health risks (cancer, respiratory, neurological) from inhalation of air toxics from multiple types of sources (point, mobile, background) at the census tract level
    - Apelberg et al. 2005, Pastor et al. 2005; Morello-Frosch & Jesdale 2006; Gilbert & Chakraborty 2008; Linder et al. 2008; Chakraborty 2009.

Methods and Models for Measuring Disproportionate Proximity and Exposure to Environmental Hazards

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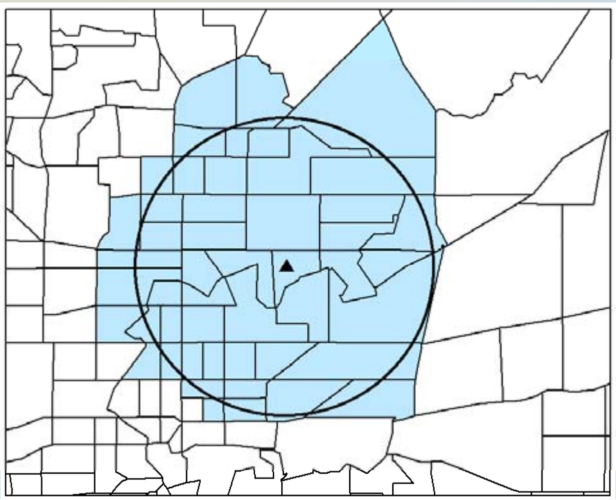
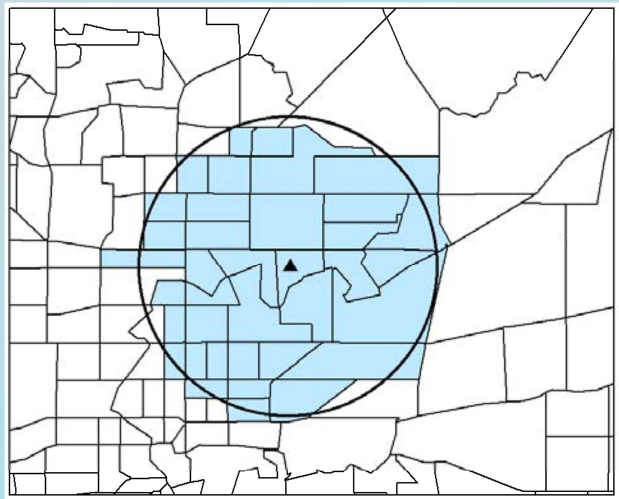
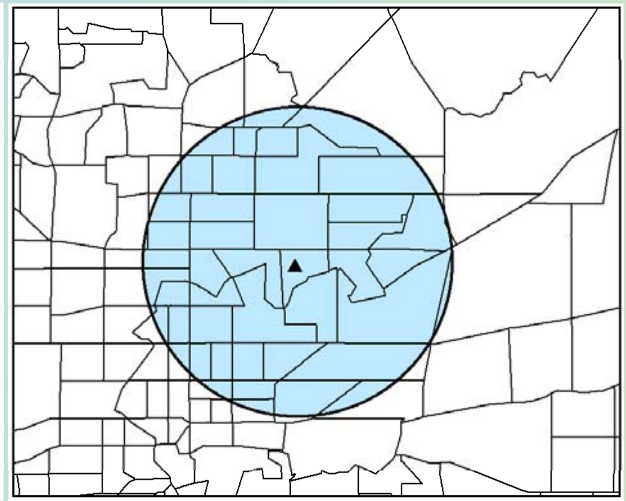
- **Estimating Characteristics of Proximate Populations**
- Emerging Geostatistical Techniques

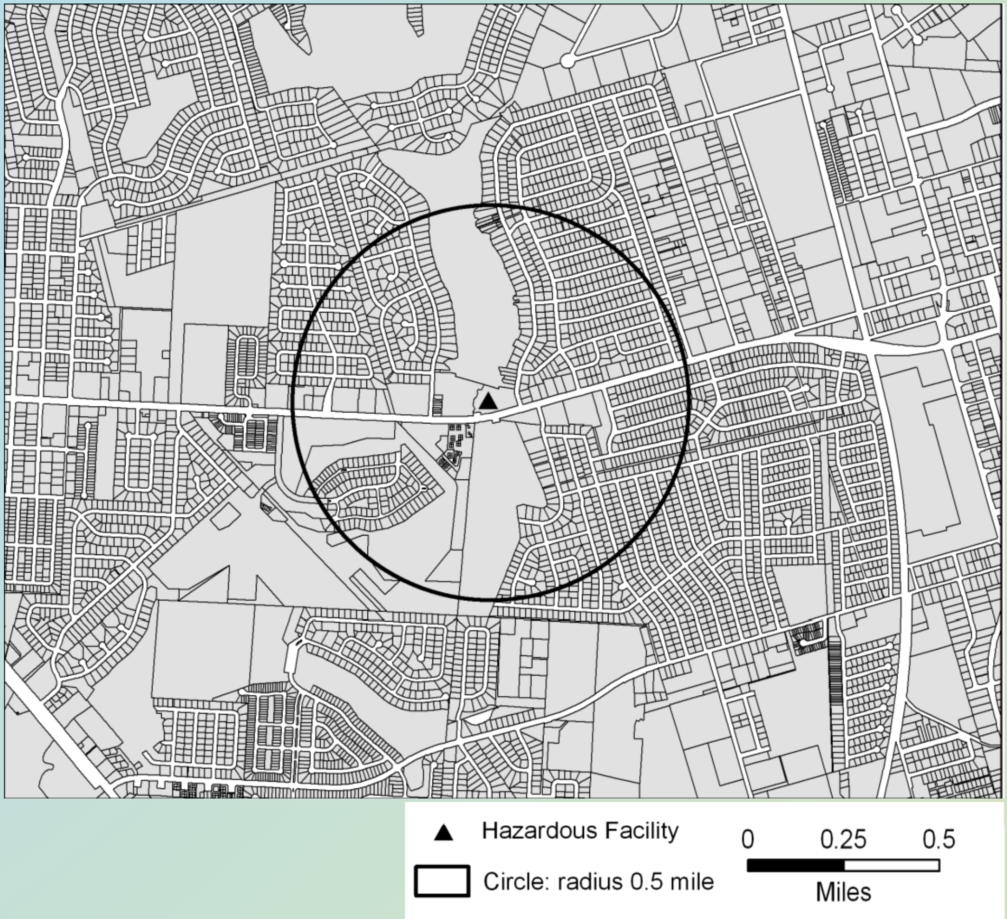
Estimating Characteristics of the Population Proximate to Hazards

- **Point Interpolation:** used only when the addresses of all individuals or households relevant to the study are available and can be located on a map. Examples from EJ research:
  - Mohai & Bryant 1992; Chakraborty & Armstrong 2001; Bevc et al. 2007; Chakaborty & Zandbergen 2007; Mohai et al. 2009.
- **Areal Interpolation:** based on data aggregated at the level of pre-defined geographic entities or census units. Three approaches used in previous EJ studies include:
  - Polygon containment
  - Centroid containment
  - Buffer containment

Polygon Containment	Centroid Containment	Buffer Containment
		
• Aggregation of census units either within or in contact with the buffer. • Also known as *boundary intersection* method. • Variation: cut-off criteria to limit census units partially enclosed (e.g., 50% area containment).	• Aggregation of census units whose geographic centers (centroids) fall within the buffer. • Assumes a point (centroid) represents entire spatial unit in terms of population characteristics.	• Population of each census unit weighted by the % of its area inside the buffer. • Assumes uniform distribution of population characteristics within unit. • Also known as *areal apportionment*.

Dasymetric Mapping

- Use ancillary data (e.g., land use/land cover) to redistribute population in a more accurate and logical manner.
- Cadastral dasymetric mapping shown in recent studies to represent a substantial improvement on the use of aggregated census data
  - Maantay et al. 2008.
  - Maantay & Maroko 2009



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1. Problem with Conventional Statistical Analysis: Spatial Dependence

- Classical statistical tests (e.g., correlation or regression) assume independently distributed observations and errors.
- Waldo Tobler's *First Law of Geography*: everything is related to everything else, but near things are more related than distant things (1970).
- Observations from nearby locations are often more similar than what can be expected on a random basis (spatial dependence or positive spatial autocorrelation).
- Correlation/regression analysis of spatial data can lead to incorrect inferences regarding model coefficients when spatial autocorrelation is present and when model specifications do not include proper corrections for spatial dependence.

Addressing Spatial Dependence in the Data

- **Spatial autoregressive (SAR) models**: consider spatial autocorrelation as an additional variable in the regression equation and estimate its effect simultaneously with the effects of other explanatory variables.
- Application of SAR models now supported by GIS and spatial analysis software programs (e.g., *GeoDa*).
- A spatial weights matrix is used to specify, for each location, which other locations are 'neighbors' and may have an influence on values at that location.
- Recent EJ studies have demonstrated the utility of SAR models:
  - Pastor et al. 2005; Grineski & Collins 2008; Chakraborty 2009.

2. Problem with Conventional Statistical Analysis: Spatial Homogeneity

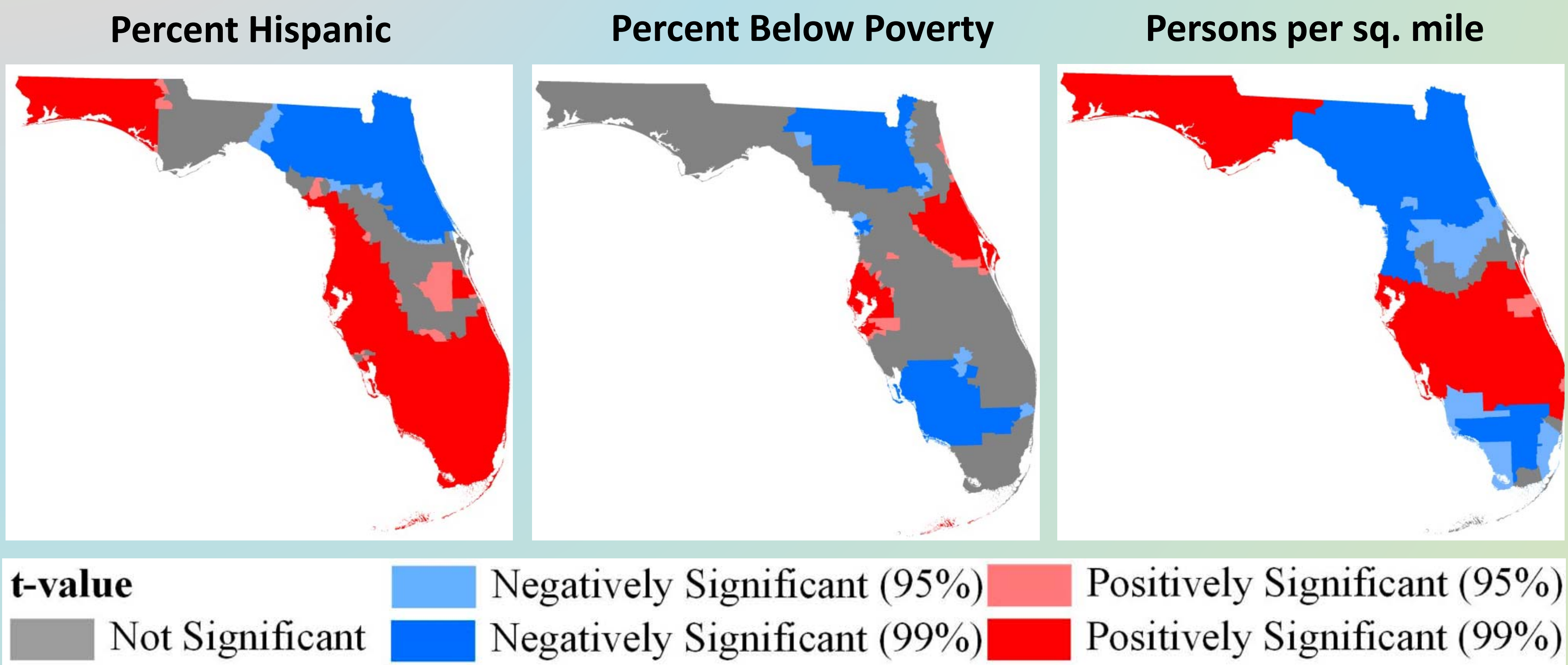
- Classical linear regression model assumes a generating process that is considered to be spatially stationary or homogeneous.
- The use of a single or 'global' regression model for an entire study area assumes model parameters or statistical relationships do not vary spatially within a study area.
- Conventional regression cannot be used to explore this *spatial nonstationarity* or examine local differences in statistical associations between the dependent and independent variables.

Addressing Spatial Nonstationarity

- **Geographically Weighted Regression (GWR)**: a local spatial statistical technique for exploring how relationships differ from place to place within a study area.
  - ➢ A separate regression is carried out at each location using other observations that fall within a user-specified local area surrounding that location.
  - ➢ A statistical device used to weigh the attributes of nearby observations within the local area more highly compared to the attributes of distant observations.
- Instead of generating a single global regression equation for an entire study area, GWR produces a separate regression equation or a unique set of parameters for each location or spatial unit.

GWR Example: Florida

Dependent Variable: lifetime cancer risk from ambient exposure to minor point sources of air toxics (1999 NATA: census tract level data)



Source: Gilbert 2009.

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III.
Health Outcomes and Proximity to Environmental Hazards

Health outcomes and proximity to environmental hazards - Introduction

- Perceived excesses of adverse health outcomes near environmental entities
  - Is residential proximity to potential environmental hazards associated with adverse health outcomes?
  - Does this residential characteristic impact minority and lower-income populations differently than other populations?

Approach to review

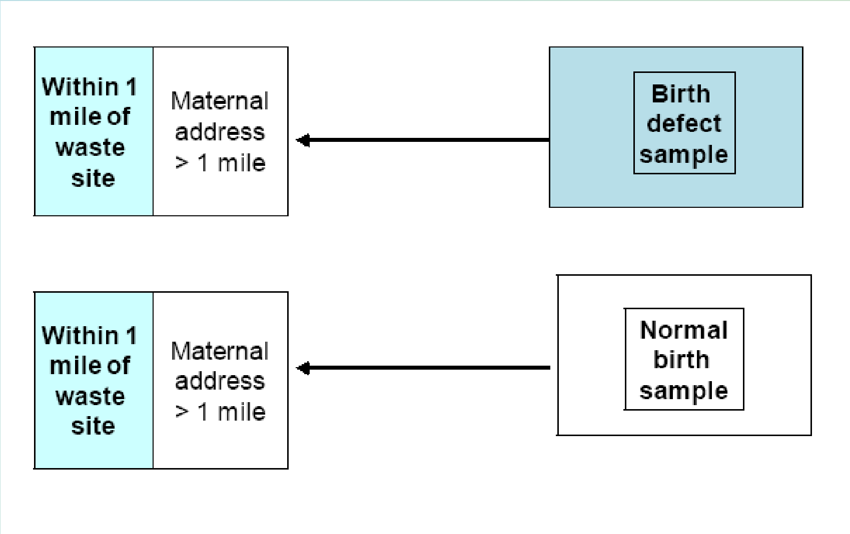
- Comprehensive review of the literature - *proximity to environmental hazards and health outcomes*
- Focus on:
  - Adverse pregnancy outcomes
  - Childhood cancer
  - Cardiovascular and respiratory illnesses
  - Diabetes
  - End-stage renal disease

Approaches used in pregnancy outcome and childhood cancer studies

Study Designs*

1. Ecologic study
2. Case-control study
   - most common design used
3. Retrospective cohort study

*(In order of weakest to strongest design)

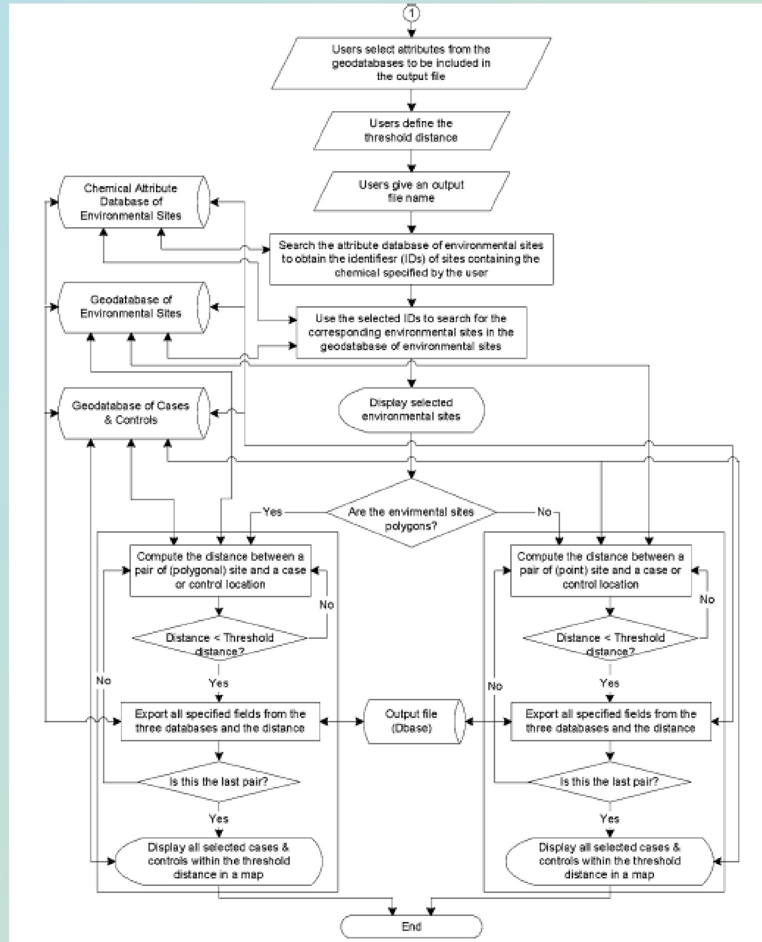


Case-control study design example

Linkage of environmental locations to outcomes

- Methods used*
  1. Spatial coincidence analyses
     - Used mostly with ecologic studies
  2. Distance-based analyses
     - Most common approach
  3. Pollution plume modeling

*(In order of weakest to strongest exposure assessment)



Example of distance-based approach
(Zhan, Brender, Han et al., 2006)

Adverse pregnancy outcomes

- Focused on studies published within past 15 years
- Fifty-four studies reviewed
- Review elements
  - Types of study designs and populations
  - Pregnancy outcomes included
  - Exposure assessment
  - Major findings and limitations

Residential proximity to **waste sites** and pregnancy outcomes

Outcomes studied	**Populations**	**Associations noted with maternal residential proximity**
Congenital malformations	USA, Canada, Denmark, Europe, Great Britain	CNS defects (neural tube defects), heart defects, gastroschisis & exomphalos, hypospadias and epispadias, chromosomal anomalies
Fetal/neonatal deaths	USA	Fetal deaths associated with proximity to pesticide-contaminated waste sites
Low birth weight (LBW) Small for gestational age (SGA)	USA, Canada, Great Britain	LBW & SGA associated with municipal waste sites; LBW with hazardous waste sites and sites contaminated with PCBs
Preterm birth	Canada	No association noted in two studies

Residential proximity to **active industrial sites*** and pregnancy outcomes

Outcomes studied	**Populations**	**Associations noted with maternal residential proximity**
Congenital malformations	USA, Europe, France, Hungary, Israel, Japan, United Kingdom	CNS defects, chromosomal anomalies, heart defects, musculoskeletal defects, oral clefts, renal dysplasia, undescended testis
Fetal/neonatal deaths	Israel, Japan, United Kingdom	Stillbirths, perinatal mortality, infant deaths
Low birth weight (LBW)	United Kingdom	Percent low birth weight increased

*Industrial complexes, incinerators, crematoriums

Residential proximity to other potential environmental hazards and pregnancy outcomes

Type of environmental entity	Populations	Associations noted with maternal proximity
Cornfields and fields with soybeans	USA	Increased risk for limb malformations with maternal proximity to cornfields
Land area with pesticide applications	USA	Increased risk for neural tube defects and fetal deaths from congenital malformations
Roadways, highways, and areas with high traffic density/traffic-related pollution	USA Canada	Increased risk for preterm birth and term/preterm low birth weight

Childhood cancer

- Focused on studies published within past 15 years
- Twenty-five studies reviewed
- Periods of exposure covered in studies
  - Address at time of diagnosis
  - Birth residence only
  - Birth and death addresses
  - Childhood addresses
  - Residence of longest duration
  - Maternal addresses prior to birth to diagnosis of cancer

1. Residential proximity to potential environmental hazards and childhood cancer

Type of environmental entity	**Populations**	**Associations noted with residential proximity**
Cropland and areas of pesticide applications	USA	Acute lymphoblastic leukemia, Burkitt lymphoma, germ-cell tumors, leukemia, non-Hodgkin lymphoma
Hazardous waste sites & landfills	USA Great Britain	None noted
Nuclear power plants	Germany Scotland	Association noted with leukemia in Germany
Roadways and proximity to traffic-related pollution	USA, Denmark, Italy, United Kingdom	Associations noted in Italy and UK with leukemia; in Denmark with Hodgkin lymphoma

2. Residential proximity to potential environmental hazards and childhood cancer

Type of environmental entity	Populations	Associations noted with residential proximity
Industries reporting under Toxic Release Inventory (TRI)	USA	Associated with brain cancer in children less than 5 years of age within 1 mile of TRI facilities emitting carcinogens and within 1 mile of TRI facilities overall
Petrol station or repair garage	France Taiwan	Incident leukemia (France); leukemia death (Taiwan)
Petrochemical plants	Taiwan	Associated with brain cancer deaths in persons 0 – 29 years of age; associated with leukemia in young adults (20-29 years) but not in children

Proximity to Environmental Hazards and Disparities by Health Outcomes

Population	Outcome	Disparity examined	Environmental hazard & outcome disparity
Israel	Birth defects, perinatal mortality	Ethnicity – Jewish or Bedouin	Proximity to industrial complex associated with birth defects/perinatal mortality in Bedouins but not Jewish
USA (Texas)	Birth defects	Hispanic ethnicity	Proximity to waste sites – Klinefelter variants in Hispanic births only; Proximity to TRI facilities – NTDs in non-Hispanic births only
Montreal, Canada	Preterm birth, LBW, SGA	Education and income	Proximity to highways associated with preterm, LBW, and SGA among births to more wealthy and most highly educated women
USA (California)	Birth defects	Race/ethnicity	Residence in census tract with NPL waste sites – strongest association with birth defects in American Indians

Limitations

- Use of one address to assign exposure
  - Residential mobility
- Subject/environmental addresses not ideal for health outcome
  - e.g., used address at delivery for birth defects; address at diagnosis or death for cancer
- Residential proximity used to assign exposure status
- Potential residual confounding
  - Race/ethnicity
  - Socioeconomic status
  - Parental occupation
- Inconsistent findings across studies
  - Is the expectation of consistency realistic in such studies?

Cardiovascular, Respiratory and other Chronic Diseases

A comprehensive review of the literature was conducted to examine the relation between residential proximity to environmental hazards and cardiovascular, respiratory, and other chronic diseases.

Studies employing a range of geospatial techniques, such as proximity analysis and air dispersion modeling, and using Geographical Information Systems Science (GISc) as an organizing framework, were selected to examine the public health effects of living near environmental burdens. A total of 20 studies were identified, representing a wide range of hazards and health outcomes:

- Cardiovascular and respiratory illness – air pollution;
- PCB toxicity, end-stage renal disease, diabetes – hazardous waste sites;
- Cancer – industrial & nuclear plants, air pollution.

Exposure	Outcome	Reference, Year, Country	Study design, Regional description	Health outcomes included	Exposure description	Target Population	Geospatial Methods	Findings	Health outcome associated with proximity & limitations (blue=significant associations purple=mixed evidence, black=no sign. associations)
Industrial Plants	Respiratory	Aylin et al., 2001, England & Wales	Small area study (England and Wales), proximity analysis	Emergency hospital admissions primary diagnosis of respiratory or cardiovascular diseases	Industrial plants: Distance (buffers up to 7.5km buffers) from operating coke works facility	Adults 65 years and over (n=87,760), Children under 5 years (n=43,932)	Distance decline model based on concentric areas around the facility	Older adults: only sign. regression result- coronary heart disease near Teesside plant RR=1.04 (1.00,1.08); no sign. findings for coke works combined Children: respiratory disease RR=1.08 (0.98,1.20); asthma RR=1.07 (0.98,1.18); at Teeside plant gradation of declining risk with distance for both respiratory illness and asthma	Possible elevated risk of respiratory disease and asthma in children with proximity to Teesside coke works. Migration and mobility not controlled, use of a simple radial dispersion-decline model for estimating exposure.
Hazardous Waste sites	PBC levels	Choi et al., 2006, USA	Small area study (New Bedford, Acushnet, Fairhaven, and Dartmouth, Massachusetts), proximity and multivariate regression analysis	Cord serum polychlorinated biphenyl (PBC) levels in infants (collected at birth)	Exposure to superfund sites: Residences within 5 mile radius of superfund hot spot	Infants born to mothers residing near contaminated New Bedford Harbor	Residential distance to superfund hot spot	No association found between cord serum PCB levels and distance to hot spot. Maternal age and birthplace remained most significant predictors of PCB levels.	No evidence that living near New Bedford superfund site is associated with increased cord serum PCB. But, higher levels found in children born before and during dredging of harbor. Exposure measurement simplified (pathway), cross-sectional study design.
Air pollution	Respiratory	Edwards et al., 1994, UK	Case-control study (Birmingham, UK), proximity analysis	Hospital admission for asthma	Mobile source air pollution: Residential proximity (within 200 and 500 meters) to major roads and traffic flow (>24,000 vehicles per hour)	Children under 5 years (cases: n=715, hospital controls: n=736, community controls: n=?)	Distance decline model based on fixed distance buffers around major roads (200, 500 m) and high traffic flows	Sign. association between exposure to traffic and asthma hospitalization versus community control group: for distance to mj road: OR=1.52 (1.22,1.90, p<0.0002); for high traffic flow roads: OR=1.40 (1.13,1.74, p<0.002), also between hospital controls: OR=1.29 (1.04,1.50, p<0.02); evidence of a dose-reponse relationship for traffic flow	Evidence of increased odds of asthma hospitalization with proximity to major roads and high traffic flow areas. Possible confounding (no controls for SES), measurement error (single exposure measure).
Air pollution	Respiratory	English et al., 1999, USA	Case-control study (San Diego County, CA), proximity analysis with logistic regression	Hospital admissions for asthma	Mobile source air pollution: Residential proximity to high traffic flow (within 550 ft of residence)	Children 14 years or younger (cases: n=5,996, controls: n=2,284)	Fixed 550 ft buffer around residence, and actual distance from residence to street, traffic flow dispersion model	Only sign. results: among cases, those residing within high traffic flow areas more likely to have 2 or more visits than only 1 visit per year. OR=2.89 (1.07,7.40, p<0.05)	No evidence of increased hospital visits for asthma with higher traffic counts near residence. Among asthmatic children, greater number of visits associated with higher traffic counts (contributing rather than causal). Possible confounding (smoking), exposure misclassification.
Hazardous Waste sites	End-stage renal disease	Hall et al., 1996, USA	Ecological case-control study (20 counties, New York State), logistic regression analysis	End-stage renal disease (ESRD)	Exposure to hazardous waste sites: Listed on NY inactive hazardous waste site registry	Cases of ESRD reported to Health Care Financing Administration in 20 NYS counties (n=259) and pair-matched control (n=259)	Fixed distance (1 mile) buffers around each site, 25 sections classified within each buffer as high, medium, low, and unknown liklihood of exposure	Elevated associations found between residence within buffer, number of years at residence, high/medium exposure and ESRD but ORs not significant	No evidence of increased odds of living near hazardous waste facility and ESRD. Exposure measurement errors (residential vicinity as proxy for actual exposure measurement), small sample size).
Air pollution	Stroke Mortality	Hu et al., 2008, USA	Ecological study (Northwest Florida, Escambia and Santa Rosa counties), Bayesian hierarchical model	Stroke mortality (age-adjusted death rate) at census tract level	Air pollution (recorded point and mobile sources): Toxic Release Inventory (TRI) facilities, dry cleaning, sewer treatment, solid waste disposal superfund sites, and vehicular traffic	Residents of Escambia and Santa Rosa counties	Dasymetric mapping for environmental exposure value and spatial interpolation to create air pollution density surfaces	Elevated risk of stroke mortality in areas with high pollution, low income and low level of green space: 95% credible sets for traffic: 0.034, 0.144; monitored point sources: 0.419, 1.495; unmonitored point sources: 0.413, 1.522	Increased risk of stroke mortality in high pollution areas. Measurement error (ischemic vs. hemorrhagic stroke and individual exposure assessments), ecological fallacy.
Industrial Plants	Cancer	Johnson et al., 2003, Canada	Case-control study (Canada), residential distance and logistic regression analysis	Non-Hodgekin lymphoma (NHL)	Industrial plants: residential proximity (0.5 - 2 miles) to industrial plants: copper smelters, lead smelters,	Cases of NHL (newly diagnosed) reported to provincial cancer registry (n=1,499) and population	Residential distance to industrial plants (lat/long), distance categories of <0.5, 0.5-2, >2 miles	No sign. association found between proximity to industrial plant (all categories) and NHL. But sign. findings for 1) residing within 2 miles	No evidence of increased odds of NHL with residential proximity to industrial plants. Some significant finding with specific industry and

Summary of Cardiovascular and Respiratory Disease Research

The results from these 14 studies suggest that residential proximity to both stationary sources (TRIs, NEIs, HAPs, petroleum refineries, etc.) and, with a few exceptions, heavily trafficked roads, is significantly associated with asthma hospitalizations (Edwards et al., 1994; Maantay and Porter-Morgan, 2004; Maantay et al., 2009c; Smargiassi et al., 2009).

In addition, exposure to mobile sources air pollution increases the occurrence of chronic respiratory symptoms by exacerbating asthma (English et al., 1999; Oosterlee et al., 1996; Vliet et al., 1997; Venn et al., 2001; Wjst et al., 1993).

The studies reviewed (Hu et al., 2008; Maheswaran and Elliott, 2003; Aylin et al., 2001) also suggest that there is a significant association between residential exposure to combined sources of air pollution and stroke mortality.

Summary of Research on PCB Toxicity, Renal Disease, and Diabetes – Hazardous Waste Sites

Three studies examined the impact of residing near hazardous wastes sites using GISc, although the health outcomes of interest were different: cord blood Polychlorinated biphenlys (PCB) level, end-stage renal disease (ESRD), and diabetes.

Although there is some evidence linking residential proximity to hazardous waste sites and adverse health impacts (Choi et al., 2006; Hall et al., 1996; Kouznetsova et al., 2007), the dearth of literature makes cross-study comparisons difficult. Although there may be an association between exposure to hazardous waste sites and outcomes such as PCB toxicity, ESRD, and diabetes, more research is needed.

Summary of Research on Cancer – Industrial and Nuclear Plants, and Air Pollution

Three studies exploring the relationship between environmental burdens and cancer using GISc were reviewed. The environmental exposures of interest in these studies range from industrial plants, a nuclear facility, and air pollution. The evidence is mixed regarding proximity to industrial plants and nuclear facilities.

Leukemia was significantly associated with proximity to Pilgrim nuclear power plant among women (Morris and Knorr, 1996). Although one study failed to find a relationship between cancer and exposure to the Pan Britannica Plant (Wilkinson et al., 1997), another found significant associations between other industrial plants and some cancers: for instance, NHL was significantly associated with proximity to a copper smelter and sulfite pulp mill (Johnson et al., 2003).

IV. Conclusions and Recommendations

Conclusions

1. A higher proportion of minorities and lower-income populations reside near environmental hazards, such as:

- Toxic Release Inventory facilities;
- National Emissions Inventory facilities;
- other sources of hazardous air pollutants;
- hazardous waste treatment, disposal, and storage facilities;
- landfills;
- sewage treatment plants;
- power plants;
- major roadways;
- solid waste facilities;
- industrial zones in general; and
- air craft noise from airports.

Conclusions (continued)

2. Although the results are mixed, a number of studies have found significant relationships between residential proximity to environmental hazards and adverse health outcomes, such as:

- adverse pregnancy outcomes, (including increased risks for central nervous system defects, congenital heart defects, oral clefts, renal dysplasia, limb malformations, chromosomal anomalies, preterm births, low birth weight, small-for-gestational-age, fetal deaths, and infant deaths);
- childhood cancers (including leukemia, brain cancer, germ-cell tumors, non-Hodgkin lymphoma, and Burkitt lymphoma);
- asthma hospitalizations and chronic respiratory symptoms;
- stroke mortality;
- PCB toxicity;
- end-stage renal disease; and
- diabetes.

Conclusions (continued)

3. Given that racial/ethnic minorities and/or lower-income populations are more likely to live near such environmental hazards, and research has indicated that this residential characteristic might be associated with adverse health outcomes, it is highly likely that there is a disproportionate impact of this exposure on the health of minorities and lower-income populations.

4. However, few studies have examined whether such exposure are more or less likely to increase risk for adverse health outcomes among minority and lower-income populations.

Conclusions (continued)

5. Methods for assessing spatial proximity and potential exposure to hazards have evolved from comparing the prevalence of minority or low-income residents in pre-defined geographic units hosting hazardous facilities to more rigorous techniques that are based on precise distances between hazards and people, quantity and quality of emitted pollutants, chemical fate and transport modeling, and data sets which provide modeled estimates of adverse health risks from cumulative exposure to multiple pollutants and emission sources.

6. The lack of address-specific, individual/household data and information on day-time locations of people are major impediments in measuring disparities in proximity or exposure to environmental health hazards accurately and comprehensively.

7. While conventional statistical methods such as correlation or regression have been used extensively in previous studies to evaluate racial/ethnic or socioeconomic disparities, these techniques violate several classical statistical assumptions (i.e. independence and homogeneity) and may not be appropriate for analyzing spatial data and relationships.

Recommendations

Given the conclusions above, which are based on the evidence of disparities by race and income in relation to proximity to environmental hazards, the adverse health outcomes for populations in close proximity to environmental hazards, and acknowledgement of the health disparities experienced in general by communities of color and lower-income communities, we suggest that these factors be given serious consideration in the decision-making process by governmental environmental and health agencies regarding:

- the siting of environmentally-burdensome facilities and land uses,
- in regulatory and enforcement efforts concerning pollution, and
- in the active promotion of environmental health justice and environmental health protection.

Our technical recommendations are informed primarily by the limitations of current research. We recommend that the following deficiencies in available data, research methods, and research emphasis be addressed:

Recommendations (continued)

1. **Research gaps** - there are significant gaps in current research, especially regarding the assessment of overall health outcomes in relation to proximity to environmental hazards, and regarding the relationships between these issues and minority, low-income, and other populations considered to be more vulnerable.

2. **Data needs** – the data necessary for more definitive research on these relationships require increased accuracy and higher spatial resolution. Data on health outcomes need to be made available at the individual patient level, which is possible now since issues of maintaining patient information confidentiality can successfully be handled through geo-coding masking and randomization techniques in graphic display. Aggregated health data is not sufficiently fine-grained enough for most research on the relationship between proximity to environmental hazards, health outcomes, and characterization of affected populations. Data on environmental quality factors, meteorological conditions, and physical environmental infrastructure parameters are generally not complete or exact enough to serve as inputs to complex models, and these need to be augmented by better data as well.

Recommendations (continued)

3. **Methodological approaches** – conventional statistical methods, which have been used for many health studies, are not the most appropriate or effective methods for fine-grained spatial analysis, but more location-based geostatistical methods have not been adopted as frequently as would be desirable, due to the fact that many health and environmental researchers who conduct this type of research lack awareness of these methods and knowledge of their utilization. Increased education and training in geostatistical analytic techniques would be useful to encourage new research incorporating these methods, and to assist researchers in developing additional new geographically-based methods. Furthermore, although environmental modeling is often held out as the gold-standard of environmental impact assessment, it is still relatively cumbersome, labor-intensive, computer-intensive, and necessitates a high level of computational skills, as well as requiring extensive data inputs that are usually quite difficult to obtain. Better and more generalized, easy-to-use models should be developed, preferably models that are well-integrated or closely-coupled with GISc software, rather than stand-alone models. Multidisciplinary teams, such as those with expertise in GIS, epidemiology, environmental science, and statistical modeling, as well as community scientists, are in the best position to investigate the relation between proximity to environmental hazards and adverse health outcomes (Maantay et al., 2009b).

Recommendations (continued)

4. **Paucity of environmental impacts investigated** – many studies investigate the same type of hazard, (for example, TRI facilities) usually because of data limitations and the default use of hazard databases available at the national scale. Most studies look at only one or two environmental hazards at a time. Cumulative and synergistic impacts have rarely been examined, yet these types of impacts may have a larger than acknowledged connection to adverse health outcomes.

5. **Residential focus vs. daytime location** – studies in this review that used census data to assess disproportionate impacts examined proximity to hazards from the perspective of residential location of the potentially exposed population, although, except for small children and perhaps the elderly, most people do not spend the majority of their time at home. The true environmental impact on various populations can only be ascertained by achieving a better understanding of where people actually are located, other than simply their residential addresses.

Recommendations (continued)

6. **Exposure assessment** – most studies of proximity to environmental hazards and health outcomes based exposure assessment on a single residential address. This approach does not take into account residential mobility and residential location history, and is potentially a significant source of exposure misclassification. Furthermore, the appropriate temporal sequence was a problem in some studies in which data on current environmental conditions were linked to past residential locations.

These deficiencies in research focus, methodological techniques, exposure assessment, and data availability and access may be mitigated by providing more targeted funding to help correct some of these problems, and ensure that future research does not suffer from these drawbacks.

This would lead to increased reliability of results, stronger evidence, increased understanding of the complex interactions of environment-human factors, and better hope for finding real solutions to environmental health injustices and environmentally-related diseases and conditions.

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Proximity to Environmental Hazards:
Environmental Justice and Adverse Health Outcomes

Maantay, Chakraborty, and Brender