10-1-1997

Assessing the impact of segregation on environmental equity using GIS

Jayajit Chakraborty
University of Iowa

Marc P Armstrong
University of Iowa

Chakraborty, J. and Armstrong, M.P. Assessing the impact of segregation on environmental equity using GIS. Proceedings of GIS/LIS'97. Bethesda, MD: American Congress on Surveying and Mapping.

ASSESSING THE IMPACT OF SEGREGATION ON ENVIRONMENTAL EQUITY USING GIS

Jayajit Chakraborty
and
Marc P. Armstrong

Department of Geography
The University of Iowa
316 Jessup Hall
Iowa City, IA 52242

(319) 335-0153
(319) 335-2725 (fax)
jayajit-chakraborty@uiowa.edu
marc-armstrong@uiowa.edu

ABSTRACT

A considerable amount of empirical research, conducted during the last decade, has attempted to determine whether racial minorities and the economically disadvantaged are disproportionately located in neighborhoods that contain environmental hazards. Demographic studies on this subject, however, have failed to examine the effect of the intra-urban spatial distribution of various social groups and how this factor constrains the equitable distribution of hazards. The objective of this paper is to conduct a GIS-based analysis of the effect of residential segregation on environmental equity assessment. The relationship between a commonly used index of segregation and an aggregate distance-based measure of environmental equity is examined, using a stratified random sample of 15 urban counties. We specifically focus on income segregation and income inequities in the distribution of industrial toxic emission locations in these counties. The indices of segregation and equity are computed by using the analytical capabilities of GIS software and 1990 Census data at the block group level of aggregation. Our findings indicate a moderately strong negative linear association between the measures of segregation and equity.

1. INTRODUCTION

The concept of fairness in the distribution of environmental risks and hazards, commonly referred to as 'environmental equity', has been the focus of a considerable amount of empirical research in recent years. In particular, several demographic studies on environmental equity have relied on the use of GIS-based techniques to determine whether racial minorities and the economically disadvantaged are disproportionately located in neighborhoods that contain environmental hazards. Though specific methodologies have varied, the primary objective of these studies has been to establish whether the locational pattern of locally undesirable land uses (LULUs) in a study area is inequitable with respect to the racial and economic status of its population.

Given the well-documented existence of residential segregation in U.S. cities, minorities and low-income residents are not distributed uniformly across the urban landscape. The previously reported approaches, however, do not consider the intra-urban spatial arrangement of various racial and income groups and fail to examine whether this factor contributes to inequities in the distribution of environmental hazards. In a perfectly unsegregated city, where spatial clustering of specific population groups is totally absent, it is theoretically impossible to locate LULUs such that one group is closer to these hazards than others. On the other hand, if a city is segregated, the underlying spatial configuration of specific racial or income groups could be responsible for restricting the locations of LULUs in such a manner that the resulting distribution becomes inequitable. The effect of this constraint posed by urban spatial structure and its implications have not been addressed adequately in the empirical literature on environmental equity.

The purpose of this research is to analyze the effect of residential segregation on the results of environmental equity assessment. We specifically focus on segregation by income, and examine the relationship between a commonly used measure of segregation--the index of dissimilarity and an aggregated GIS-based measure of environmental equity, for a set of 15 urban areas. The next two sections of the paper focus on the measurement of residential segregation and environmental equity, respectively. The fourth section provides the details of the methodology, which is followed by a discussion of the results in section five. The final section contains our concluding comments and suggested directions for future research.

2. RESIDENTIAL SEGREGATION AND EVENNESS

Residential segregation is generally defined as the degree to which two or more groups live separately from one another, in different parts of the urban environment. Massey and Denton (1988), who provide a comprehensive review of the different definitions and measures of segregation, conceive residential segregation to be a multi-dimensional phenomenon varying along five distinct axes of measurement: evenness, exposure, concentration, centralization, and clustering. The key idea is that two groups may live apart and be 'segregated' in five different ways. The minority group may be distributed in such a way that they are overrepresented in some areas and underrepresented in others, varying on the characteristic of *evenness.* They may be spatially distributed so that their *exposure* to the majority group members is limited because they rarely share a neighborhood with the latter. They may be spatially *concentrated* within a very small area, occupying less physical space than majority members. They may be geographically *centralized,* congregating around the urban core, and occupying a more central location than the majority group. Finally, areas of minority settlement may be tightly *clustered* to form one large contiguous enclave, or be scattered widely around a city.

The aspect of segregation we focus on in this study is evenness, which involves the differential distribution of two groups among geographic units in an urban area. According to this construct, a minority group is segregated if it is unevenly distributed over geographic units in an urban area. Evenness is not measured in an absolute sense, but is scaled relative to another group. Evenness is maximized and segregation minimized when all units have the same relative number of minority and majority members as the city as a whole. Conversely, evenness is minimized, and segregation maximized when no minority and majority members share common geographic units of residence.

The index recommended by Massey and Denton (1988) for measuring evenness is the index of dissimilarity *(D),* which has been the most popular measure of segregation among geographers and sociologists since Duncan and Duncan's (1955) seminal paper on residential segregation. Several recent studies (Coulton *et al.,* 1996; Abramson *et al.,* 1995; Morrill, 1995; Massey and Eggers, 1993) have also used this index to examine income segregation in various cities of the U.S. This measure is easy to compute and interpret, and is useful for relative comparison at different geographic scales. The dissimilarity index varies between 0.0 and 1.0, and conceptually, it represents the proportion of members of the group that would have to move from one neighborhood (defined usually by census tracts or block groups) to another to achieve an even distribution, with the number of members moving being expressed as a proportion of the number that would have to move under conditions of maximum segregation. Although the *D* index was later modified to include more than two population groups (Morgan, 1975; Sakoda, 1981), it has been traditionally defined as:

$$D = \sum_{i=1}^{n} \frac{t_i |p_i - P|}{2TP(1-P)}$$

where

t_i: total population of spatial unit i

p_i: minority proportion of spatial unit i

T: total population of entire city/county

P: minority proportion of entire city/county, divided into n units.

The concepts of evenness and dissimilarity and their effect on equity can be explained with the help of two hypothetical distribution patterns of low-income

populations (Figure 1). In each urban area, the cells represent spatial units shaded on the basis of the proportion of the population below the poverty level. In city A, the poor are uniformly and evenly distributed, their proportion being similar in all spatial units in the city (D=0) and equal to the city-wide percentage. The entire population below the poverty line in city B. in contrast, is spatially concentrated on the right-hand side; none reside in the other half of the city (D=1.0).

What are the implications of these dissimilarities in the spatial arrangement of low-income populations on the results of environmental equity analysis in the two cities? Assuming that equity is measured on the basis of the populations living near locations of environmental hazards, we would always find greater inequity in city B. The uniform pattern of city A ensures equal impacts on all population groups; the proportion of poor residing near a LULU located anywhere in the city is equal to those further away. In city B. an unfair burden will be imposed on either the high-income or the low-income group, depending on which side of the city (left or right) the LULU is sited. The segregated pattern thus makes it difficult to find a location where all groups will be affected equally, constraining the achievement of environmental equity. Although scholars (e.g. Hodge and Gatrell, 1976; McLafferty, 1982; 1984) have examined the effect of urban spatial form on the equitable location of public services and facilities, the impacts of this constraining factor on the assessment of environmental justice have not been investigated.

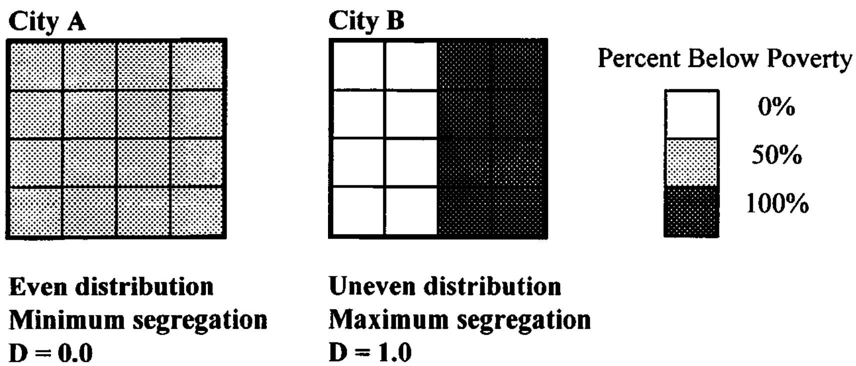

Figure 1. Two Hypothetical Examples of Urban Spatial Structure

3. THE MEASUREMENT OF ENVIRONMENTAL EQUITY

The primary focus of most empirical studies on environmental equity has been on establishing a spatial association between the locations of hazardous facilities and the racial and economic characteristics of the surrounding population, based on the assumption that proximity leads to risk. The most common approach used in this research is to estimate and compare the proportion of minority or low-income populations in geographic units that contain hazardous facilities to those that do not include such facilities, or to the proportions in the entire region, county, or state. Researchers have also used GIS to delineate the boundaries of impacted areas by aggregating census data units in the shape of a circle (e.g. Glickman and Hersh, 1995) or dispersal footprints (e.g. Chakraborty and Armstrong, 1995).

For this particular study, however, we developed a proximity-based, aggregate measure of environmental equity that allows meaningful comparison with the dissimilarity index in any study area. This index, the Spatial Index of Environmental Justice *(SIEJ), is* an indicator of the spatial association between locations of environmental hazards in a county and the proportion of low income individuals in surrounding geographic units. The index is a correlation coefficient that represents the relationship between the proportion of the population below the poverty line in geographic units (e.g. block groups) and their distances to the nearest environmental hazard (e.g. industrial toxic emission location) in a study area. It is relatively easy to implement since the analytical capabilities of a GIS can be used to determine centroids of polygons and to compute point-to-point distances. In effect,

SIEJ = correlation between (proportion below poverty in a geographic unit) *and* (distance from the centroid of a unit to the nearest TRI site).

This index, which theoretically varies from -1.0 to +1.0, will be negative in a study area where a higher proportion of low-income individuals resides nearer hazard locations, indicating the existence of environmental inequity. The index is positive where high-income residents live closer to the hazards than low-income residents.

4. RESEARCH METHODOLOGY

The objective of the methodology was to examine the relationship between segregation *(D)* and environmental equity *(SIEJ)* in selected urban counties of the U.S. Although our analysis is based on income segregation and income inequities in the distribution of toxic facilities, the same methodology can be applied to examine the association between racial segregation and racial inequities.

Locations of industrial toxic emissions from EPA's Toxic Release Inventory (TRI) database were used to represent environmental hazards. The TRI is a comprehensive data source for facilities releasing toxic substances in the U.S. and provides the latitude-longitude coordinates of each toxic release site. The data on these sites in the counties chosen for the analysis was obtained from the RTK Net's on-line copy of EPA's TRI area report for 1994 (Right-to-Know Network, 1996). The unit of analysis chosen for computing the *SIEJ* and *D* indices was the block group, the smallest geographic unit for which census income information is available. Since the *SIEJ* assumes population concentration at the centroid of an areal unit, the use of larger units (e.g. census tracts) would mask the effect of hazardous facilities on the surrounding population. Data on the economic characteristics of the population at the block group level were obtained from the 1990 Census Summary Tape File Extract 3A (Census of Population and Housing, 1990). Figure 2 summarizes the methodology for computing the two indices for a single study area. The analytical tools required for each step are available in most commercial GIS software packages.

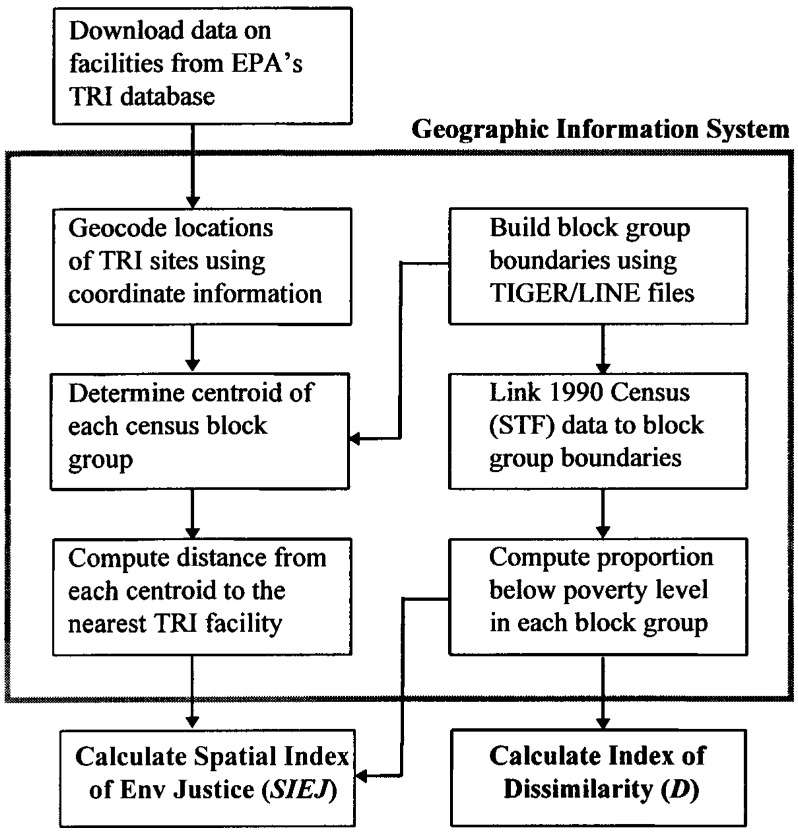

Figure 2. Methodology for Computing the Indices of Dissimilarity and Environmental Justice using GIS

Selection of Study Areas

Abramson *et al.* (1995) used census tract data to measure segregation of the poor in the 100largest metropolitan areas in the U.S. and ranked these areas on the basis of the dissimilarity index. Their results were used to choose a stratified random sample of 15 counties for our analysis. To obtain substantial variation in terms of the extent of segregation, five metropolitan areas were randomly selected from each of the three following sets based on the values of the *D* Index reported by the authors of the article:

a) high segregation ($D > 0.44$);
b) moderate segregation ($0.30 < D < 40$); and
c) low segregation ($D < 0.28$).

Though Abramson *et al.* computed *D* indices for metropolitan areas, we performed our analysis at the county-level, since county boundaries are well defined and temporally stable. In addition, several scholars (e.g. Morrill, 1995) have computed the index of dissimilarity for counties, while a majority of published environmental equity studies recommend the use of the county as the appropriate geographic scale for analyzing the distribution of hazardous facilities. Further justification for using the county was provided by a high correlation (r=0.92) between the metropolitan-level dissimilarity indices reported by Abramson *et al.*, and our county-level estimates of D, for the set of 15 areas. The unit of analysis chosen for computing the *D* index in our study was the block group, which was consistent with the census data unit used for calculating the *SIEJ.*

5. RESULTS

The results of the analyses of segregation and environmental equity in the 15 study areas are provided in Table I. All values of the *SIEJ* are found to be negative, which suggests that TRI sites are distributed inequitably with respect to low-income populations in these counties. The *D* values are found to be generally higher than the corresponding indices computed by Abramson *et al.* (1995), a likely consequence of the differences in: i) the size of study area (county vs. metropolitan area); and ii) the unit of analysis (block group vs. census tract) in the two studies. Values of segregation indices generally tend to be higher at the level with smaller areal units than at the level with larger units (Won", 1996). This is often referred to as the scale effect in the modifiable areal unit problem (MAUP) literature (Openshaw, 1984).

The values of the segregation and equity indices are also plotted against each other (Figure 3). Each observation represents one of 15 counties in this scatterplot, which reveals an overall negative association between the two variables. In most cases, higher values of *D* accompany lower values of *SIEJ,* and vice versa. There is also some evidence of a linear relationship between the indices. The strength and direction of this linear association is examined through bivariate regression analysis, the results of which are summarized in Table 2. The *SIEJ* represents the dependent variable, and the *D* index the explanatory variable. The analysis provides a statistically significant coefficient for *D,* and supports the existence of a negative linear relationship between the two variables.

Table 1. Computed Values of *D* and *SIEJ* in the 15 Urban Areas

Metropolitan Area	County	*D*	*SIEJ*
Cleveland, OH	Cuyahoga	0.549	*-0.495*
Milwaukee, WI	Milwaukee	0.541	*-0.404*
Minneapolis, MN	Hennepin	0.520	*-0.322*
Buffalo, NY	Erie	0.514	*-0.332*
Baton Rouge, LA	East Baton Rouge	0.492	*-0.241*
Newark, NJ	Essex	0.473	*-0.344*
Philadelphia, PA	Philadelphia	0.461	*-0.310*
Austin, TX	Travis	0.442	*-0.075*
Jacksonville, FL	Duval	0.421	*-0.354*
Knoxville, TN	Knox	0.394	*-0.453*
Sacramento, CA	Sacramento	0.389	*-0.286*
Tacoma, WA	Pierce	0.372	*-0.201*
Orlando, FL	Orange	0.356	*-0.173*
Portland, OR	Multnomah	0.345	*-0.299*
Jersey City, NJ	Hudson	0.300	*-0.044*

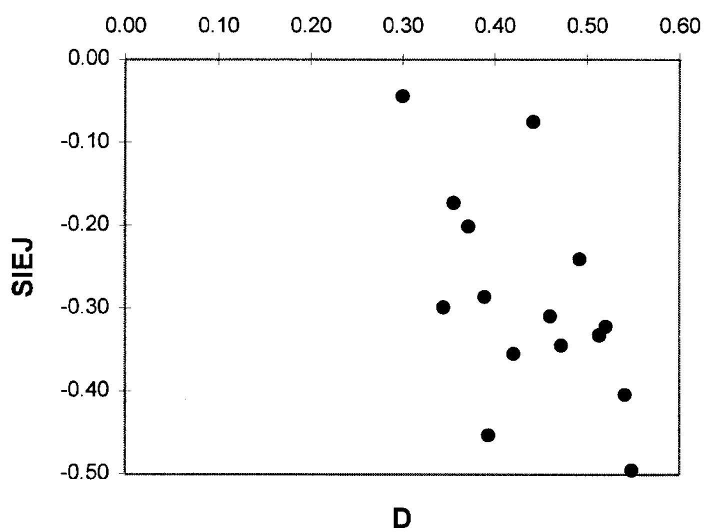

Figure 3. Relationship between *D* and *SIEJ* in the 15 Urban Counties

Table 2. Results of Linear Regression Analysis (Dependent variable: *SIEJ*)

	Coefficients	*Std.Error*	*t Statistic*	*P-value*
Intercept	0.127	0.163	0.776	0.452
Slope: *D**	-0.949	0.368	-2.583	0.023
Correlation (*r*)	*-0.583*			

*significant at 95% level of confidence

6. CONCLUDING DISCUSSION

The objective of this research was to explore the nature of the relationship between the extent of environmental equity and residential segregation in an urban area. For this purpose, the popular index of dissimilarity (D) was compared and correlated with an aggregate measure of equity *(SIEJ)* for 15 urban counties that represent varying levels of segregation. The results of the analyses indicate a statistically significant and moderately strong ($r=-0.58$) linear association between the two indices. Though all counties contain an inequitable distribution of TRI sites, the extent of this inequity is generally larger in areas that are highly segregated on the basis of income, and vice versa. This evidence partially supports our assertion that residential segregation has an adverse effect on the equitable distribution of environmental hazards in a study area. There are, however, several limiting assumptions in this study that we plan to address in our future research.

The first set of limitations involves the measurement of environmental equity. Industrial toxic emissions are considered to be the only environmental threat to the populations in different urban areas. The *SIEJ* measure also assumes that the entire population of a spatial unit is located at the centroid, which limits its ability to assess the impact of a hazard when the population is concentrated elsewhere within a spatial unit. Another key assumption of the *SIEJ is* that the distance from a toxic site is the only indicator of risk from the facility, which seems to be consistent with the procedures used in proximity-based analyses of environmental equity. However, the impact of other hazardous facilities (besides the nearest one) on the population was not considered. In addition, the index does not reflect the quantity or the toxicity of chemicals stored at each hazardous site. Future work would focus on 'weighting' the index with variables that represent the magnitude of the environmental hazard. We also plan to incorporate the cumulative effects of multiple hazardous sites into the aggregate measure of equity.

The second set of limitations deals with the index used for measuring the degree of residential segregation. The index of dissimilarity is a measure of evenness, and this is the only dimension of segregation examined in this paper. In spite of its popularity, several scholars (e.g. White, 1983; Morrill, 1991; Wong, 1993) have criticized the *D* index on the grounds that it is insensitive to the spatial configuration of the segregated group. A high value of *D* does not always imply that the minority groups are spatially segregated. It is necessary, therefore, to explore the effect of other dimensions and indices of segregation that are more capable of describing the spatial distribution of the population group being studied.

To explore the relationship between segregation and environmental equity in a variety of urban contexts, a large sample of urban areas is required. Though the stratified random sample of counties used in this study provides variation in terms of the dissimilarity index, a larger sample would incorporate a wider diversity of urban forms and spatial arrangement of income groups, and would consequently strengthen the generality of the analyses.

Finally, further research is required to determine the precise nature of the relationship between the degree of residential segregation and the extent of environmental equity. If the spatial form of a city restricts the equitable distribution of hazardous facilities, it is also important to determine what portion of the measured inequity is caused solely by segregation. This would add a new dimension to environmental equity research, and should provide important insights on the assessment of disproportionate impacts on minority and low-income populations.

7 REFERENCES

Abramson, A., Tobin, M. and VanderGoot, M. (1995). The Changing Geography of Metropolitan Opportunity: The Segregation of the Poor in U.S. Metropolitan Areas, 1970 to 1990. *Housing Policy Debate,* 6(1):45-72.

Chakraborty, J. and Armstrong, M. P. (1995). Using Geographic Plume Analysis to Assess Community Vulnerability to Hazardous Accidents. *Computers, Environment, and Urban Systems. 19* (5/6): 341-356.

Duncan, O. D. and Duncan, B. (1955). A Methodological Analysis of Segregation Studies. *American Sociological Review.* 20: 210-217.

Glickman, T. S., and Hersh, R. (1995). Evaluating Environmental Equity: The Impacts of Industrial Hazards on Selected Social Groups in Allegheny County, Pennsylvania. *Discussion Paper 95-13* (March), Resources for the Future, Washington, D. C.

Hodge, D. and Gatrell, A. (1976). Spatial Constraint and the Location of Urban Public Facilities. *Environment and Planning A. 8:* 215-230.

Massey, D. S. and Denton, N. A. (1988). The Dimensions of Residential Segregation. *Social Forces.* 67: 281-315.

Massy, D. S. and Eggers, M. L. (1993). The Spatial Concentration of Affluence and Poverty during the 1970s. *Urban Affairs Quarterly.* 29 (2): 299-315.

McLafferty, S. (1982). Urban Structure and Geographical Access to Public Services. *Annals of the Association of American Geographers.* 72 (3): 347-354.

McLafferty, S. (1984). Constraints on Distributional Equity in the Location of Public Services. *Political Geography Quarterly.* 3 (1): 33-47.

Morgan, B. S. (1975). The Segregation of Socioeconomic Groups in Urban Area. *Urban Studies.* 12: 47-60.

Morrill, R. L. (1991).On the Measure of Geographic Segregation. *Geography Research Forum. 11:* 25-36.

Morrill, R. L. (1995). Racial Segregation and Class in a Liberal Metropolis. *Geographical Analysis.* 27 (1): 22-41.

Openshaw, S. (1984). *The Modifiable Areal Unit Problem: Concepts and Techniques in Modern Geography.* Number 38. Geo Books, Norwich.

Right-To-Know Network (1996). EPA's Toxic Release Inventory Area Standard Report. http://rik.net/www/dataftri_area.html.

Sakoda, J. N. (1981). A Generalized Index of Dissimilarity. *Demography.* 18: 245-250.

White. M. J. (1983). The Measurement of Spatial Segregation. *American Journal of Sociology.* 88: 1008-1018.

Wong. D. W. S. (1993). Spatial Indices of Segregation. *Urban Studies.* 30 (3): 559-572.

Wong. D. W. S. (1996). Enhancing Segregation Studies using GIS. *Computers, Environment, and Urban Systems.* 20 (2): 99-109.