

# Disproportionate Proximity to Environmental Health Hazards: Methods, Models, and Measurement

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We sought to provide a historical overview of methods, models, and data used in the environmental justice (EJ) research literature to measure proximity to environmental hazards and potential exposure to their adverse health effects. We explored how the assessment of disproportionate proximity and exposure has evolved from comparing the prevalence of minority or low-income residents in geographic entities hosting pollution sources and discrete buffer zones to more refined techniques that use continuous distances, pollutant fate-and-transport models, and estimates of health risk from toxic exposure.

We also reviewed analytical techniques used to determine the characteristics of people residing in areas potentially exposed to environmental hazards and emerging geostatistical techniques that are more appropriate for EJ analysis than conventional statistical methods.

We concluded by providing several recommendations regarding future research and data needs for EJ assessment that would lead to more reliable results and policy solutions. (*Am J Public Health*. Published online ahead of print August 11, 2011; e1–e10. doi:10.2105/AJPH.2010.300109)

## ENVIRONMENTAL JUSTICE (EJ)

is defined broadly as the disproportionate distribution of environmental “goods” and “bads,” with the burden of the bads and the dearth of the goods falling mainly on racial and ethnic minorities, lower income populations, and other vulnerable groups. Since the 1980s, a large body of literature on EJ has emerged, mainly focused on areas in the United States and often using geographic information systems (GIS) to assess the proximity of vulnerable subpopulations to environmental hazards as a proxy for exposure and the potential for deleterious health impacts.<sup>1–11</sup> GIS technology is well suited to EJ research because it allows for the integration of multiple data sources, cartographic representation of data, and the application of various spatial analytical techniques for proximity analysis.<sup>11,12</sup> Although maps are effective in visually demonstrating the disproportionate spatial distribution of environmental hazards, researchers have commented on the challenges and limitations inherent in spatial analysis and questioned GIS’s efficacy in demonstrating pollution’s health impacts. Spatial and attribute data deficiencies and methodological problems, especially those related to geographical considerations, have been well documented.<sup>6,11,13–23</sup>

However, development of methods for producing more meaningful spatial analyses is feasible, and health geographers and other researchers have been using GIS to demonstrate the correspondence among factors such as proximity to

hazards, disproportionate exposure, and health disparities.

We reviewed methods commonly used by EJ researchers in articles that were selected to provide a comprehensive overview and synopsis of quantitative research on EJ and disproportionate proximity to environmental hazards over the past 2 decades. We searched these databases for relevant published literature: Sociological Abstracts, Social Science Citation Index, Science Citation Index, and the National Library of Medicine’s PubMed. We initially selected studies by using the search terms *environmental justice*, *environmental equity*, and *environmental racism*. We attempted to find studies exhibiting as wide a range as possible in terms of geographic extent studied, variety of hazards examined, and analytical techniques used. We excluded literature review articles and those using purely theoretical or qualitative approaches. The final list of references selected for our critical review of EJ research methodology consisted of quantitative case studies (n = 80) that examined racial–ethnic and socioeconomic disparities in the distribution of, or proximity to, environmental health risks, pollution sources, and undesirable land uses. Most of these studies indicated a disproportionate distribution of environmental burdens with respect to both race and socioeconomic status (SES). Although SES variables pointed to more significant risks of exposure than race,<sup>17,24–27</sup> race tended to be significant even when controlling for SES.<sup>28–31</sup> We

summarized the most frequently cited and significant studies (n = 55) reviewed in Online Supplemental Table 1 (available at [www.ajph.org](http://www.ajph.org)), which includes the study parameters and scope, pollution indicators used, methodology used, and findings.

We provide a historical overview and critical assessment of (1) analytical approaches used to spatially define the boundaries of areas potentially exposed to environmental hazards, (2) methods for estimating population characteristics of such areas, and (3) emerging geostatistical techniques that address limitations of conventional approaches.

## SPATIAL DEFINITION OF PROXIMITY AND EXPOSURE TO HAZARDS

Spatial coincidence, in the context of EJ research, is a technique that assumes potential exposure to environmental hazards is confined to the boundaries of predefined geographic entities or census units containing such hazards.

### Spatial Coincidence Analysis

Although its implementation has changed over time, the most widely used and traditional method of spatial coincidence analysis, known as unit–hazard coincidence,<sup>32</sup> uses the presence of a hazard source within an analytical unit as a proxy for environmental exposure. Sociodemographic characteristics of spatial units containing a hazard (host

# Residential Proximity to Environmental Hazards and Adverse Health Outcomes

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How living near environmental hazards contributes to poorer health and disproportionate health outcomes is an ongoing concern. We conducted a substantive review and critique of the literature regarding residential proximity to environmental hazards and adverse pregnancy outcomes, childhood cancer, cardiovascular and respiratory illnesses, end-stage renal disease, and diabetes.

Several studies have found that living near hazardous wastes sites, industrial sites, cropland with pesticide applications, highly trafficked roads, nuclear power plants, and gas stations or repair shops is related to an increased risk of adverse health outcomes.

Government agencies should consider these findings in establishing rules and permitting and enforcement procedures to reduce pollution from environmentally burdensome facilities and land uses. (*Am J Public Health*. Published online ahead of print May 5, 2011; e1–e16. doi:10.2105/AJPH.2011.300183)

## CONCERNS ABOUT HEALTH

and environmental hazards transcend the academic, scientific, and regulatory worlds; they are also of compelling interest to the public, who often recognizes a relationship between environmental hazards and health. In a 1999 national telephone survey among US voters,<sup>1</sup> 74% of respondents thought that environmental factors had an important impact on childhood cancer, and 73% thought these factors had an impact on birth defects. More than 50% of respondents felt that air pollution, contaminated drinking water, and toxic waste had a great deal of impact on a person's health. These concerns often resulted in public perceptions of disease clusters near hazardous waste sites, industrial facilities, and other potential sources of chemical releases. With the advent of geographic information systems, environmental scientists and public health researchers have been able to address these concerns more comprehensively and objectively with the use of various proximity analyses.

We undertook a systematic review of 94 studies that examined residential proximity to environmental hazards in relation to adverse reproductive outcomes, childhood cancer, respiratory and cardiovascular conditions, or other adverse health outcomes. In our review, unlike in previously published reviews, we focused on a wide range of health outcomes in relation to residential proximity to multiple environmental hazards and identified each study's

limitations. If the evidence indicates that residential proximity is associated with poorer health outcomes, regulatory agencies may need to factor in nearby populations when siting industrial facilities, municipal waste sites, incinerators, and other potential sources of emissions.

## APPROACH

We identified studies of environmental proximity analyses in relation to health through the National Library of Medicine's PubMed, using search terms that combined *proximity to* and adverse pregnancy outcomes (birth defects, fetal death, low birth weight, preterm birth, and spontaneous abortion), childhood cancer, cardiovascular and respiratory illnesses, end-stage renal disease, and diabetes. We also identified additional relevant studies in these studies' bibliographies. With respect to cancer, we focused our review primarily on childhood cancers. Given the relatively long induction and latent period of solid tumors in adults, studies would need to include residential histories for as many as 15 to 30 years before a cancer diagnosis to capture pertinent environmental exposures. Although several recently published studies have included extensive residential histories,<sup>2–4</sup> such studies are scarce. Even though various respiratory and cardiovascular conditions may originate many years before manifestation of overt disease, environmental exposures to pollutants could have acute

effects, for example, precipitating asthma attacks or myocardial infarction in susceptible individuals.

We summarized information from each study regarding target populations, type of study design used, health outcomes included, methods of proximity analyses and exposure assessment, major findings, and limitations. We also examined study results for evidence of racial or economic disparities in health outcomes in relation to residential proximity. In addition to discussing overall findings, we summarized the conclusions of studies that had minimal limitations with respect to exposure assessment and outcome.

A wide variety of methods were used in the reviewed studies to examine the relation between proximity to potential environmental hazards and adverse health outcomes, including spatial coincidence analyses (e.g., residence in a zip code with  $\geq 1$  hazardous waste sites), distance-based analyses (e.g., residence  $\leq 1$  mile of industrial facilities as defined by a 1-mile buffer), and pollution plume modeling (i.e., the dispersion footprint of the pollutant as a proxy for exposure). The most frequently used method was distance-based analysis.

## ADVERSE PREGNANCY OUTCOMES

We reviewed 49 studies that examined the relation between residential proximity to 1 or more potential environmental hazards and adverse pregnancy outcomes.

# Chapter 17

## Revisiting Tobler's First Law of Geography: Spatial Regression Models for Assessing Environmental Justice and Health Risk Disparities

Jayajit Chakraborty

**Abstract** Multivariate regression has been used extensively to determine if race/ethnicity or socioeconomic status is related to presence of pollution sources, quantity of pollutants emitted, toxicity of emissions, and other indicators of environmental health risk. Most previous studies assume observations and error terms to be spatially independent, thus violating one of the standard regression assumptions and ignoring spatial effects that potentially lead to incorrect inferences regarding explanatory variables. This chapter focuses on the problem of spatial autocorrelation in geospatial analysis of environmental justice and explores the application of simultaneous autoregressive (SAR) models to control for spatial dependence in the data. A case study uses both traditional and SAR models to examine the distribution of cancer risk from exposure to vehicular emissions of hazardous air pollutants in the Tampa Bay MSA, Florida. Several approaches are explored to augment the standard regression equation, identify the neighborhood structure of each tract, and specify the spatial weights matrix that accounts for variations in cancer risk not predicted by explanatory variables. Results indicate that conventional regression analysis could lead to erroneous conclusions regarding the role of race/ethnicity if spatial autocorrelation is ignored, and demonstrate the potential of SAR models to improve geospatial analysis of environmental justice and health disparities.

**Keywords** Air pollution · Cancer · Environmental justice · Spatial regression · Spatial statistics

### List of Abbreviations

AIC	Akaike Information Criterion
ASPEN	Assessment System for Population Exposure Nationwide
EPA	Environmental Protection Agency
HAPEM5	Hazardous Air Pollution Exposure Model 5
NEI	National Emissions Inventory

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# Chapter 5

## Proximity Analysis for Exposure Assessment in Environmental Health Justice Research

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**Abstract** This chapter provides a historical overview and constructive critique of analytical approaches and methods that have been used to measure proximity to environmental health hazards and potential exposure to their adverse effects in the environmental justice (EJ) research literature. After providing an introduction to environmental health justice research and key findings, we examine how quantitative EJ analysis has emerged from comparing the prevalence of minority or low-income populations in spatial units hosting environmental hazards and circular buffer zones to more advanced techniques that utilize GIS, pollution plume models, and estimates of health risk from ambient exposure to multiple pollutants and emission sources. We also review spatial analytical approaches used in previous studies to determine the demographic and socioeconomic characteristics of people residing in areas potentially exposed to environmental hazards, as well as newly emerging geostatistical techniques that are more appropriate for spatial analysis of EJ than conventional statistical methods used in prior research. The concluding section focuses on highlighting the key limitations and identifying future research needs associated with assessment of environmental health justice.

**Keywords** Environmental health justice · Proximity analysis · Buffer analysis · Areal interpolation · Dispersion model · Spatial regression · Geographically weighted regression

### 5.1 Environmental Health Justice

Environmental Justice, both as a term in our vocabularies and as a movement, came into being more than 20 years ago. Narrowly interpreted, Environmental Justice (EJ) is the attempt to document and address the disproportionate environmental and health burdens borne by the poor and people of color. In a broader context, EJ theory encompasses everything that is unsustainable about the world we have

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