Urban Environmental Justice Indices

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Environmental justice is the principle that environmental costs and amenities ought to be equitably distributed within society. Due to the ethical, political, and public-health implications, and because many choices confront those researching environmental justice, standardized measures are needed to inform public dialogue and policy. We develop and test seven indices on three Colorado cities to measure the relationship between the distribution of environmental hazards and minority and poverty-stricken populations, and recommend the Comparative Environmental Risk Index as a preliminary, standardized measure for comparing urban areas. This index is particularly relevant to disadvantaged communities, regional planning organizations, environmental-justice networks and scholars, and state and federal agencies. **Key Words: Colorado, environmental justice, GIS.**

The Environmental Protection Agency (EPA) website (EPA 2001) defines environmental justice (EJ) as the "fair treatment for people of all races, cultures, and incomes, regarding the development of environmental laws, regulations, and policies." EJ policies seek to create environmental equity: the concept that all people should bear a proportionate share of environmental pollution and health risk and enjoy equal access to environmental amenities. EJ policies are intended to overcome environmental racism caused by racial and economic advantages built into policy-making, enforcement, and locating of waste disposal and polluting industries.

Executive Order 12898, passed in 1994, requires each federal agency to adopt the principle of environmental justice in policy development. As a result, there is an increasing need for a single quantitative EJ measurement method to help federal and state policymakers in their decision processes. To date, EJ has been measured in many different ways, often with contradictory results (Mohai 1996; Weinberg 1998; Lester and Allen 1999; Williams 1999; Holifield 2001). Researchers have debated such issues as the most appropriate scale, the spatial units of analysis, the selection of socioeconomic variables, statistical techniques, the definition of facilities or physical features that pose a threat, selection of at-risk populations, and demographic characteristics of areas at the time noxious facilities were sited. Standardized methodologies are needed in order to compute benchmark measures against which other results can be compared (Cutter 1995; Mohai 1995; Cutter, Holm, and Lloyd 1996; McMaster, Leitner, and Sheppard 1997). In this article we develop seven EJ indices using geographic information systems (GIS). We evaluate these measures using data from three Colorado metropolitan statistical areas (MSAs) and propose a standardized measure that is a preliminary indicator of environmental justice.

Developing Indices

Researchers and policymakers have long recognized the value of trying to measure EJ. Prior work has explored using various geographic units of analysis, types of statistical tests, and risk indicators. The geographic units of analysis used in previous research include states (Lester and Allen 1999), counties (Stockwell et al. 1993; Cutter, Holm, and Lloyd 1996), zip codes (United Church of Christ 1987), census tracts (Cutter, Holm, and Lloyd; Yandle and Burton 1996), and census block groups (Cutter, Holm, and Lloyd; Chakraborty and Armstrong 1997; Sheppard et al. 1999). Demographic variables used to measure EJ include median family income (Yandle and Burton), nonwhite population (Yandle and Burton), percent nonwhite (Glickman 1994; Chakraborty and Armstrong), percent below poverty level (Cutter, Holm, and Lloyd; Chakraborty and Armstrong; Sheppard et al.), African-American and Hispanic (Lester and Allen), and median household income and percent black (Cutter, Holm, and Lloyd). Statistical tests assessing the magnitude of

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disparities in the distribution of environmental hazards include chi-square and Cramers V (Yandle and Burton), multiple regression (Mohai and Bryant 1992), and t-tests (Cutter, Holm, and Lloyd). The EPA (1994) has also developed an EJ index in which categorical rankings for degree of exposure (based on population density) are multiplied by degree of vulnerability (based on minority and economically stressed rankings). The source of environmental threat considered has included waste disposal facilities (United Church of Christ; Yandle and Burton;), transport, storage, and disposal (TSD) sites monitored under the Research Conservation and Recovery Act (RCRA) (Mohai and Bryant), the Toxic Release Inventory (TRI) (Stockwell et al; Glickman; Scott and Cutter 1997; Sheppard et al), and TSD, TRI, and Superfund sites (Cutter, Holm, and Lloyd). Research also has attempted to improve upon the problem of under- or overestimating those at risk due to discrete boundary changes between the units of analysis by employing buffers around toxic sites (Glickman; Anderton 1996), a series of buffers (Mohai and Bryant; Glickman; Sheppard et al.), a combination of buffers and plume analysis (Chakraborty and Armstrong), and a cumulative distance decay function (Cutter, Hodgson, and Dow 2001).

In addition to inconsistencies in measurement and analysis, researchers have conducted longitudinal case studies to determine demographic characteristics at the time of hazardous waste facility siting (Yandle and Burton 1996; Boone and Modarres 1999), addressed problems with the conceptualization of racism (Pulido 2001), explored the definition of "community" (Williams 1999), and examined the treatment of EJ in local sustainability efforts (Warner 2002). Research into EJ has also confronted such issues as unequal enforcement of environmental laws, exclusionary decision-making processes, and discriminatory zoning (Bullard 1996). These and other research projects address different dimensions of EJ and its determinants, including procedural inequities, generational inequities, and outcome inequities (Cutter 1995).

The focus of this project is quite specific: to develop an EJ index that is conceptually valid and easily computed for any city. Our goal is to develop a standard index that is relatively simple to calculate and interpret.

Although many hazardous waste sites occur in rural areas (Bullard 1996), this study is confined to urban areas. Toxic sites tend to be correlated with low income and minority areas in urban areas (Cutter 1995), and most toxic release and transfer sites are near large population centers (Stockwell et al. 1993). We look at potential exposure to toxic sites only, but our tests are flexible enough to expand the analysis to certain other environmentally sensitive issues. Provided an environmental threat or amenity has a known location, such as a floodplain, a zone of urban blight, open space preserves, or transportation corridors, these features could substitute for the toxic sites used in this study, thereby broadening the usual conception of "environment" and opening new possibilities for EJ research (Holifield 2001). We measure outcome equity between MSAs, a comparative measure for one point in time only. We do not attempt to determine the causes of environmental inequity or policy discrimination, we do not perform longitudinal case studies, and we do not delve into the sociological constructs of race, ethnicity, or community. The indices we develop are tools, and should be useful for researchers to address the nuances of specific locales (Mohai and Bryant 1992; McMaster, Leitner, and Sheppard 1997) and explore the relationship of EJ to such topics as political culture, sustainability, segregation, economic base, growth, and community. Our results will provide a benchmark for further scholarly research, a practical community indicator of environmental justice, and an initial comparison measure between cities.

Conclusions often vary among EJ studies because the research questions differ. We address four EJ dimensions of toxic siting that have concerned scholars, officials, and affected populations: (1) the likelihood of exposure for different groups, (2) demographic differences between at-risk and not-at-risk populations, (3) the relationship of *concentration* of toxic sites to social characteristics, and (4) the relationship of the *toxicity* of sites to social characteristics. The following indices address these dimensions:

1. *Comparative Environmental Risk Index (CERI)*: Are racial minorities and low-income people more likely to be exposed to environmental hazards than is the rest of the population?

2a. *Toxic Demographic Difference Index (TDDI)*: Do the demographics for areas of the city that are vulnerable to toxic hazards differ significantly from those for other areas of the urban region?
2b. *Toxic Demographic Quotient Index (TDQI):* Are the proportions of racial minorities and low-income people in the at-risk areas greater than in not-at-risk areas?
3a. *Toxic Concentration Equity Index (TCEI)*: Are the numbers of toxic sites more *concentrated* in minority and low-income areas?
3b. *Concentration Risk Comparison Index (CRCI)*: Are racial minorities and low-income people more likely to live near areas of high toxic *concentrations* than the rest of the population?
3c. *Concentration Demographics Index (CDI)*: Do the demographic characteristics of areas of the city with high toxic concentrations differ significantly from other areas of the urban region?
4. *Toxicity Equity Index (TEI)*: Do minority and low-income areas contain more potentially dangerous *types* of toxic sites?

We use accepted GIS algorithms in our analysis, which introduce a higher degree of objectivity (Glickman 1994) and are recognized to be the tools now needed to address current problems in EJ analysis (Cutter, Holm, and Clark 1996).

Our units of analysis are census block groups. These are the smallest unit for which the Census Bureau reports the necessary socioeconomic information, ensuring the best possible degree of representativeness in geographic areas (Cutter, Holm, and Clark 1996; Yandle and Burton 1996; McMaster, Leitner, and Sheppard 1997; Sheppard et al. 1999). With the GIS we generate buffers around toxic sites (when appropriate) to select block groups (buffer distances are discussed below) to best define at-risk and not-at-risk populations (Mohai 1995). Numerous people recognize the need to use buffers around toxic sites so as to avoid the boundary problem associated with the units of analysis and to avoid undercounting those at risk (Glickman 1994; Mohai 1995; Anderton 1996; Bullard 1996).

Where possible, we define toxic sites comprehensively as any location included in federal and state databases (Table 1). The need for measures that treat toxic sites comprehensively, rather than particular subsets of toxic sites, is well known (Mohai 1995; McMaster, Leitner, and Sheppard 1997). Furthermore, state and regional databases are frequently superior to federal records (Anderton 1996). We therefore use a comprehensive list that includes state data in addition to federal data. We use the Environmental Geographics™ data from VISTA Information Solutions, Inc., a GIS data vendor that provides continually updated and reliable locations of toxic sites from all known sources (VISTA 1998, 2000). These toxic sites are represented as both point and polygon (area) features.

While it is often desirable to assign some level of potential threat to each site (Stockwell et al. 1993; Glickman 1994; Cutter, Hodgson, and Dow 2001), several factors preclude this for six of our seven indices. Much of the data concerning the exact volume and chemical makeup of toxins in these sites are unavailable for all of the datasets. Also, on-site toxins vary greatly on a daily basis for most sites, which means the risk at a site is never stable. Having acknowledged this, we still want to incorporate some measure that addresses the discrepancies in the level of potential threat each *type* of site poses. Even this proves difficult, however, because the levels of toxins between sites for even one type, such as RCRA large generators, vary

Table 1 *Data Sources for Toxic Sites*

• National Priorities List (NPL) superfund sites	• All other superfund sites (Comprehensive Environmental Response Compensation and Liability Act/CERCLIS)
• Research Conservation and Recovery Act (RCRA) Corrective Actions sites (CORRACTS)	• RCRA large generators
• RCRA small generators	• RCRA Transport, Storage, and Disposal Facilities (TSDFs)
• State-level equivalents of the federal data sets	• Toxic Release Inventory sites (TRIs).

Sources: VISTA (1998) for Pueblo and El Paso counties; VISTA (2000) for Adams, Arapahoe, Denver, Douglas, and Jefferson counties.

greatly. The only realistic ranking scheme we can use for a comprehensive list of toxic sites concerning the level of potential threat these datasets contain is that the Superfund sites are *probably* worse than the rest (Superfunds are the only confirmed polluted sites in the database, while many other types of sites may use and store toxins but never release them, or may release toxins within allowable specifications). We account for this by generating larger buffer distances around Superfund National Priority List (NPL) and Comprehensive Environmental Response Compensation and Liability Information System (CERCLIS) sites (one mile) than the rest (one-half mile) in those tests where buffers are used.

The choice of buffer distances is also a contested issue (Bowen 1999). Landfill impact on housing values range from 2 to 2.5 miles (Mohai 1995). Glickman (1994) claims the radius of an area affected by a major chemical release often exceeds one mile. Zimmerman (1994) uses a one-mile buffer around NPL sites, while Chakraborty and Armstrong (1997) use both one-half- and one-mile buffers around TRI sites. Sheppard and colleagues (1999) use 100-, 500-, and 1000-yard buffers around TRI sites. The EPA (1989) has determined "inner zones," or zones of plausible exposure, for their Hazard Ranking System (HRS) for NPL sites: one mile for air; four miles for surface water; and for land, twelve feet for the depth to aquifer, one mile for the distance to the nearest well, and one-half mile for down-gradient runoff. These EPA figures are only guides, because the HRS is a peer-reviewed process of NPL sites that accounts for site-specific characteristics about volume and type of toxins present. Cutter and colleagues (2001) avoid buffers altogether by using a distance-decay function—a thorough yet computationally intense method. We chose one-half- and one-mile buffers to be on the conservative side, because the comprehensive nature of our toxic-site data includes many sites that probably never actually release contaminants, such as the RCRA sites, and are thus only *potential* threats.

While we feel using two buffer distances is the best method by which to address variations in the level of toxicity associated with different types of sites at this time, our last measure specifically addresses discrepancies in the level of toxicity—but in TRI sites only. Here we employ a measure for the total emissions from these sites, weighted by a toxicity ranking for the type of chemicals emitted. The drawback is that the sites are not comprehensive to all toxic datasets, but the severity of risk is factored in (see Table 2 for a summary of the strengths of each test).

Methods to select the geographical areas at risk still cause considerable variation in the at-risk population even when an acceptable buffer distance is determined. Buffers are only used to select the underlying units of analysis, because these are the units at which socioeconomic data are reported. This again shows the value of using the smallest possible unit of analysis (block groups) in order to best approximate the actual buffer radius used. Buffers can be used to select all block groups that intersect the buffers, all that have their centroid within the buffer, or only those that are completely within the buffer. Alternatively, the population for each block group that intersects the at-risk buffers can be estimated by using the proportion of the block group that lies within the buffer (buffer containment method—see Sheppard et al. 1999). Chakraborty and Armstrong (1997) estimated the at-risk population in this way, but found almost identical values between the centroid containment method and the buffer containment approximation method. Because we want to best approximate the buffer

Table 2 *Strengths of Tests*

Strength	Test 1	Test 2a	Test 2b	Test 3a	Test 3b	Test 3c	Test 4
Uses buffers to best define those at-risk	Yes	Yes	Yes	No	Yes	Yes	No
Comprehensive list of toxic sites	Yes	Yes	Yes	Yes	Yes	Yes	No
Accounts for differences between individual toxic sites	Partially[a]	Partially[a]	Partially[a]	No	No	No	Yes
Accounts for concentrations of toxic sites	No	No	No	Yes	Yes	Yes	No

[a] *By using different buffer distances between Superfund sites and all others.*

radius and minimize computations, we select only those block groups that have their centroid within the buffer, eliminating those with large spatial extent for which the majority of the area lies outside of the toxic site buffer.

The discussion thus far on use of buffers, buffer distances, measures of toxicity, and spatial units of analysis requires a clarification about the underlying assumptions in these tests and the usefulness of the results. We recognize that equating proximity (however defined) with risk is a crude measure. Bowen (1999) recognizes that proximity has become the standard proxy for risk, but attacks this assumption as far too simplistic. The complexities of each site—issues such as toxin doses, exposure times, and synergistic effects of simultaneous multiple chemical exposure, as well as details on wind, atmospheric, and hydrographic conditions—must be fully analyzed before a definitive statement of risk can be made. Only this level of detail will define risk. It is not our intent to provide the methodology needed to accurately measure risk in any specific place, but to find a *preliminary indicator* that is easy to perform and compares relative conditions between places. We do not specifically equate proximity with risk. Our indices reveal inequalities in *potential* risk. Furthermore, our analysis should clarify confusion as to why EJ studies often generate conflicting results, and it provides a necessary step toward standardization (Szasz and Meuser 1997). Researchers can use our measure as a starting point, then proceed into local histories and local conditions as needed.

We perform all tests for race, ethnicity, and poverty level from the 1990 Census (U.S. Bureau of the Census 1990). Race is measured by using the nonwhite populations. Because "Hispanic" can include all racial categories, Hispanics are treated separately from race.[1] We also use persons below poverty level for the low-income index: some of our tests generate mean values, so we cannot use median or mean Census values, such as median household income, to generate our mean values. We therefore generate an EJ index measured against racial minorities, Hispanics, and the poor for each MSA. We then average these indices and normalize by the rate of toxic sites in the MSA using the formula:

$$(\text{number of toxic sites/population}) \times 1000 \qquad (1)$$

This normalized composite index controls for variations in the overall burden an MSA population bears in terms of toxic sites. We do this because some cities have relatively low overall environmental dangers, with few toxic sites per capita, while others have a higher per-capita number of toxic sites. Normalizing the indices allows for direct comparison of the EJ index between cities, where cities with greater levels of environmental risk score higher.

Case-Study Cities

The three cities chosen for this analysis are Pueblo, Colorado Springs, and Denver (Figure 1). All are located along the front range of Colorado, a high-growth corridor. Each city has unique characteristics that should be reflected in the EJ indices. We chose these cities for their proximity and diversity. The purpose is not to determine the specifics of EJ in these cities per se, but to test between these cities in order to correlate the best EJ index. Our familiarity with these cities and ready access for field observations allows ongoing "reality checks" for our EJ calculations.

Colorado Springs is the second-largest city in Colorado, with a 2000 MSA (El Paso County) population of 516,929. Founded by General William Jackson Palmer in 1871, the city was neither the typical Western boomtown nor a transportation hub. Rather, it was explicitly founded to be a blue-blood resort town, a clean getaway for elites from the East Coast. Dubbed "Newport in the Rockies," Colorado Springs was initially a dry town with many millionaires, a wide representation of churches, and the moral values of its founder stamped on the social space. The Cripple Creek gold rush of the 1890s brought more wealth to the city, but also changed the ambiance with the introduction of gold smelters and more heavy industry. Today the city hosts a strong military presence (typically an important player for local environmental concerns), plus a concentration of high-tech industries, including silicon-chip manufacturers. Minority percentages match the national averages, but are low for an urban area.

Pueblo was historically larger than neighboring Colorado Springs because of its strategic location on the Arkansas River, but today has only 141,472 people. Pueblo is a blue-collar

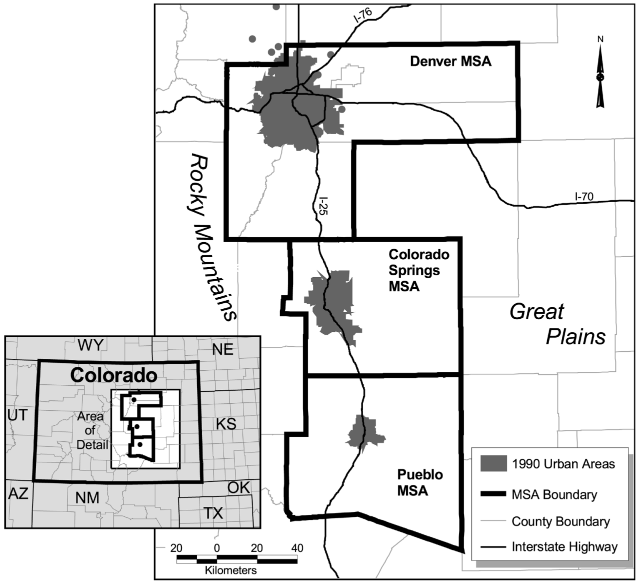

Figure 1 *Case-study urban areas and MSA boundaries in Colorado.*

city with a large Hispanic population, many of whom are migrants from neighboring New Mexico (with more recent Mexican immigrants) who worked in the Colorado Fuel and Iron Company steel mill. Pueblo has a rich diversity of other European ethnic groups, ancestors of earlier immigrants who came to work in the mills. The steel mill, now called Rocky Mountain Steel, still operates today but employs far fewer workers than its 1920 peak of over 6,500. General Palmer chose the site of the mill to build rails for his Denver and Rio Grande Railroad because of the availability of water, nearby coal, and limestone, but also to ensure that the noxious industry was not located in his beloved Colorado Springs, where the high society lived.

Denver, the central place for a vast "empire" of mountains and plains, is the dominant urban player in the region. The MSA consists of five counties (Denver, Arapahoe, Adams, Jefferson, and Douglas) with a 2000 population of 2,109,282. The city has a large Hispanic population and a diversity of other racial and ethnic types. In addition, it has a large manufacturing sector, which historically included ore smelters and later nuclear arsenal plants, but is dominated today by the telecommunications industry and other high-tech offices. Denver is experiencing rapid urban sprawl, which may have the effect of leaving disadvantaged groups behind in the potentially noxious industrial locations.

In order to compare results between cities, we normalize our composite indices by the rate of toxic sites. The toxic site rate is highest for Denver (1.21948 toxic sites per 1000 people), next highest in Colorado Springs (0.85891), and lowest in Pueblo (0.72480). Denver, therefore, has the highest overall number of toxic sites per capita, so its normalized composite indices will be scaled higher than the other cities.

Test 1: Comparative Environmental Risk Index

The first index measures whether minorities and low-income people are more likely to be exposed to environmental hazards than are the rest of the population. This measure selects all block groups that have their centroid within a one-mile buffer around NPL/CERCLIS sites and a one-half-mile buffer around all other toxic sites to define the at-risk population.

To generate the race index, we sum the nonwhites in at-risk block groups and divide by the total MSA nonwhites, then do the same for the whites. The index is a quotient (a ratio of ratios) of the two, or percent of nonwhites at risk divided by the percent of whites at risk. We repeat this measure for Hispanics and persons below poverty level.[2] To calculate an overall CERI, we then average the three individual quotients and normalize by multiplying by the total MSA toxicity rate to account for the per capita number of toxic sites.

The results show that in Pueblo and Denver, the poor as a group are at greater toxic risk than nonwhites (Table 3). In Colorado Springs, nonwhites are at highest risk (but all 3 indices are similar). The highest risk for all groups and all cities is on the poor in Denver, who are 33.8 percent more likely to be at risk than are the non-poor. In Colorado Springs, nonwhites are 33 percent more likely to be at risk than are whites. Pueblo has the lowest levels of inequality for the three cities.

Overall, much higher percentages of all three groups (nonwhite, poor, and Hispanic) are at risk in Denver than in the other two cities. This higher overall risk in Denver is accentuated by the fact that Denver has a higher rate of toxic sites than do the other two cities (accounted for in our normalization procedure). The normalized composite index ranks Denver as most severe, Colorado Springs second, and Pueblo the least severe.

Test 2a: Toxic Demographic Differences Index

This index determines if there are statistically significant differences between nonwhite, Hispanic, and poor populations near toxic sites (at-risk) and away from toxic sites (not-at-risk). To do so, we first determine the at-risk and not-at-risk populations with the same buffer distances and block group selection method as above, then calculate the mean number of nonwhites, Hispanics, and persons below poverty level in both populations. Since the two populations are mutually exclusive, independence is maintained. The t-score from the difference of means between these populations indicates the probability of this inequality occurring at random, and one minus the significance level ($1 - p$) is the index for each variable.[3]

Results show that differences in the populations for all three variables in each city are highly significant (Table 4). On average, at-risk areas have higher proportions of nonwhites, Hispanics, and low-income people. In Denver, the percent poor in at-risk areas is over three times that of not-at-risk areas, and differences between the percent nonwhite is nearly as great. Pueblo again shows the smallest differences between at-risk and not-at-risk

Table 3 *Comparative Environmental Risk Indices (Test 1)*

Pueblo

$$CERI_{nw} = \frac{\text{(at risk nonwhites/total MSA nonwhites)}}{\text{(at risk whites/total MSA whites)}} = \frac{0.49261}{0.43316} = 1.137$$

$$CERI_{h} = \frac{\text{(at risk Hispanic/total MSA Hispanic)}}{\text{(at risk non-Hispanic/total MSA non-Hispanic)}} = \frac{0.48443}{0.41874} = 1.157$$

$$CERI_{p} = \frac{\text{(at risk poor/total MSA poor)}}{\text{(at risk non-poor/total MSA non-poor)}} = \frac{0.52019}{0.42300} = 1.229$$

Normalized composite CERI = $(1.137 + 1.157 + 1.229)/3 \times (0.73140) = 0.8555$

Colorado Springs

$$CERI_{nw} = \frac{\text{(at-risk nonwhites/total MSA nonwhites)}}{\text{(at-risk whites/total MSA whites)}} = \frac{0.64966}{0.48804} = 1.331$$

$$CERI_{h} = \frac{\text{(at-risk Hispanic/total MSA Hispanic)}}{\text{(at-risk non-Hispanic/total MSA non-Hispanic)}} = \frac{0.63478}{0.49896} = 1.272$$

$$CERI_{p} = \frac{\text{(at-risk poor/total MSA poor)}}{\text{(at-risk non-poor/total MSA non-poor)}} = \frac{0.64093}{0.49596} = 1.292$$

Normalized composite CERI = $(1.331 + 1.272 + 1.292)/3 \times (0.85891) = 1.1143$

Denver

$$CERI_{nw} = \frac{\text{(at-risk nonwhites/total MSA nonwhites)}}{\text{(at-risk whites/total MSA whites)}} = \frac{0.81796}{0.62529} = 1.308$$

$$CERI_{h} = \frac{\text{(at-risk Hispanic/total MSA Hispanic)}}{\text{(at-risk non-Hispanic/total MSA non-Hispanic)}} = \frac{0.79929}{0.63120} = 1.266$$

$$CERI_{p} = \frac{\text{(at-risk poor/total MSA poor)}}{\text{(at-risk non-poor/total MSA non-poor)}} = \frac{0.84605}{0.63227} = 1.338$$

Normalized composite CERI = $(1.308 + 1.266 + 1.338)/3 \times (1.21948) = 1.5902$

Table 4 *Toxic Demographic Differences Indices (Test 2a)*

	At Risk Mean	Not-At-Risk Mean	One-Tailed *t*	Probability[a]	
Pueblo					
Percent nonwhite	0.179	0.121	$t = 3.005$[c]	$p = 0.0015$	$TDDI_{nw} = (1 - p) = 0.9985$
Percent Hispanic	0.420	0.303	$t = 3.239$[b]	$p = 0.0007$	$TDDI_h = (1 - p) = 0.9993$
Percent poor	0.253	0.176	$t = 3.528$[b]	$p = 0.0003$	$TDDI_p = (1 - p) = 0.9997$
Normalized composite TDDI = (0.9985 + 0.9993 + 0.9997)/3 × (0.73140) = 0.7308					
Colorado Springs					
Percent nonwhite	0.157	0.106	$t = 3.761$[b]	$p = 0.0001$	$TDDI_{nw} = (1 - p) = 0.9999$
Percent Hispanic	0.112	0.066	$t = 5.719$[b]	$p < 0.0000$	$TDDI_h = (1 - p) = 1.0$
Percent poor	0.145	0.084	$t = 5.527$[c]	$p < 0.0000$	$TDDI_p = (1 - p) = 1.0$
Normalized composite TDDI = (0.9999 + 1.0 + 1.0)/3 × (0.85891) = 0.8589					
Denver					
Percent nonwhite	0.196	0.073	$t = 15.316$[c]	$p < 0.0000$	$TDDI_{nw} = (1 - p) = 1 .0$
Percent Hispanic	0.164	0.077	$t = 11.289$[c]	$p < 0.0000$	$TDDI_h = (1 - p) = 1.0$
Percent poor	0.138	0.045	$t = 18.049$[c]	$p < 0.0000$	$TDDI_p = (1 - p) = 1.0$
Normalized composite TDDI = (1.0 + 1.0 + 1.0)/3 × (1.21948) = 1.2195					

[a] *All probabilities are significant.*
[b] *Equal variance assumed.*
[c] *Equal variance not assumed.*

populations; nonetheless, the differences are significant.

The normalized composite index is the average of the three indices, again normalized by the rate of toxic sites in the MSA. As with test 1, Denver showed the highest inequality, Colorado Springs second, and Pueblo third.

Test 2b: Toxic Demographics Quotient Index

We can also measure inequality by comparing the proportions of racial minorities and poor in at-risk areas to their proportions in not-at-risk areas. The index is the quotient between the at-risk percentages and the not-at-risk percentages. We use the same selection method to define the at-risk population as in the two previous tests.

As expected, the minority and poor proportions of the population in at-risk areas are higher than their proportions in not-at-risk areas for each city (Table 5). The highest inequity shows that the proportion of poor people in the at-risk population in Denver is nearly three times higher than the proportion of poor people in the not-at-risk population. The Denver at-risk areas also have over two times the proportions of minorities of the not-at-risk areas. Colorado Springs indices show that at-risk areas have over one and a half times higher proportions of minorities and poor than not-at-risk areas. Pueblo again shows the least inequality. When the individual indices are normalized by the MSA toxic site rates, Denver has the highest composite index of 3.0211, Colorado Springs the next, and Pueblo the lowest.

Test 3a: Toxic Concentration Equity Index

This procedure generates an index indicating the degree to which toxic sites are concentrated within nonwhite, Hispanic, and low-income areas. The previous tests found at-risk populations near toxic sites, but gave no indication as to the *number* of toxic sites nearby. To generate this index, we compare two distributions: the percent of an MSA's toxic sites in each block group, and the percent of the MSA population in each block group. The assumption is that equity occurs when a block group's proportion of the MSA's toxic sites equals that block group's proportion of the MSA population. The ratio of disadvantage, or the percentage of toxic sites divided by the percentage of the population, indicates the relative burden for each block group. Numbers greater than 1.0 indicate a disproportionate burden of toxic sites given their share of the population, numbers less than 1.0 have less than their fair share.

A Gini coefficient (G) tells the degree of inequality between the two distributions (percent of toxic sites and percent of the MSA population):

$$G = .5 \times \Sigma|(\text{percent of toxic sites}) - (\text{percent of total population})| \qquad (2)$$

Table 5 *Toxic Demographic Quotient Indices (Test 2b)*

Pueblo						
$TDQI_{nw}$	=	$\frac{\text{(at-risk nonwhites/total MSA at-risk)}}{\text{(not-at-risk nonwhites/total MSA not-at-risk)}}$	=	$\frac{0.16964}{0.13852}$	=	1.2247
$TDQI_{h}$	=	$\frac{\text{(at-risk Hispanic/total MSA at-risk)}}{\text{(not-at-risk Hispanic/total MSA not-at-risk)}}$	=	$\frac{0.39141}{0.33026}$	=	1.1852
$TDQI_{p}$	=	$\frac{\text{(at-risk poor/total MSA at-risk)}}{\text{(not-at-risk poor/total MSA not-at-risk)}}$	=	$\frac{0.23247}{0.16999}$	=	1.3655
Normalized composite TDQI = (1.2247 + 1.1852 + 1.3655)/3 × (0.73140) = 0.9204						
Colorado Springs						
$TDQI_{n}w$	=	$\frac{\text{(at-risk nonwhites/total MSA at-risk)}}{\text{(not-at-risk nonwhites/total MSA not-at-risk)}}$	=	$\frac{0.17605}{0.09897}$	=	1.7788
$TDQI_{h}$	=	$\frac{\text{(at-risk Hispanic/total MSA at-risk)}}{\text{(not-at-risk Hispanic/total MSA not-at-risk)}}$	=	$\frac{0.10473}{0.06282}$	=	1.6671
$TDQI_{p}$	=	$\frac{\text{(at-risk poor/total MSA at-risk)}}{\text{(not-at-risk poor/total MSA not-at-risk)}}$	=	$\frac{0.12499}{0.07300}$	=	1.7122
Normalized composite TDQI = (1.7788 + 1.6671 + 1.7122)/3 × (0.85891) = 1.4768						
Denver						
$TDQI_{n}w$	=	$\frac{\text{(at-risk nonwhites/total MSA at-risk)}}{\text{(not-at-risk nonwhites/total MSA not-at-risk)}}$	=	$\frac{0.17862}{0.07473}$	=	2.3902
$TDQI_{h}$	=	$\frac{\text{(at-risk Hispanic/total MSA at-risk)}}{\text{(not-at-risk Hispanic/total MSA not-at-risk)}}$	=	$\frac{0.15701}{0.07412}$	=	2.1183
$TDQI_{p}$	=	$\frac{\text{(at-risk poor/total MSA at-risk)}}{\text{(not-at-risk poor/total MSA not-at-risk)}}$	=	$\frac{0.12420}{0.04248}$	=	2.9237
Normalized composite TDQI = (2.3902 + 2.1183 + 2.9237)/3 × (1.21948) = 3.0211						

Gini coefficients vary from 0 (complete equality) to 100 (complete inequality). The calculated Gini coefficient shows that Pueblo has the most unequal burden between toxic concentrations and the overall population concentrations—fully 75 percent of the toxic sites would need to be redistributed to achieve equity (Table 6). However, this measure says nothing about the population that is adversely affected by inequality. To generate an EJ index,

Table 6 *Toxic Concentration Equity Index (Test 3a)*

Pueblo					
Percent nonwhite	RD = 13.31 − 27.836 (%nw)	$R^2 = 0.038$	$F = 1.476$	$p = 0.232$	$TCEI_{nw}$ = (1 − p) = 0.768
Percent Hispanic	RD = 11.83 − 6.240 (%Hispanic)	$R^2 = 0.009$	$F = 0.345$	$p = 0.561$	$TCEI_{h}$ = (1 − p) = 0.439
Percent poor	RD = 2.35 + 14.060 (%poor)	$R^2 = 0.142$	$F = 6.126$	$p = 0.018$[a]	$TCEI_{p}$ = (1 − p) = 0.982
Multiple regression					
RD = 6.719 + 7.65 (%nw) −32.27 (%Hispanic) + 59.47 (%poor)		$R^2 = 0.280$	$F = 4.535$	$p = 0.009$	
Normalized composite TCEI[b] = (1− 0.009) × (0.73140) = 0.7248					
Colorado Springs					
Percent nonwhite	RD = 4.37 − 2.875 (%nw)	$R^2 = 0.005$	$F = 0.500$	$p = 0.481$	$TCEI_{nw}$ = (1 − p) = 0.519
Percent Hispanic	RD = 4.17 − 2.487 (%Hispanic)	$R^2 = 0.001$	$F = 0.135$	$p = 0.714$	$TCEI_{h}$ = (1 − p) = 0.286
Percent poor	RD = 1.695 + 15.240 (%poor)	$R^2 = 0.102$	$F = 12.405$	$p = 0.001$[a]	$TCEI_{p}$ = (1 − p) = 0.999
Multiple regression					
RD = 2.975 − 4.92 (%nw) −13.49 (%Hispanic) + 22.07 (%poor)		$R^2 = 0.162$	$F = 6.920$	$p = 0.000$	
Normalized composite TCEI[b] = (1− 0.000) × (0.85891) = 0.8589					
Denver					
Percent nonwhite	RD = 3.94 + 7.795 (%nw)	$R^2 = 0.009$	$F = 4.950$	$p = 0.026$[a]	$TCEI_{nw}$ = (1 − p) = 0.974
Percent Hispanic	RD = 4.40 − 5.567 (%Hispanic)	$R^2 = 0.004$	$F = 2.432$	$p = 0.119$	$TCEI_{h}$ = (1 − p) = 0.881
Percent poor	RD = 4.50 + 5.420 (%poor)	$R^2 = 0.002$	$F = 1.305$	$p = 0.254$	$TCEI_{p}$ = (1 − p) = 0.746
Multiple regression					
RD = 3.99 + 8.06 (%nw) + 2.58 (%Hispanic) − 3.52 (%poor)		$R^2 = 0.010$	$F = 1.794$	$p = 0.147$	
Normalized composite TCEI[b] = (1− 0.147) × (1.21948) = 1.0402					

Note: Pueblo: Gini = 74.76; Colorado Springs: Gini = 65.70; Denver: Gini = 69.35.
[a] *Significant relationships.*
[b] *Normalized composite (TCEI): 1 − (p value of multiple regression) × (number of toxic sites)/(total population) × 1000.*

we use simple linear regression to regress the ratio of disadvantage on the percent nonwhite, then on percent Hispanic, and finally on the percent poor for each block group. Each index is one minus the probability associated with each regression equation (the linear relationship between areas with disproportionate numbers of toxic sites and each demographic variable). We excluded all block groups that had zero toxic sites because the dependent variable (ratio of disadvantage) is highly skewed when all block groups are included (as many block groups have no toxic sites). We are therefore testing whether, for the *population at risk*, higher percentage of poor, nonwhite, or Hispanic explain higher concentrations (burdens) of toxicity.

Although Pueblo has an unequal distribution of toxic sites compared to population, only the percent poor is significantly related to this inequality, explaining 14.2 percent of the variation in the burden ratio. Colorado Springs also has a strong relationship between percent poor and toxic concentrations ($R^2 = 0.102$), while the percent nonwhite explains almost 1 percent of the variation in toxic concentrations in Denver.

To generate a composite index, we first run a multiple regression with all three variables in the equation, then calculate a normalized composite index by multiplying one minus the multiple regression probability times the MSA toxic site rate. Once again, Denver has the highest composite index, Colorado Springs the second, and Pueblo the lowest.

Tests 3b and 3c

Using the ratio of disadvantage from test 3a allows a new method to define those areas at-risk. We first select all block groups that bear more than five times their fair burden (ratio of disadvantage >5.0), then include all block groups whose centroid is within one-half mile of this selected set. This selection method defines at-risk areas as only those block groups near areas of high burden (toxic-site concentrations higher than population concentrations). Once this selection method is completed, we compare the demographics for those areas to the remainder of the population with a comparative-risk test similar to test 1 and a difference-of-means test similar to Test 2a.

Normalized composite indices for test 3b show the same trend in rankings, with Denver the highest EJ index, Colorado Springs second, and Pueblo third (Table 7). However, within the cities, likelihoods of living near concentrations of toxic sites for the demographic groups

Table 7 *Concentration Risk Comparison Indices (Test 3b)*

Pueblo

$$\text{CRCI}_{nw} = \frac{\text{(at risk nonwhites/total MSA nonwhites)}}{\text{(at risk whites/total MSA whites)}} = \frac{0.39324}{0.33575} = 1.171$$

$$\text{CRCI}_{h} = \frac{\text{(at risk Hispanic/total MSA Hispanic)}}{\text{(at risk non-Hispanic/total MSA non-Hispanic)}} = \frac{0.40746}{0.30950} = 1.317$$

$$\text{CRCI}_{p} = \frac{\text{(at risk poor/total MSA poor)}}{\text{(at risk non-poor/total MSA non-poor)}} = \frac{0.43918}{0.32118} = 1.367$$

Normalized composite CRCI = (1.171 + 1.317 + 1.367)/3 × (0.73140) = 0.9398

Colorado Springs

$$\text{CRCI}_{nw} = \frac{\text{(at risk nonwhites/total MSA nonwhites)}}{\text{(at risk whites/total MSA whites)}} = \frac{0.33354}{0.24139} = 1.382$$

$$\text{CRCI}_{h} = \frac{\text{(at risk Hispanic/total MSA Hispanic)}}{\text{(at risk non-Hispanic/total MSA non-Hispanic)}} = \frac{0.35965}{0.24443} = 1.471$$

$$\text{CRCI}_{p} = \frac{\text{(at risk poor/total MSA poor)}}{\text{(at risk non-poor/total MSA non-poor)}} = \frac{0.40734}{0.23720} = 1.717$$

Normalized composite CRCI = (1.382 + 1.471 + 1.717)/3 × (0.85891) = 1.3084

Denver

$$\text{CRCI}_{nw} = \frac{\text{(at risk nonwhites/total MSA nonwhites)}}{\text{(at risk whites/total MSA whites)}} = \frac{0.77758}{0.63704} = 1.221$$

$$\text{CRCI}_{h} = \frac{\text{(at risk Hispanic/total MSA Hispanic)}}{\text{(at risk non-Hispanic/total MSA non-Hispanic)}} = \frac{0.79200}{0.63722} = 1.243$$

$$\text{CRCI}_{p} = \frac{\text{(at risk poor/total MSA poor)}}{\text{(at risk non-poor/total MSA non-poor)}} = \frac{0.82976}{0.63877} = 1.299$$

Normalized composite CRCI = (1.221 + 1.243 + 1.299)/3 × (1.21948) = 1.5296 are greater than those seen in test 1. For example, in Colorado Springs, the poor are 72 percent more likely to live near toxic-site concentrations than are the non-poor; Hispanics are 47 percent more likely to do so, and nonwhites are 38 percent more likely to do so.

Like test 2a, test 3c shows highly significant differences between the at-risk populations of nonwhites, Hispanics, and poor and the not-at-risk populations. On average, there are much higher percentages for each of these groups near toxic site *concentrations* (Table 8). Again, Denver has the highest level of inequality, Colorado Springs the second, and Pueblo the lowest.

Test 4: Toxicity Equity

For the final test, we want to better account for the degree of severity, or actual threat, between toxic sites, rather than to treat all toxic sites within a certain database as equal. We therefore employ a measure of total emission releases for sites in the TRI database. The emission releases are then weighted by the level of toxicity for each chemical released, as developed by the Office of Pollution Prevention and Toxics in the *Risk Screening Environmental Indicators* CD (EPA 1999). This measure discriminates between toxic sites, rather than treating them all the same, but only includes TRI sites (as opposed to a comprehensive list, in the previous tests).

For this method, we query the EPA index [(emissions) × (toxicity value)] for each TRI site in the three MSAs, then regress its log transformation (because the range of values, a unitless measure, is very large) on the three demographic variables. Pueblo is excluded from this test because only two TRI sites were identified with the EPA toxicity index. Colorado Springs is included, but only has a sample size of eleven. No significant results occurred, so no *linear* relationship exists between the toxicity index for TRI emissions and the demographic variables (Table 9). Denver again has a higher composite EJ index than Colorado Springs.

Test Comparisons and Conclusions

While the indices we generated indicate varying degrees of environmental injustice, the end results are remarkably similar. All tests show that Denver has the highest levels of injustice, while Pueblo has the lowest. The similarities between indices are encouraging, showing that contradictory results between EJ measures are probably not as common as some claim, although investigators could substitute other variables or at-risk selection methods that may alter results.

When comparing the similarities between indices, test 1 shows up as most similar to the others (Table 10). Test 1 and test 3b employ the same statistical test, but with a different method to select those at-risk (as is also true between tests 2a and 3c). It is not surprising

Table 8 *Concentration Demographics Indices (Test 3c)*

	At Risk Mean	Not-At-Risk Mean	One-Tailed t	Probability[a]	
Pueblo					
Percent nonwhite	0.168	0.133	$t = 1.740$[b]	$p = 0.0419$	$CDI_{nw} = (1 - p) = 0.9581$
Percent Hispanic	0.434	0.307	$t = 3.444$[b]	$p = 0.0004$	$CDI_{h} = (1 - p) = 0.9996$
Percent poor	0.270	0.174	$t = 4.303$[b]	$p = 0.00001$	$CDI_{p} = (1 - p) = 0.9999$
Normalized composite CDI = (0.9581 + 0.9996 + 0.9999)/3 × (0.73140) = 0.7211					
Colorado Springs					
Percent nonwhite	0.174	0.113	$t = 3.837$[c]	$p = 0.00009$	$CDI_{nw} = (1 - p) = 0.9999$
Percent Hispanic	0.125	0.073	$t = 5.391$[c]	$p < 0.0000$	$CDI_{h} = (1 - p) = 1.000$
Percent poor	0.170	0.090	$t = 6.099$[c]	$p < 0.0000$	$CDI_{p} = (1 - p) = 1.000$
Normalized composite CDI = (0.9999 + 1.0 + 1.0)/3 × (0.85891) = 0.8589					
Denver					
Percent nonwhite	0.186	0.098	$t = 8.904$[c]	$p < 0.000$	$CDI_{nw} = (1 - p) = 1.000$
Percent Hispanic	0.162	0.078	$t = 11.330$[c]	$p < 0.000$	$CDI_{h} = (1 - p) = 1.000$
Percent poor	0.135	0.051	$t = 16.460$[c]	$p < 0.000$	$CDI_{p} = (1 - p) = 1.000$
Normalized composite CDI = (1.0 + 1.0 + 1.0)/3 × (1.21948) = 1.2195					

[a] *All probabilities are significant.*
[b] *Equal variance assumed.*
[c] *Equal variance not assumed.*

Table 9 *Toxicity Equity Index (Test 4)*

Pueblo	N/A				
Colorado Springs					
Percent nonwhite	logtox = 8.57 − 6.240(%nw)	R^2 = 0.075	F = 0.725	p = 0.417	TEI_{nw} = (1 − p) = 0.583
Percent Hispanic	logtox = 7.50 − 1.056(%Hispanic)	R^2 = 0.001	F = 0.005	p = 0.944	TEI_h = (1 − p) = 0.056
Percent poor	logtox = 6.86 + 4.493(%poor)	R^2 = 0.067	F = 0.648	p = 0.442	TEI_p = (1 − p) = 0.558
Multiple regression					
logtox = 8.95 − 6.38 (%nw) −22.44 (%Hispanic) + 13.36 (%poor)		R^2 = 0.288	F = 0.943	p = 0.470	
Normalized composite TEI[a] = (1 − 0.470) × (0.85891) = 0.4552					
Denver					
Percent nonwhite	logtox = 6.03 + 0.505(%nw)	R^2 = 0.006	F = 0.327	p = 0.570	TEI_{nw} = (1 − p) = 0.430
Percent Hispanic	logtox = 6.27 − 4.200(%Hispanic)	R^2 = 0.002	F = 0.097	p = 0.757	TEI_h = (1 − p) = 0.243
Percent poor	logtox = 5.58 + 2.892(%poor)	R^2 = 0.047	F = 2.639	p = 0.110	TEI_p = (1 − p) = 0.890
Multiple regression					
logtox = 5.76 − 0.64 (%nw) −2.09 (%Hispanic) + 5.09 (%poor)		R^2 = 0.085	F = 1.575	p = 0.207	
Normalized composite TEI[a] = (1 − 0.207) × (1.21948) = 0.9670					

[a] *Normalized Composite (TEI) = 1− (p value of multiple regression) × (number of toxic sites)/(total population) × 1000.*

then that these indices are highly correlated. Test 1 is also highly correlated with tests 2a and 3c. The index most unlike the others was test 3a, where we regressed the ratio of disadvantage on the demographic variables.

The two tests that calculate quotients, tests 1 and 2b, produce numbers that are most meaningful. They are also simple to calculate and easily interpretable. Test 1 calculations show the percentage of each demographic group that is at risk in an urban area, and how much more likely that group is to live in at-risk areas than is the remainder of the population. Test 2b shows the proportion of the at-risk population that is comprised of each demographic group, the same for not-at-risk areas, and the ratio (inequality) between these proportions.

The remaining tests are less easy to interpret, or the methods to produce the indices have shortcomings. Tests 2a and 3c only determine whether a statistical difference occurs between populations, a conclusion that is not as useful as the results from tests 1 or 2b. The difference of means for tests 2a and 3c also have very low probability values (for instance, $p <$ .0000000000 for all demographic groups in test 3c for Denver); hence, the indices equal 1.0, and the normalized composite index is reduced to simply the toxicity rate for that MSA.

The goal of keeping the index simple disfavors tests 3a, 3b, and 3c because they require more calculations for little to no extra benefit. The measures of concentration used in those tests are simply a refinement on tests 1 and 2a, a different method to determine the at-risk groups. The normalized composite indices calculated using multiple regression (tests 3a and 4) are also somewhat flawed. Since some, if not all three, of the demographic variables are not linearly related to the dependent variable in these tests, several actually have a negative coefficient in the multiple regression equation. This occurs even though the mean value for all demographic variables in the at-risk group is significantly higher and the likelihood of being exposed is greater.

Test 4 is the only measure that accounts for toxicity levels, a point many researchers claim

Table 10 *Correlations between Indices*[a]

	Test 1	Test 2a	Test 2b	Test 3a	Test 3b	Test 3c	Test 4
Test 1	1.00	0.931[c]	0.831[c]	0.248	0.694[b]	0.950[c]	0.638
Test 2a	0.931[c]	1.00	0.669[b]	0.198	0.640[b]	0.995[c]	0.513
Test 2b	0.831[c]	0.669[b]	1.00	0.353	0.346	0.695[b]	0.711[b]
Test 3a	0.248	0.198	0.353	1.00	0.113	0.195	0.491
Test 3b	0.694[b]	0.640[b]	0.346	0.113	1.00	0.670[b]	0.179
Test 3c	0.950[c]	0.995[c]	0.695[b]	0.195	0.670[b]	1.00	0.513
Test 4	0.638	0.513	0.711[b]	0.491	0.179	0.513	1.00

[a] *n = 12 for all tests except test 4, where n = 8.*
[b] *Significant at the 0.05 level (2-tailed).*
[c] *Significant at the 0.01 level (2-tailed).*

is necessary. Relying on TRI data for this measure excludes a comprehensive set of toxic sites, so this test is only applicable to larger urban areas. While we agree that the level of toxicity is an important variable that could be used in defining an EJ index, at this time adequate data are not available. Should more thorough measures of site toxicity become available in the future, indices could be developed using regression (as we attempted), or by ranking sites into toxicity categories and comparing the demographics between them. Certainly using level of toxicity is an avenue that should be explored more thoroughly in the future, when it can be better measured.

Given the ease of calculation, the interpretability of the numbers, and the high correlation to other measures, we conclude that test 1 is the best measure, and the normalized composite is the best candidate for a preliminary standardized EJ indicator. Test 2b is also a valuable quotient, but it measures a different aspect of EJ. Where test 1 captures comparative risk, test 2b reveals the relative burden a group bears. We feel the latter is less useful than test 1's information about the likelihood that each demographic group will be located in an at-risk area.

While we recommend the adoption of our CERI as a standardized indicator, investigators may have a specific research question that requires some other index. Our results can be used to clarify the strengths and relationships between other EJ indices and the standardized measure we propose. Note again that this measure does not adequately measure risk, but is a preliminary indicator that can be used to compare places. By substituting, for toxic sites, natural hazards that have a known location, transportation corridors, or environmental amenities such as parks or open space, the same index can be expanded to measure environmental justice in other dimensions. It is our hope that this index will have a direct impact on community groups and government agencies by making a contribution towards building sustainable communities in poor and minority neighborhoods in U.S. cities and providing benchmarks for detailed, site-specific analysis. ■

Notes

[1] EJ analyses typically measure inequity for minorities and/or the poor. We initially wanted to develop only two indices, one for minorities and one for poor, but we did not find an easy way to combine race and Hispanic variables at the block-group level.

[2] Poverty level is calculated annually by the Census Bureau based on a ratio of income to costs of an economic food plan. Number of family members is included in the calculation to determine the total number of persons below poverty level.

[3] We subtract p from 1.0 so that this index "reads" in a comparable form—i.e., a higher number means more inequality.

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