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Environmental justice and toxic exposure: Toward a spatial model of physical health and psychological well-being ☆

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Abstract

The relationship often assumed by environmental justice researchers is that proximity to a hazardous waste site is a measure of exposure to harmful chemicals. Few researchers, however, explicitly address the methodological challenge of measuring the causal relationship between toxic chemical exposure and health problems. To better understand the methodological task of moving beyond the proximity-exposure assumption, the three most commonly used quantitative methodological approaches in environmental justice research are briefly outlined. Using geographic information system techniques, we operationalize toxic exposure as an interval-level variable and integrate this data with geocoded health and social survey information. We develop a methodological design that enables researchers to assess what factors cause mental and physical health problems for individuals living in contaminated areas. The results of the hierarchical multiple regression analyses indicate that sociodemographic, perceived exposure, objective exposure, and food consumption variables are significant predictors of physical health and psychological well-being. We also found a significant relationship between physical health and psychological well-being. The data used in this paper were collected in a low-income, African-American community in Fort Lauderdale, Florida. This community is contiguous to a Superfund site (EPA) called the Wingate Road Municipal Incinerator and Landfill.

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1. Introduction

While many large-scale technological disasters (e.g., Three Mile Island, *Exxon Valdez* Oil Spill), as well as chronically polluted areas (e.g., Love Canal, Cancer Alley), have received much media attention and have been the focus of extensive research, we know relatively little about the long-term health effects of living in contaminated communities. This lack of knowledge is troubling given the scope of contamination. Currently, there are 1236 sites in the United States listed on the Superfund's National Priorities List (EPA, 2005). In 1985, it was estimated that there were approximately 378,000 sites where toxic materials may have been improperly disposed (Szasz and Meuser, 1997; US GAO, 1983). In 1987, an estimated 20 billion pounds of toxic chemicals were released into the air, water, and land (Foster, 1994). Clearly, the high profile technological disasters mentioned above represent the "tip of the iceberg" (Edelstein, 2003).

In the late 1970s, people began to mobilize to either address problems associated with existing contaminated sites or prevent the locating of a new hazardous waste facility in their community (Cable and Cable, 1995). With growing public awareness and seminal research efforts, the environmental justice (EJ) movement emerged in the 1980s in response to the fact that low-income people and people of color are disproportionately impacted by toxic environmental contamination (Bullard, 1983; UCC/CRJ, 1987; US GAO, 1983). The EJ movement has had some success at blocking the placement of new hazardous facilities in communities already burdened by contamination (e.g., Roberts and Toffolon-Weiss, 2001). Yet, the EJ movement and associated research efforts have not adequately addressed the likely long-term physical and mental health problems associated with living in contaminated areas.

The purpose of this research is threefold: first, we provide a brief review of EJ research with a focus on methodological advances and weaknesses. Second, by using geographic information system techniques, we expand EJ research by measuring toxic exposure as an interval-level variable and merging this data with geocoded health and social survey information. Third, we contend that EJ research should inform efforts to assist people who live in contaminated communities. Toward this end, we develop a methodological design that enables researchers to assess what factors cause mental and physical health problems for individuals living in contaminated areas. We specify a model that includes sociodemographic, life style, risk perception, and objective exposure variables as predictors of psychological well-being and physical health. The data used in this paper were collected in a low-income, African-American community in Fort Lauderdale, Florida. This community is contiguous to a Superfund site (EPA) called the Wingate Road Municipal Incinerator and Landfill (EPA, 1996, ID: FLD981021470).

2. Environmental justice research methods

Over the past 25 years, EJ researchers have examined the geographic distribution of environmental hazards at national, regional, and local levels. While EJ research has

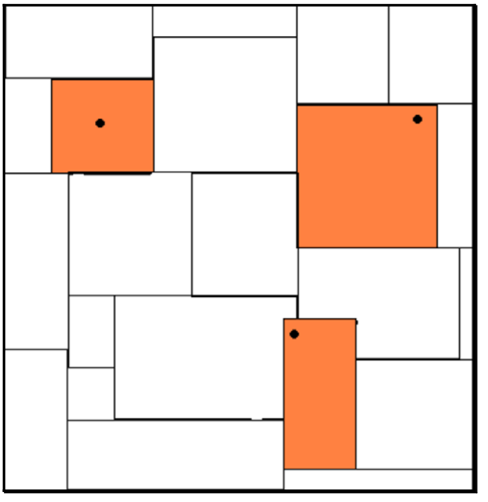

Fig. 1. Unit-hazard coincidence.

contributed significantly to bringing national attention to environmental inequities and preventing new hazardous waste facilities from locating in the US, much of this research has narrowly focused on determining which sociodemographic groups are disproportionately impacted by environmental hazards. Specifically, effort has centered on identifying which variable, class or race, is the root cause of environmental inequities. Although this narrow focus may have had positive movement and legal implications, the methods used are rife with unacknowledged caveats. Most critically, the implicit relationship assumed by EJ researchers is that proximity to a hazardous waste site is a measure of exposure to harmful chemicals. Few EJ researchers, however, explicitly address the methodological challenge of measuring the causal relationship between toxic chemical exposure and health problems (Brulle and Pellow, 2006). To better understand the arduous methodological task of moving beyond the proximity-exposure assumption, we briefly outline and critique the three most commonly used quantitative methodological approaches in EJ research—unit-hazard coincidence, distance-based, and geographic plume methods.[1]

A majority of national studies use the *unit-hazard coincidence method* (UHC) to assess the relationship between sociodemographic characteristics and environmental inequities (Anderton et al., 1997; Been, 1994; Davidson and Anderton, 2000; Goldman and Fitton, 1994; Hamilton, 1995; Hird, 1993; UCC/CRJ, 1987; Zimmerman, 1993, 1994). The UHC method, sometimes referred to as the spatial coincidence method, involves the selection of pre-defined geographic units of analysis, such as census tracts or zip codes, and the identification of units containing the hazard (McMaster et al., 1997; Mohai and Saha, 2003). Once the hazard is identified, indicated by the black dots in Fig. 1, the "host" unit's sociodemographic characteristics are compared to that of the non-host units (Mohai and Saha, 2003). If statistically significant sociodemographic differences exist, e.g., the household income of those living in host units are lower than in non-host units, then it is implicitly assumed that low-income people are disproportionately exposed to hazards.

[1] The discussion and critique of the unit-hazard coincidence and distance-based methods were partially drawn from the work of Mohai and Saha (2003).

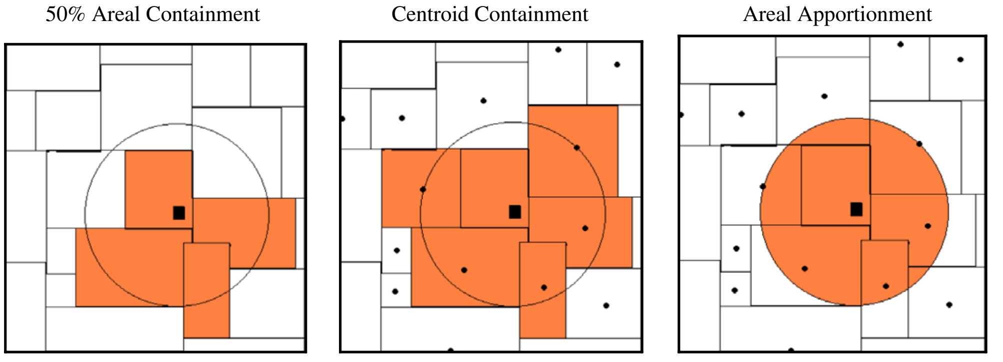

Fig. 2. Distance-based methods.

Given the unit of analysis, the researcher has no choice but to assume that everyone living within host units (shaded areas in Fig. 1) have been equally exposed to the hazard, while those in the non-host units have not been exposed at all. Thus, the assumption is "that populations in large host units necessarily live as near to the potential environmental hazard or locally unwanted land uses under investigation as populations in small host-units" (Mohai and Saha, 2003, p. 5). Furthermore, this method does not take into account the exact geographic location of the hazard within the host unit or the spatial distribution of sociodemographic variation within the host and non-host units (McMaster et al., 1997; Mohai and Saha, 2003).[2]

The three *distance-based methods* of analysis, illustrated in Fig. 2, also rely on pre-defined geographic units of analysis. The large black square in each figure represents the location of the hazard. Those individuals who live within the shaded areas of each figure are treated by the researcher as exposed to the hazard, those outside the shaded areas have not been exposed. In contrast to the unit-hazard coincidence method, these methods identify the exact location of the hazard (Mohai and Saha, 2003). Based on a reanalysis of data used in a leading national study (Been, 1995; Been and Gupta, 1997), Mohai and Saha (2005) empirically demonstrate that distance-based methods provide a more rigorous measure of proximity than the unit-hazard coincidence method.

In previous studies, the radial proximity was somewhat arbitrarily pre-defined by the researcher, resulting in concentric circles as a measure of assumed exposure (Downey, 2003; Hamilton and Viscusi, 1999; Mohai and Saha, 2005; Pastor et al., 2001; Pollack and Vittas, 1995). By relying on concentric circles, the distance-based methods assume that contamination radiates equally and evenly from the point source, falsely treating the relationship between the degree of exposure and proximity, in any direction, as linear. Not surprisingly, research has found that contamination does not radiate evenly outward from

[2] In Cancer Alley, an area along the Mississippi River between Baton Rouge and New Orleans (LA), evidence suggests that blacks are more likely than whites to live literally right next to the petrochemical industries (Roberts and Toffolon-Weiss, 2001). One reason for this pattern is that with few options after slavery was abolished, former slaves continued to work on the plantations as wage laborers or sharecroppers. Nearly a century later, these plantations, as large tracts of inexpensive land next to the Mississippi River, became ideal locations for petrochemical industries. In many cases, descendants of former slaves continue to live around the perimeter of the petrochemical plants (Roberts and Toffolon-Weiss, 2001).

the point source, but is the result of exposure pathways determined by the unique geological, hydrological, and meteorological characteristics of the local environment (Chakraborty and Armstrong, 1995, 1997; Edelstein and Wandersman, 1987).

To account for site-specific characteristics, researchers have developed a *plume-based method* to identify contaminated areas (Chakraborty and Armstrong, 1997). In contrast to the UHC and distance-based methods, the plume-based method (see Fig. 3) is not based on pre-defined geographic units or concentric circles. The plume-based methods, based on estimated exposure pathways and site-specific characteristics, dichotomizes the study area into "exposed" or "not exposed" (Chakraborty and Armstrong, 1995, 1997). There are at least 187 different computer models used by various government and private agencies, including the EPA and Department of Energy, to inform cleanup decision-making at hazardous and radioactive waste sites (Moskowitz et al., 1995). Since the parameters of distinguishing between exposed and not exposed are defined by site-specific characteristics, the plume-based method is more methodologically sophisticated than the UHC and distance-based methods. However, if the primary research focus is on health outcomes, an approach more rigorous than the plume-based method would estimate the degree of exposure and accumulated exposure over time.

Ultimately, the implicit goal of each of the three methods are to measure exposure to toxic chemicals, but the methods used are weakened by many problematic assumptions. While the distance-based methods are an improvement on UHC, and the plume-based methods are an improvement on both, there are still significant problems for understanding exposure patterns. Biophysical variables, such as air quality and toxic emissions, have only been considered by researchers in a limited capacity (Bowen et al., 1995; Chakraborty and Armstrong, 1997; Freeman, 1972). If one of the goals of EJ research is to assist those living in contaminated communities, we must develop models of physical health and psychological well-being which include biophysical variables in the analysis. The continued omission of biophysical variables results in disciplinary-specific and under-specified models. This argument is supported by the United Church of Christ's Commission on Racial

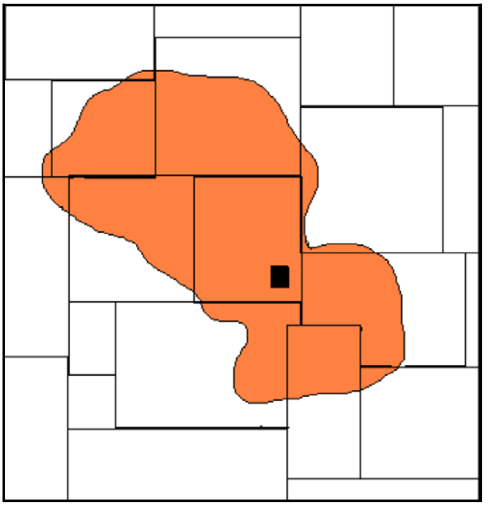

Fig. 3. Geographic plume analysis.

Justice's (UCC/CRJ) report on toxic waste which recommended the consideration of physical characteristics, such as groundwater, soil, and topography, in case studies of individual facilities (UCC/CRJ, 1987).

It is worth noting that while EJ researchers have failed to examine the effects of hazardous waste sites on human health, this relationship is often the primary focus of toxicologists and epidemiologists working in the areas of public and environmental health. Despite this focus, efforts to assess human health hazards due to chemical exposure is attenuated by a lack of exposure data (De Rosa, 2003). Measurement issues are even more daunting considering that humans with health problems have typically been exposed to multiple chemicals via multiple pathways (Teuschler and Hertzberg, 1995).

For example, the Agency for Toxic Substances and Disease Registry (ATSDR), the principal federal agency in the United States involved with hazardous substances and public health, prioritized a list of 275 hazardous substances identified at hazardous waste sites and found 100 or more toxic chemicals at a single waste site (De Rosa et al., 1996). As such, ATSDR and toxicologists began to focus on exposure to chemical mixtures and health outcomes (De Rosa et al., 1996; Eide, 1996; Teuschler and Hertzberg, 1995). Based on a review and summary of 50 studies, Vrijheid notes that "... epidemiologic studies have based the assessment of exposure to landfills mainly on surrogate measures such as residence in an area close to a waste site or distance of residence from a waste site" (2000, p. 104). In short, even with a central focus on hazardous waste sites and human health, toxicologists and epidemiologists have difficulty establishing, with any certainty, causal relationships between chemical exposure and health problems.

In this research, the case study is a municipal waste incinerator and the study area is not defined by extant political boundaries (i.e., census tracts, ZIP codes, etc.), but rather the parameters of the geographic plume are determined by an ash deposition model. We integrate biophysical data and geocoded health and social survey data to develop an interdisciplinary model of psychological well-being and physical health. Rather than create a dichotomous "composite footprint" of the dispersion of the contamination, we operationalize toxic exposure variables at the interval-level. Finally, this research supplements site-specific, qualitative EJ studies (Russell, 1989; Stults, 1988; UCC/CRJ, 1987), but also with a focus on developing a methodological approach that can be used to evaluate exposure patterns and health issues in other contaminated communities.

3. History of the Wingate community

Seminal research on environmental justice, the UCC/CRJ's report on Toxic Waste and Race (1987), identified Fort Lauderdale as one of 50 metropolitan areas in the United States with African-Americans living in communities with uncontrolled (unregulated) toxic waste sites. Furthermore, when ranked by racial inequities, the city was sixth with 97% of African-Americans living in a community with uncontrolled toxic waste sites compared to 46.2% for Whites (UCC/CRJ, 1987, p. 57). This research focuses on one of these toxic waste sites—the Wingate Road Municipal Incinerator and Landfill (EPA, 1996, ID: FLD981021470).

In 1951, the City of Fort Lauderdale purchased a 61-acre site for a new municipal incinerator and landfill. The site, located northwest of downtown Fort Lauderdale, is five miles from the coast and less than one mile from an interstate highway (I-95). Because the National Environmental Protection Act (1969) and the Clean Air Act (1970) were not passed until after the two incinerators were constructed and began operation, there were no regulatory limits or restrictions on the amount of particulate matter and pollutants that could be released into the air. The incinerators began operating in 1954 and closed in 1978 due to violations of the Clean Air Act (1970). Also, during this period, medical and industrial waste were not separated from municipal waste. In 24 years of operation, the incinerators burned somewhere between 410 and 560 tons per day and emitted at least 300 tons of particulate (ash) annually (Rogers and Reynolds, 2002). The waste from over 1500 businesses, including large petroleum and chemical industries, was delivered by truck and incinerated on site. At the time, no laws or regulations prohibited the disposal of hazardous waste into the landfill. Up until the late 1970s, hazardous waste was "discarded without consideration of the danger they posed" (UCC/CRJ, 1987, p. 3).

After 1986, the site was leased to Production Central Inc., a film production company where scenes from movies, such as Cape Fear and Speed 2, were filmed on the site. The overgrown, dense vegetation and deteriorating buildings on site often became a playground for local children. As it had been used over the past 50 years, Rock Pit Lake, a burrow pit and former percolation pond located on the southeast corner of the property, continued to be used as a regular swimming and fishing area for local children and adults alike.

In 1989, the site was placed on the Environmental Protection Agency's (EPA) National Priorities List, a list ranking contaminated sites in the Superfund program. In 1996, the EPA's Record of Decision assessment of the site stated the "actual or threatened releases of hazardous substances from this site may present an imminent and substantial endangerment to public health, welfare, or the environment" (1996, p. 2). The EPA identified 33 companies as Principle Responsible Parties. Clean up and remedial action efforts were delayed as a result of pending investigations, environmental sampling and analyses of the site. The final results of the environmental sampling found known toxic and carcinogenic contaminants (such as, benzene, dioxin, lead, mercury, and arsenic) in the soil and water samples on site and in Rock Pit Lake (EPA, 1996). Additional private soil sampling of the local community found dioxin and furan levels above recommended EPA levels (Stephens, 2001). In 2002, the recommended remedial action was completed with the contaminated landfill material placed under a single-layer synthetic cap, referred to as "Cancer Mountain" by residents (Lewis, 2002).

4. Methods

4.1. Data collection

4.1.1. Social and health data

Household selection was based on three spatial criteria: proximity to the site, location within the Wingate community, and likely exposure patterns defined by the ash deposition model (see below).[3] Members of the research team went door-to-door asking residents to

[3] Ideally, the parameters of the study area would be based on the dispersion of airborne particulate matter as determined by the ash deposition model. The population would be all individuals that live within the study area. The sample would be comprised of randomly selected households that are both spatially representative of and uniformly distributed within the study area. Contingent on the number of households within the study area, sampling could be proportionately stratified by block or some other spatially defined grid pattern. These techniques were not used in our study because the health and social survey was designed, and implemented before funding was made available to use geographic information systems as a means of integrating the survey and biophysical data.

come into the local legal aid office to fill out the Wingate Health and Social Survey. Trained professionals proctored the self-administered survey to 132 residents over a 3-day period during April 2003. Following this initial data collection, researchers again went door-to-door to supplement the number of completed surveys. An additional 91 surveys were completed over the next 6 months, bringing the total completed surveys to 223.[4] Most respondents lived within approximately 2.5 miles of the site. Since the sample is non-random, the results cannot be generalized beyond the respondents who completed the survey and the response rate cannot be calculated.

Following earlier research, geographic coordinates (latitude and longitude) for current and all previous residential addresses were geocoded and integrated with ash deposition data in Geographic Information Systems (GIS) software to determine individual-level estimates of relative exposure intensity (see, for example, Brody et al., 2002; Swartz et al., 2003). A line-centre method was used, where the addresses of survey respondents correspond to a point on a line which represents the center of the street in front of their house (Ratcliffe, 2002). As exposure is based on geocoding the respondents' residence(s), this estimate is subject to measurement error contingent on the accuracy of respondents reporting their residential history. The residential histories of the respondents ranged from 0 to 72 years.

4.1.2. Exposure data

The environmental hazard in this case-study is a municipal waste incinerator (MWI). We assume that the ash and landfill associated with municipal waste incineration in the Wingate community is toxic based on the findings in previous research and the rulings of the United States Supreme Court (Johannssen, 1996). MWI ash has been found to contain dioxin, furan, PCBs, lead, zinc, iron, sodium chloride, and potassium chloride (Inoue, 2001; Matzing et al., 2001). The dioxins, furans, and PCBs are known by-products of the incineration process itself and found in the fly ash produced by MWIs (Inoue, 2001; Till et al., 1997). Also, we assume, along with others, that the location of a respondent's house in the ash deposition model and the number of years they lived in the house is a proxy measure of that respondent's exposure to toxins (Brody et al., 2002; Swartz et al., 2003; Vine et al., 1997).

The Florida's Department of Environmental Protection (FDEP) ash deposition model for the Wingate site, re-examined by Egan Environmental, Inc., was used to estimate potential exposure to toxins. The model estimates the amount of particulate (fly ash) emitted from an incinerator's stacks (point source) based on various factors including, but not limited to, long-term average weather conditions, incinerator location and feed rates. The computer simulation model consists of 1600 points placed at 100 m intervals in a 40×40 grid around the incinerator site. The model provides estimated levels of deposition in unit grams per square meter for each point. The deposition levels were divided into ten equal

[4] We acknowledge the potential for a self-selection bias. It is likely that the people who would take the time to come into the legal aid clinic and fill out the survey would have more health problems than those who did not come into the clinic. Surprisingly, we found no significant physical health differences between those who completed the survey at the clinic and those who completed the survey at home. However, those who completed the survey at the clinic were significantly less depressed and stressed than those who completed the survey at home. Perhaps this suggests that the residents of Wingate have more mental health problems than the survey respondents.

intervals. Because the ash deposition level of the model was calculated in g/m^2 for a period of 8 years, the ash deposition value was divided by 8 to determine the average annual level of deposition.

As presented in Fig. 4, we overlayed the geocoded household addresses and the ash deposition model to estimate an annual level of deposition for each household (the large dot represents the incinerators and smaller dots represent households). The outer circle is 3 miles from the site. Higher levels of deposition (the darker shaded areas) occurred in areas to the west and northwest, as well as the southeast. The deposition patterns are the result of the southeast trade winds and various low-pressure systems that impact the area in the winter and spring.

In order to estimate respondent exposure, we multiplied the average annual level of deposition for each household by the number of years lived at that household. If the respondent lived in multiple locations, we summed these values for each respondent-household to get the cumulative weighted ash deposition for each respondent. In Eq. (1), Y_n = years of residence at each location, and X_n = estimated average annual level of ash deposition (g/m^2) at each location.

$$\begin{aligned}&\text{Respondent Cumulative Ash Deposition}\\&\quad = (Y_1 * (X_1/8)) + (Y_2 * (X_2/8)) + (Y_3 * (X_3/8)). \qquad (1)\end{aligned}$$

As discussed earlier, this study is more rigorous than the plume-based method, because exposure is operationalized as an interval-level variable. Values for the cumulative ash deposition variable ranged from 0 to 134.

We also used GIS to estimate exposure based on household proximity to the incinerator site. As noted in the literature review, proximity, as a measure of exposure, is crude and less rigorous than estimated exposure based on cumulative ash deposition. However, we include this measure to empirically test the proximity-exposure assumption and because other aspects of proximity (e.g., odors, views of the landfill, and walking distance to lakes

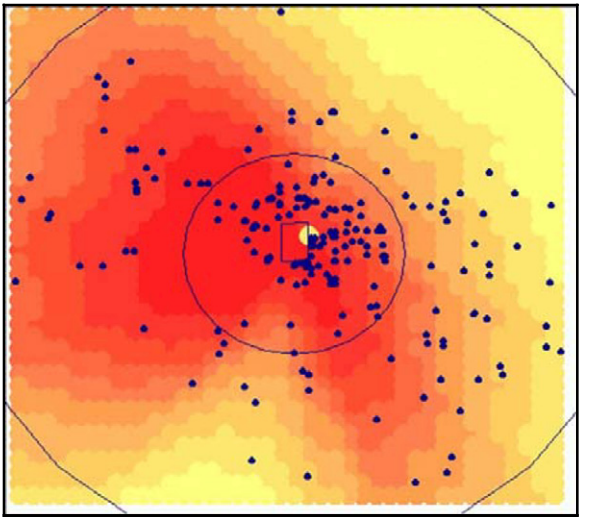

Fig. 4. Ash deposition model with geocoded household addresses.

for swimming and fishing) may have an influence on physical health and psychological well-being. Also, in contrast to earlier research, we measure a person's proximity over time and at multiple locations. The average radial proximity (in miles) was determined using the exact spherical distance between the geographic coordinates of the respondent's household(s) and the incinerators (point source).[5] If the proximity-exposure assumption is valid, then as the distance between the respondent's household and the site increases, exposure decreases. As such, the inverse of the distance from the household to the site was multiplied by the years of residence at that household. This was repeated for each household and the totals were summed to represent a cumulative weighted distance. The weighted proximity for each respondent ranged from 0 to 484, with higher numbers equal to increasing levels of exposure. We hypothesize that cumulative weighted proximity will not be significantly related to physical health and psychological well-being.

4.2. Measures

4.2.1. Sociodemographic and lifestyle variables

Four sociodemographic variables (age, education, income, and gender) and one lifestyle variable (smoke cigarettes) will be included in the multivariate analyses. The response set for the education variable ranged from 1 = less than high school degree and 9 = advanced professional degree. The response set for annual household income ranged from 1 = less than \$10,000 to 7 = over \$60,000.

4.2.2. Exposure variables

For the exposure and psychological well-being measures, we used maximum likelihood factor analysis with varimax rotation to confirm the dimensionality of selected scales. Unless noted otherwise, simple additive scales were used to create variables which will be used in the multivariate analyses. We found a unidimensional factor structure underlying the six questions measuring perceived exposure and health problems stemming from living in the Wingate community (see Section 5 for question wording). The single factor (eigenvalue = 3.58) explained 59.6% of the total variance. Since the factor loadings varied significantly (from .520 to .921), we saved this dimension as a regression factor score to be used in the multivariate analyses. Also, we asked respondents if they consumed fish caught at the two on-site lakes. Airborne ash was deposited on the surface of both lakes during the 24 years of incinerator operation and, before being capped in 2002, some of the stormwater percolating through the landfill would drain into the lakes. We created a variable "local fish consumption" and assigned a value of 2 if the respondent consumed fish caught from both lakes, a value of 1 if they consumed fish caught from one of the two lakes, and 0 if they had not consumed fish caught from either lake.

A person living in the Wingate community during the years of incinerator operation (1954–1978) may have been directly exposed to airborne ash and particulate matter. Since we have the number of years lived at each residence, but not the exact dates, we are unable

[5] Spherical distance refers to the distance between two spherical coordinates of latitude and longitude. In this case, the coordinates are those for the site and the respondent's geocoded address of residence. This method of measurement takes into consideration the curvature of the earth, which is different from determining the distance between two points in a planar coordinate systems, which assumes the coordinates are placed on a Cartesian ($x - y$ axis) plane.

estimate the respondent's direct exposure to ash. Rather, we use the respondent's cumulative weighted ash deposition to estimate indirect exposure through soil, food, and well water. Respondents were asked if they drank well water and if they grew vegetables. The heavier the ash deposition, the more likely the respondent would be exposed to contaminants from drinking well water (ingestion), gardening (soil contact), and eating home-grown vegetables (ingestion). As such, we multiplied the respondent's cumulative weighted ash deposition by the dichotomous (0 = no, 1 = yes) variables of drinking well water and growing vegetables to create two interval-level objective exposure variables. Finally, we included the cumulative weighted proximity variable in the multivariate analyses.

4.2.3. Psychological well-being

Psychological well-being was operationalized utilizing two scales—the Impact of Events Scale (IES) and the Depression Scale. The IES is comprised of sixteen items, measuring two subscales—stress avoidance and intrusive stress (see Horowitz et al., 1979).[6] The respondents were asked to "... please indicate how often it was true for you in terms of the contamination in your neighborhood as it relates to the Wingate Landfill and Incinerator during the past week or 7 days." For each question, the respondent indicated whether a specific intrusive recollection occurred "not at all," "rarely," "sometimes," or "often." The eigenvalues (7.14, 1.81) and the factor loadings indicate two underlying dimensions, with the first dimension measuring stress avoidance (31.3% of total variance; Cronbach's $\alpha = .89$) and the second measuring intrusive stress (14.0% of the total variance; Cronbach's $\alpha = .90$). Since the factor loadings varied significantly for stress avoidance (from .480 to .726) and intrusive stress (.511 to .877), we saved these dimensions as regression factor scores. The IES has been found to be correlated with clinical diagnoses of post-traumatic stress disorder and other stress-related illness (Baum and Fleming, 1993).

The Depression Scale is a modified and shortened version of the scale created by the Center for Epidemiologic Studies Depression (CES-D). Introduced in 1977, the scale is designed to measure the current level of depressive symptomology (Radloff, 1977). We found a unidimensional factor structure underlying the CES-D items. Given the strength and relative equivalency of the factor loadings (.690 to .833; Cronbach's $\alpha = .93$), the Depression variable was created as a simple additive scale. The IES and CES-D scales have been used extensively in previous research and have been found to be reliable measures of psychological well-being (Horowitz et al., 1979; Picou and Gill, 1996; Picou et al., 2004; Shore et al., 1989; Solomon, 1989).

4.2.4. Physical health

Physical health was measured by asking respondents if they had been diagnosed (by a physician) with eight symptoms and whether or not they had 23 undiagnosed symptoms.

[6] The Impact of Events Scale (IES) was originally designed to measure stress associated with experiencing a single traumatic event (Horowitz et al., 1979). However, the IES has been used as a measure of stress associated with a traumatic event whose effects are ongoing, such as the *Exxon Valdez* Oil Spill in Prince William Sound, Alaska (see Marshall et al., 2004; Picou and Gill, 1996; Picou et al., 2004). In addition, the IES has been used to measure psychological stress associated with long-term residence in a contaminated neighborhood (Gill and Picou, 1998). The Wingate community did not experience a single traumatic event, but did experience 24 years of ash falling from the sky and chronic exposure to toxic chemicals. Also, the landfill, declared a Superfund site by EPA, is highly visible and a constant reminder of early incidences of falling ash and contamination.

We coded these questions as follows: 0 = no, 1 = yes. By summing the set of diagnosed and undiagnosed symptoms, we created two physical health variables. While both variables are measures of physical health, symptoms diagnosed by a doctor is arguably more objective than undiagnosed symptoms.

5. Results

In this section, we present the results of univariate, bivariate, and multivariate analyses. Respondent ages ranged from 19 to 84, with a mean age of 51 years old. Over one quarter (26.9%) of the respondents had less than a high school degree and few (7.6%) were college graduates. Approximately one-third of the respondents had an annual household income of less than $10,000 (31.4%), $10,000 to $30,000 (36.3%), or over $30,000 (32.3%). Over two-thirds (70.4%) of the respondents were women and one-third (34.1%) smoked cigarettes or used tobacco products.

Perceived exposure questions gauged the level to which respondents felt they had been exposed to health-threatening chemicals from the Wingate Incinerator and Landfill. The response set for the six questions was a 5-point likert scale (strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree). Approximately half of the respondents "strongly agreed" with each of the following statements: "I believe my home and personal property were exposed to health-threatening chemicals because of the Wingate Incinerator and Landfill" (55.8%); "I believe I was exposed to health-threatening chemicals from the Wingate Incinerator and Landfill" (54.3%); "Because I have lived in the Wingate community, I have an increased chance of getting cancer" (45.3%); "Because I have lived in the Wingate community, I have been exposed to dangerous levels of health-threatening chemicals" (46.2%); and "Because I have lived in the Wingate community, I worry a lot about my future health" (53.4%). Just over one-third of the respondents "strongly agreed" with the statement that "Because I have lived in the Wingate community, my friends from outside my neighborhood are think that my has been exposed to dangerous chemicals" (34.1%).

Questions regarding drinking well water, growing own vegetables, and the consumption of fish caught at the two on-site lakes were used to measure likely exposure pathways. Nearly half of the respondents indicated that they had consumed well-water (45.7%) and grew their own vegetables (43.2%). Almost half (48.0%) of the respondents had not consumed fish caught in either of the lakes and just over one-fourth had eaten fish caught in one of the two lakes (26.5%), or both lakes (25.6%).

Respondents were asked if they had been diagnosed by a doctor with eight conditions. The diagnosed symptoms that follow are ordered from highest to lowest frequency (% yes): irregular heartbeat (35.9%), bronchitis (29.6%), anemia (26.0%), diabetes (25.6%), asthma (24.2%), other skin conditions (18.4%), cancer (12.6%), and chloracne (3.6%). Compared to African-American adults nationally (NHIS, 1998), respondents have been diagnosed with considerably higher rates of irregular heartbeat, anemia, diabetes, asthma, other skin conditions, and cancer.[7]

[7] The 1998 national average prevalence rates for African-American adults were generated by the National Health Interview Survey, an annual project of the CDC National Center for Health Statistics. Also, Barker (1999) compared the incidence rates (per 1000 residents) of cancer in the Wingate community to a control community. The study found, compared to the control community, that Wingate residents had elevated levels of liver cancer (36.5 vs. 6.6), leukemia (53.6 vs. 14.1), and bone cancer (54.1 vs. 16.0).

Table 1
Physical health hierarchically regressed on sociodemographic, exposure, and psychological well-being variables

Independent variables	Physical health	
	Diagnosed symptoms	Undiagnosed symptoms
Age	.021 (.190)[c]	.016 (.036)
Education	−.027 (−.038)	−.449 (−.156)[b]
Income	.027 (.027)	−.057 (−.018)
Gender	−.101 (−.029)	.949 (.069)
Smoke cigarettes	−.014 (−.004)	−.147 (−.011)
Perceived exposure	.049 (.031)	1.178 (.184)[c]
Drink well water	.005 (.123)[a]	.005 (.028)
Eat garden vegetables	.001 (.109)	.006 (.040)
Local fish consumption	.396 (.208)[c]	1.511 (.197)[c]
Proximity	−.001 (−.058)	−.009 (−.102)
Depression	.024 (.305)[d]	.116 (.367)[d]
Intrusive stress	−.187 (.116)	.057 (.009)
Stress avoidance	.031 (.018)	−.403 (−.059)
Constant	−0.327	5.657[b]
R^2	0.233	0.362
F	4.092[d]	7.623[d]
N	188	188

Notes. Main cell entries are unstandardized regression coefficients; parenthetical entries are un-standardized regression coefficients.
[a] Significant at the $p < .10$ level.
[b] Significant at the $p < .05$ level.
[c] Significant at the $p < .01$ level.
[d] Significant at the $p < .001$ level.

Also, respondents were asked about 23 undiagnosed symptoms which are ranked as follows (% yes): headache (68.6%), muscle aches and pains (63.7%), blurred vision (59.6%), soreness of joints (58.7%), numbness in figure and toes (55.6%), difficulty in sleeping (54.3%), coughing (53.4%), sneezing (53.4%), excessive tiredness (52.5%), burning eyes (51.1%), eyesight problems (48.0%), nausea (46.2%), runny nose (42.6%), psychological problems (42.2%), excess tearing of the eyes (41.7%), difficulty in concentration (41.3%), burning throat (37.7%), respiratory problems (37.2%), digestive problems (29.1%), diarrhea (27.4%), reproductive problems (25.1%), kidney problems (17.0%), and liver problems (8.5%). On average, respondents reported two diagnosed and nine undiagnosed symptoms.

Main cell entries in Tables 1 and 2 are unstandardized regression coefficients; the parenthetical entries are standardized regression coefficients. The two physical health variables were regressed on the sociodemographic, exposure, and psychological well-being variables.[8] The diagnosed symptoms model presented in Table 1 is statistically significant

[8] Because the present study does not use randomly sampled data, significance tests are not appropriate for inferential analysis. However, significance is reported here as an arbitrary criterion in deference to its widespread use in social science for exploratory analysis of non-random data. We also consider variables significant at the $p < .10$ level, an acceptable practice in exploratory research.

Table 2
Psychological well-being hierarchically regressed on sociodemographic, exposure, and physical health variables

Independent variables	Psychological well-being		
	Depression	Intrusive stress	Stress avoidance
Age	−.216 (−.156)[b]	.008 (.118)	.003 (.043)
Education	−.166 (−.019)	.033 (.076)	−.039 (−.092)
Income	−1.521 (−.152)[b]	.043 (.087)	−.043 (−.092)
Gender	.893 (.021)	−.059 (−.028)	.252 (.124)[a]
Smoke cigarettes	−2.142 (−.053)	−.197 (−.099)	−.062 (−.032)
Perceived exposure	−.071 (−.004)	−.029 (−.030)	.206 (.219)[c]
Drink well water	.016 (.034)	.000 (.005)	−.001 (−.026)
Eat garden vegetables	.023 (.048)	−.001 (−.036)	.003 (.132)[a]
Local fish consumption	1.591 (.069)	.256 (.219)[c]	.040 (.035)
Proximity	.010 (.037)	.000 (−.033)	−.001 (−.098)
Diagnosed symptoms	1.322 (.107)	−.081 (−.132)	.062 (.105)
Undiagnosed symptoms	1.078 (.339)[d]	.029(.188)[b]	.003 (.024)
Constant	31.671[d]	−0.841	−0.226
R^2	0.275	0.097	0.198
F	6.443[d]	1.57	3.632[d]
N	216	188	188

Notes. Main cell entries are unstandardized regression coefficients; parenthetical entries are un-standardized regression coefficients.

[a] Significant at the $p < .10$ level.
[b] Significant at the $p < .05$ level.
[c] Significant at the $p < .01$ level.
[d] significant at the $p < .001$ level.

and the linear combination of the independent variables account for 23.3% of the variance ($R^2 = .233$, $F(13, 188) = 4.092$, $p < .001$). Four of the independent variables were significant predictors of diagnosed symptoms. Specifically, people who were older, drank well water in areas with heavier ash deposition, consumed fish from on-site lakes, and were depressed were more likely to be diagnosed with symptoms. Relative to the other variables, depression was the strongest predictor of diagnosed symptoms, followed by eat fish from on-site lakes, age and drink well water.

The undiagnosed symptoms model was statistically significant and considerably stronger than the diagnosed symptoms model, with the set of independent variables explaining 36.2% of the variance ($R^2 = .362$, $F(13, 188) = 7.623$, $p < .001$). The results indicate that people who were less educated, perceived that they had been exposed to health-threatening chemicals, consumed fish from on-site lakes and suffered from depression had more undiagnosed symptoms. Similar to diagnosed conditions model, depression was the strongest predictor of physical health problems associated with undiagnosed symptoms.

Three psychological well-being variables were regressed on the sociodemographic, exposure, and physical health variables. The depression model presented in Table 2 was statistically significant and the independent variables account for 27.5% of the variance ($R^2 = .275$, $F(12, 216) = 6.443$, $p < .001$). Three of the variables were significant predictors of depression. Specifically, people who were younger, had lower household incomes and had more undiagnosed symptoms were more likely to be depressed. Of the three significant variables, the number of undiagnosed symptoms was the strongest predictor of depression.

The intrusive stress model presented in Table 2 is not statistically significant ($R^2 = .097$, $F(13, 188) = 1.570$). The stress avoidance model was considerably stronger than the intrusive stress model, resulting in three statistically significant independent variables which explained 19.8% of the variance ($R^2 = .198$, $F(12, 189) = 3.632$, $p < .001$). Specifically, females, people who perceived they had been exposed to health-threatening chemicals and had eaten vegetables from their garden had higher levels of stress avoidance. Perceived exposure was the strongest predictor of stress avoidance.

6. Discussion and conclusion

Lower mortality, morbidity, and disability rates for people with higher levels of socioeconomic status is a strong and consistent finding in epidemiological research (Institute of Medicine, 2001). Surprisingly, with two exceptions, educational, and household income differences were not strong predictors of physical health or psychological well-being. Less educated respondents reported having more undiagnosed symptoms than more educated respondents. Since education and the exposure variables were not significantly related, it is unlikely that less educated respondents were more exposed to contaminated (at least, not through the exposure pathways identified in this research). Education was strongly related to household income (Pearson's $r = .566$, $p < .001$) and moderately related to smoking cigarettes ($r = -.196$, $p < .01$). Perhaps less-educated respondents had more undiagnosed symptoms because they were less likely to have health insurance and more likely to eat unhealthy foods, smoke cigarettes, and/or make other unhealthy lifestyle choices. Respondents living in low-income households had more problems with depression than those in higher-income households. Low household income may be related to many factors that lead to depression—such as, difficulty in making rent or mortgage payments, working in an unrewarding job, job insecurity, less access to health care, dependence on social welfare, etc.

Arguably, diagnosed symptoms is a more objective measure of physical health than undiagnosed symptoms. Yet, if someone reports having no diagnosed and many undiagnosed symptoms, this could be because they don't have health insurance and/or simply avoid visiting a doctor. Older respondents were more likely to have health problems diagnosed by a doctor, but did not have significantly more undiagnosed symptoms. Access to medicare and/or medicaid may be a factor. Counter-intuitively, we found that younger respondents had higher levels of depression than older respondents. It is possible that as respondents age they came to accept the fact that they live in a contaminated community or they had a longer time to develop coping mechanisms. Perhaps older respondents with health insurance were more likely to take prescription anti-depressants, whereas younger people were more likely to self-medicate with recreational drugs that only provides temporary relief.

Finally, we found that women exhibited higher levels of stress avoidance than men. There is evidence that women, compared to men, have heightened perceptions of risk because they are more concerned about the health and safety of both family and community (Davidson and Freudenberg, 1996; Marshall, 2004). As such, heightened risk perceptions may lead women to avoid the stress associated with contamination in Wingate. In this case, stress avoidance may served as a coping mechanism.

Respondents who consumed fish from Rock Pit Lake and Lake Stupid had more diagnosed and undiagnosed symptoms than those who did not. Water samples indicated that

Rock Pit Lake is contaminated with toxic and carcinogenic chemicals (EPA, 1996). Furthermore, fish consumption was the strongest predictor of physical health. The consumption of contaminated fish is an important area for future research, especially considering EPA's recent focus on health problems associated with mercury contamination of fish (http://www.epa.gov/mercury) and that minorities are more likely to catch fish for consumptive purposes (Beehler et al., 2001; Toth and Brown, 1997).

Perceived exposure to health-threatening contaminants was a significant predictor of undiagnosed symptoms, but not diagnosed symptoms. This finding lends support to the suggestion that undiagnosed symptoms are a more subjective measure of physical health than diagnosed symptoms. Essentially, whether a doctor diagnoses a respondent with a particular condition is not effected by the respondent's perceived exposure. Perceived exposure was also the strongest predictor of stress avoidance. Respondents who feel that they had been exposed to health-threatening chemicals from the Wingate Incinerator and Landfill were more likely to avoid thinking about the site and contamination.

The relationship between mental and physical health is complex and reciprocal. With the widespread acceptance of the "biopsychosocial model," the medical community has acknowledged that physical health is affected by social and psychological, as well as biological, factors (Marelich and Erger, 2004, p. 11). Furthermore, the prevailing view is that "most psychosomatic diseases involve various genetic and environmental determinants, and all states of health and disease are influenced to some extent by psychosocial conditions" (Institute of Medicine, 2001, p. 138). Our results empirically validate this prevailing view. We found that depression was the strongest predictor of diagnosed and undiagnosed symptoms, and, in turn, undiagnosed symptoms was the strongest predictor of depression.

In conclusion, the empirical contribution of this research is twofold. First, EJ researchers utilizing the unit-hazard coincidence or distance-based methods implicitly assume that proximity to the toxic facility is a measure of exposure to contaminants, which subsequently leads to health problems. We provide an empirical test of this assumption. Compared to existing EJ research, we develop a more rigorous measure of proximity—the respondent's household (multiple) distance from the point source during the time period in which they lived in the community. Since the proximity variable was not significant in any of the five health models, we do not find empirical support for the proximity-exposure assumption. Furthermore, the ash deposition model (Fig. 4) also undermines the face validity of this assumption, as it is clear that airborne ash did not disperse evenly from the point source in all directions. Exposure patterns are based on the properties of the contaminant and the unique geological, hydrological, and meteorological characteristics of the biophysical environment.

Second, we found evidence that the objective measures of exposure, based on the respondent's cumulative weighted ash deposition and selected exposure pathways, were significant predictors of health. Respondents who drank well water in areas with heavy ash deposition were more likely to have diagnosed symptoms than those who did not drink well water or drank well water, but in areas with less ash deposition. Also, respondents who grew their own vegetables in areas with heavy ash deposition were more likely to avoid thinking about contamination in the community than those who did not grow their own vegetables or grew vegetables in areas with less ash deposition. Thus, ash deposition had an effect on respondent health indirectly through exposure pathways associated with soil, food, and well water. More importantly, 50 years after the incinerators went online and 25 years after they were shut down, respondents residing in the Wingate community were still experiencing the mental and physical health consequences of living in a contaminated community.

In our case study, we focused on a municipal waste incinerator and relied on the ash deposition as the primary source of likely exposure. However, the techniques used in this study are not limited to municipal waste incinerators or other airborne point sources of toxic exposure. For example, if contaminants are leaching into the soil from a landfill or storage tank, the researcher could generate a three-dimensional hydrogeologic model with data pertaining to the onsite water table, ground and surface water flow, and other hydraulic conditions. Also, soil samples, systematically selected within the study area to ensure spatial representativeness and uniform distribution, could be collected and tested for the presence of toxic chemicals. After geocoding soil sample site locations (using Global Positioning System units in the field) and survey respondent households, the biophysical information could then be integrated with the social and health survey data for analysis. As a result, these techniques provide an effective means of examining the spatial relationships between biophysical, social, and health-related variables.

While we applaud the work of EJ researchers for drawing national attention to the critical issue of environmental inequities, researchers should be more explicit about research assumptions and, if methodologically and financially possible, open these assumptions up to empirical examination. In this research, the significance of the objective exposure variables and insignificance of the proximity variable demonstrates the utility of integrating social, health, and biophysical data in environment justice research. Most importantly, we must use innovative and interdisciplinary approaches to address the physical and mental health problems of people living in contaminated communities. Greater understanding of the long-term effects of exposure to environmental contamination is still needed and should inform the development of more effective public policy and programs to support impacted communities. Toward this end, we hope that the exploratory socio-spatial model presented in this article will be replicated and further developed.

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