Distribution of Industrial Air Emissions by Income and Race in The United States: An Approach Using the Toxic Release Inventory

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Distribution of Industrial Air Emissions by Income and Race in The United States: An Approach Using the Toxic Release Inventory

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There currently is a scarcity of scientific information to guide public policy decisions about issues of "environmental justice"; broadly defined as the goal of achieving adequate protection from the harmful effects of environmental agents for everyone, regardless of age, culture, ethnicity, gender, race, or socioeconomic status. This paper highlights several key methodological issues that need to be addressed as part of ongoing efforts to strengthen the scientific foundation for informed decision-making regarding environmental justice. Specifically, careful thought must be given to the selection of appropriate (1) statistical tests, (2) geographic unit(s) of analysis, (3) exposure estimators, and (4) comparison (reference) populations. These methodological issues are examined in the context of a nationwide study looking at the differences by ethnicity/race and household income in county-level air emissions of industrial chemicals. National and regional comparisons are made for 1990 using emission estimates from the Toxic Release Inventory, demographic data from the Census, and income data from the Donnelley Marketing Information Services.

Introduction

There are mounting concerns that, compared to the general population, health risks from exposures to environmental agents in the United States are higher, on average, for those who are poor and non-white. As this issue has gained national prominence, it has been referred to by a variety of terms, including "environmental equity" (*1*), "environmental justice" (*2–4*), and "enrivornmental racism" (*5–11*). Much of the current debate has been stimulated by observational data suggesting that disadvantaged minority groups, especially African Americans and Hispanics (*1, 6, 8, 12–18*), are more likely than the general population to live near waste sites and industrial plants (*6, 13, 17, 18*) and to live in areas that violate one or more of the National Ambient Air Quality Standards (NAAQS, i.e., particulate matter, lead, ozone, carbon monoxide, sulfur oxides, and nitrogen oxides) (*7, 19, 20*). Nevertheless, there are inadequate data available on environmental exposures and related health effects to determine unequivocally (a) whether exposures differ systematically across socioeconomic classes or racial/ethnic groups, and (b) if they do, whether they cause disparities in health status among these groups.

Because attainment of environmental justice is a high priority on the nation's agenda for environmental health (*21*), it is important to understand the scientific basis for concern and to be cognizant of the implications for both research and policy decisions. The following discussion (a) provides a selective overview of the published literature on environmental justice, identifying some of the important methodological issues that must be taken into account, and (b) illustrates an approach applied to data aggregated at the county-level to study socioeconomic and ethnic/racial differences in airborne chemical releases from certain industrial operations.

Survey of Relevant Literature and Important Methodological Issues

Studies have been conducted on national, regional, and local scales to examine residential proximity to a limited number of environmental hazards by race/ethnicity and socioeconomic status (SES) (*6, 8, 13, 14, 16–18, 22–26*). Several studies have identified putative differences based on statistical correlations between (a) demographic and/or SES characteristics and (b) proximity to pollution sources at the county or zip code level (*6, 13, 14, 16, 22, 27*). These studies found positive, albeit sometimes small, correlations between the percentage of minorities in the study population and the presence of possible pollution sources or ambient levels of pollution. More recent studies (*23–25*) have shown that findings from these kinds of observational studies must be interpreted with caution because results are dependent on several key methodological issues. Among other things, findings related to issues of environmental justice can be affected profoundly by (a) selection of the geographical unit of analysis (e.g., counties, zip codes, block groups, areal rings based on distance from a source); (b) choice of statistical tests for evaluating differences among population subgroups; and (c) assumptions, either implicit or explicit, about how indirect measures of exposure (e.g., residential proximity to potential pollution sources) relate to actual exposures of people.

Methodological Critiques. As pointed out by Greenberg (*25*), different methodological approaches to examining environmental justice questions can give dramatically different results. By comparing several approaches to evaluate the demographics of towns and zip codes near waste-to-energy facilities (WTEFs), he demonstrated that findings are highly dependent on (a) choice of a statistical test (i.e., parametric versus nonparametric); (b) capacity of the WTEF and size of the host community; (c) selection of communities to be studied and those to be used for comparison; and (d) use of population-weighting techniques. Based on his research, Greenberg calls into question some of the conclusions reached in previous studies and highlights the need for a "standardized" approach(es) to environmental equity analysis.

Several recent studies (*23, 24, 28*) have evaluated two important questions: what is an appropriate geographic unit of analysis for a given situation and what impact does the choice of this unit have on the results of the analysis? The unit of analysis, often chosen as a matter of expediency based on how existing data are aggregated, may actually bear little relation to the potentially affected community and can "severely distort the outcome of the analysis" (*28*). Selection of an appropriate geographic unit of analysis should depend on the nature of the hazard being evaluated and the likely areal distribution of possible harm (*23, 24*). Different hazards will affect populations at different distances, depending on a variety of factors such as the characteristics of the source and pollutants, route of exposure, and meteorological and hydrological conditions. Moreover, there currently is little known about the relationship between distance from a pollution source, such as a hazardous waste site, and actual health risks (*24*).

Glickman et al. (*23*) explored the impact of using different units of analysis to examine the relationship between (a) the location of manufacturing facilities releasing toxicants into the air and (b) the socioeconomic and demographic characteristics of host and non-host communities in Allegheny County, Pennsylvania. They compared five different geographic units of analysis (i.e., block group, census tract, municipality, 0.5- and 1-mi radius circles around release points) and found that the choice of a unit of analysis had dramatic effects on findings related to ethnicity/race, but relatively little effect on findings related to poverty. They concluded that selection of the geographic unit of analysis is critical for meaningful evaluation of environmental justice issues and that the appropriateness of a particular unit of analysis will vary according to the nature of the situation at hand.

In a nationwide study, Anderton et al. (*24*) compared the social and demographic characteristics of census tracts hosting commercial hazardous waste treatment, storage, and disposal facilities (TSDFs) to census tracts not having TSDFs. In contrast to several previous studies (*6, 8, 18*), they found that TSDFs are no more likely to be located in tracts with higher percentages of blacks and Hispanics than in other tracts. Instead, the most consistent finding was that TSDFs were located in tracts with larger porportions of workers in industrial occupations and residents living in less expensive, more recently built housing. To test the sensitivity of these findings to the size of the geographic area, the authors evaluated a larger area, consisting of all tracts located on the periphery of a 2.5-mi radius circle around each TSDF. The findings "change dramatically", becoming more consistent with previous studies, with TSDF areas having a higher percentage of Hispanics, blacks, and families below the poverty line compared to other census tracts. The authors conclude that "claims of the previous studies rest on using larger areal aggregates (zip code areas) on the peripheries of which the densities of minority populations are higher". They speculate that the latter findings "reflect broader residential patterns largely unaffected by, and ineffective on, decisions of where to locate TSDFs".

Exposure Estimators. Another important methodological issue relates to the selection, use, and interpretation of exposure estimators. When suitable exposure measurements or models are unavailable, indirect surrogates such as emission inventories combined with proximity to release points often are used to classify or infer exposures. Because these exposure surrogates are far removed from the real point of contact between people and pollution, the use of such surrogates necessarily incorporates a variety of explicit and implicit assumptions. Consequently, using surrogates to estimate actual human exposures can be highly inaccurate and imprecise and carries with it a great deal of uncertainty (*29–31*). With the exception of the lead project conducted by the Agency for Toxic Substances and Disease Registry (ATSDR) (*26*), none of the studies we reviewed (*6, 8, 13, 14, 16–18, 22–25*) have relied on measurements of actual human exposure or dose to evaluate issues of environmental justice.

As shown in Figure 1, although the costs to obtain information about production volumes or emission estimates for environmental agents are relatively low, these data may be only marginally useful in predicting or classifying exposures accurately (*29*). According to the National Research Council (*30*), combining information about place of residence with emission estimates provides a relatively "poor" approximation of actual exposures.

It is important, therefore, to understand that residing in a county, zip code, or census tract with one or more potential sources of pollution (e.g., hazardous waste site, chemical plant) or with above-average pollutant emissions does not necessarily imply that residents are exposed to higher than average ambient concentrations of environmental agents. There may, in fact, be no direct relationship within a particular geographic unit of analysis between (a) the presence of potential sources and/or estimated contaminant releases to the environment and (b) actual ambient levels of pollution encountered by people living there. Testing of hypotheses about differences in environmental exposures is best accomplished by direct measurement of personal exposure or dose (*29, 30*).

County-Level Comparisons of Industrial Air Pollution Emissions

Possible differences in ambient exposures to hazardous air pollutants, based on race or class, are an important aspect of the debate about environmental justice (*31*). Analysis and comparison of air pollution exposures for different demographic and socioeconomic groups are however necessarily constrained by the nature, extent, and quality of the available data. The 1990 Census data allow for analysis of demographic and socioeconomic variables across a spectrum of different levels of geographic ag-

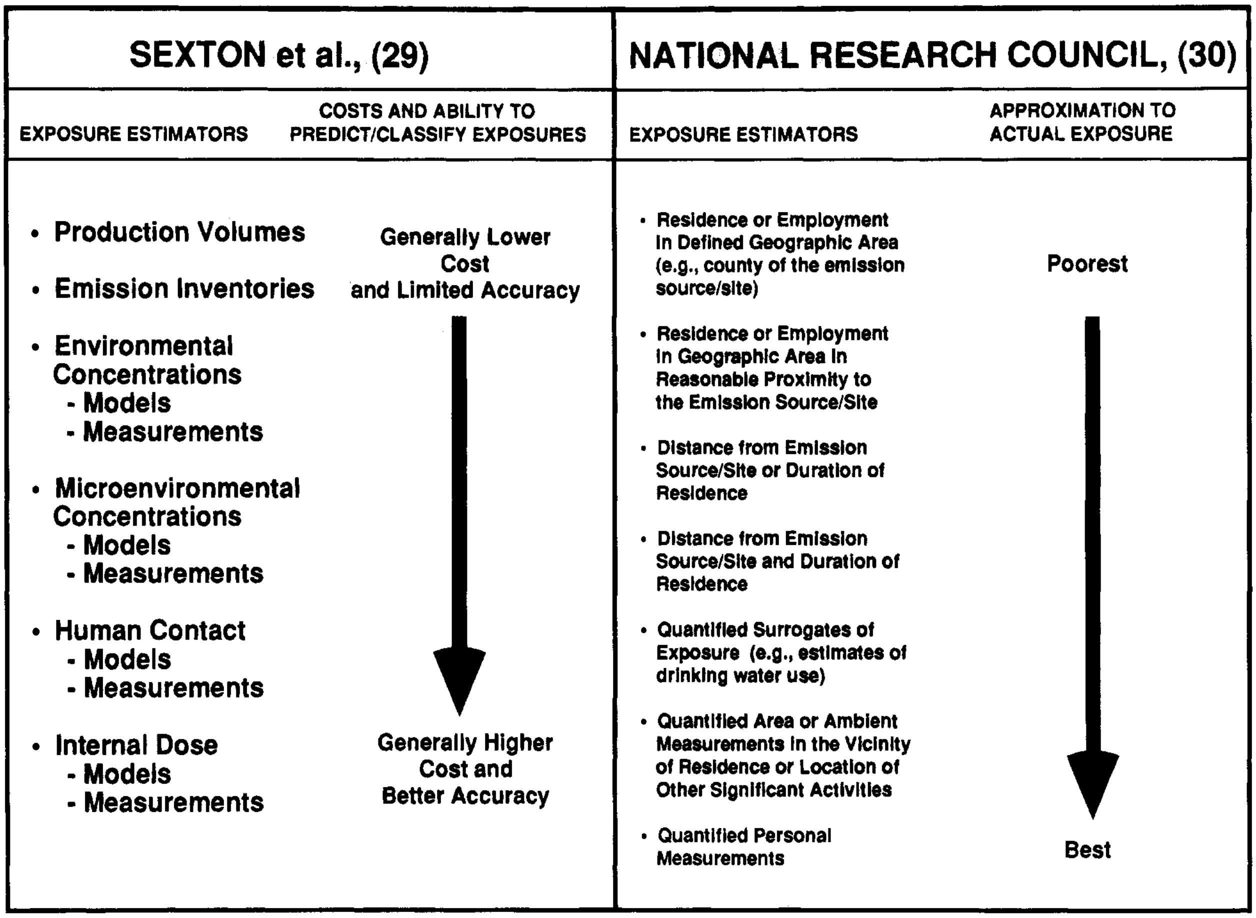


FIGURE 1. Comparing the relative merits of different exposure estimators.

gregation, including national, state, county, census tract, block group, or individual block. Nevertheless, accurate estimation of human exposures to hazardous air pollutants across all levels of geographic aggregation is constrained by the paucity of suitable monitoring methods, relevant ambient measurements, and validated models for predicting exposures to populations of interest (*29, 31*).

Although exposure data are lacking, emission estimates for many hazardous air pollutants are available from a national database called the Toxic Release Inventory (TRI) (*32–34*). The TRI has many limitations (*35*), and as pointed out by the National Research Council (*36*), relying solely on TRI data to estimate exposures is inappropriate.

> "Although the TRI provides useful information on estimated mass quantities of chemical releases, it does little to assist in understanding the potential for humn exposure to those releases and resulting impacts on public health. The inclusion of accidental and routine emissions in the total releases reported to the TRI makes estimation of downwind concentrations and exposures technically infeasible. The separate types of releases involve different exposure issues and require different analyses for determination of exposure and exposure impact. The TRI database is useful in identifying chemicals of concern, which may, with further analysis, provide data needed for exposure assessment." ..."The [TRI] data, by themselves, are inappropriate for assessing either acute or chronic exposures, because they are not linked specifically to the potential concentrations and locations of exposure of the general population ... TRI data are only one type of input data for air-dispersion models ... used to estimate potential downwind concentrations, which are then linked with human time–activity data to assess potential exposures."

We are in complete agreement with the NRC position that TRI data alone cannot and should not be used for exposure assessment. With these caveats in mind, we use TRI estimates of airborne emissions aggregated at the county level, in combination with demographic and socioeconomic data, to examine national and regional differences in emissions according to ethnicity/race and household income. The goal is to get a sense for how counties in the United States vary according to these parameters and to identify potential chemicals and/or counties for further study.

We do not assume, nor should the reader, that county-level differences in TRI emissions are necessarily associated with differences in exposure. Measurements of actual exposure/dose are required to test the hypothesis that residents of counties with higher TRI emissions experience correspondingly higher exposures.

Data Sources

We have examined the relationships among airborne emissions from certain industrial facilities and three demographic variables (ethnicity/race, household income, and urban versus rural residence) using 1990 demographic data from the Census and Donnelley Marketing Information Service (*37*) and 1990 emissions estimates from the

TABLE 1

Distribution of TRI Facilities and Racial/Ethnic Subpopulations[a] Among the EPA Regions in 1990

EPA	TRIs[c]		total of all	white		black		Native American[g]		A/P Islander[h]		other races[i]		Hispanic[j]	
regions[b]	no.	%	races (×1000)[d]	no.[e] (×1000)	%[f]	no.[e] (×1000)	%[f]	no.[e] (×1000)	%[f]	no.[e] (×1000)	%[f]	no.[e] (×1000)	%[f]	no.[e] (×1000)	%[f]
1	1528	7.0	13208	12033	6.0	628	2.1	33	1.7	232	3.2	282	2.9	568	2.5
2	1671	7.6	25721	19516	9.8	3896	13.0	78	4.0	966	13.3	1265	12.9	2954	13.2
3	2033	9.3	25917	21146	10.6	4011	13.4	49	2.5	464	6.4	247	2.5	575	2.6
4	4286	19.6	44708	34814	17.4	8979	30.0	179	9.1	389	5.4	347	3.5	1886	8.4
5	5843	26.7	46384	39894	20.0	4912	16.4	200	10.2	651	8.9	727	7.4	1492	6.7
6	2072	9.5	28218	21288	10.7	3959	13.2	484	24.7	421	5.8	2066	21.1	5118	22.9
7	1356	6.2	11950	10881	5.5	797	2.7	62	3.1	111	1.5	99	1.0	225	1.0
8	444	2.0	7604	6931	3.5	157	0.5	186	9.5	107	1.5	223	2.3	557	2.5
9	1981	9.1	35734	24869	12.5	2425	8.1	470	24.0	3624	49.8	4346	44.3	8582	38.4
10	650	3.0	9264	8311	4.2	221	0.7	219	11.2	309	4.3	204	2.1	398	1.8
total	21864		248708	199683		29985		1960		7274		9806		22355	
M/W[k]						0.15		0.01		0.04		0.05		0.11	

[a] Racial/ethnic subpopulation category definitions and counts are from the 1990 Census, Public Law 94-171. [b] See Figure 2A for Location of EPA regions. [c] Total number of TRI facilities in the region and as a percent of the total number of United States TRI facilities. Total number of TRIs in the United States is 21864. [d] For each region, the total United States population of all races (white, black, Native American, Asian and Pacific Islander, and other races). [e] Total number of each racial/ethnic group residing in the specified region. [f] Percent of the U.S. population of each racial/ethnic group that resides in the specified region. [g] Native American includes Inuits and Aleuts. [h] A/P Islander is Asian and Pacific Islanders. [i] Other races includes the remaining races that constitute the non-white population. On a racial basis, the Census Bureau divides the total United States population into whites, blacks, American Indians, Asian or Pacific Islanders, and other races. On an ethnic basis, the Census Bureau divides the total United States population into people of Hispanic or non-Hispanic origin. Population counts by race do not distinguish between individuals of Hispanic and non-Hispanic origin. For example, a person identified as a white Hispanic would be counted as both "white" and "Hispanic". [j] Hispanics are counted separately as they are considered to be an ethnic population, not a race, and are counted separately by the Census Bureau. [k] Ratio of minority to white population for the United States. These values are the N_{CS}/N_{CW} used in eqs 2 and 3 and to construct Table 5.

Environmental Protection Agency's Toxics Release Inventory.

Demographic Data. Data from the 1990 Census (Public Law (PL) 94-171) were used to enumerate the populations of all U.S. counties by race (white, black, Native American, Asian or Pacific Islander, and all remaining races categorized as "other") and ethnicity (Hispanics). Median household income from the Donnelley Marketing Information Services (DMIS) was used because similar 1990 Census data were not available at the time of the analysis. The 1990 DMIS estimates are based on projections from the 1980 Census, with values adjusted where necessary (using income data from the Internal Revenue Service and inflation data from the Consumer Price Index) to produce county-level income estimates (*37, 38*). Using both DMIS and Census data precluded simultaneous analysis of income and race/ethnicity, making it impossible to control for one while analyzing the other.

Emissions Data. The 1990 TRI includes information on about 320 individual chemicals and chemical categories for all U.S. manufacturing facilities that meet the following criteria: (a) employ 10 or more fulltime employees and (b) manufacture, process, or import more than 25000 lb annually or otherwise use more than 10000 lb annually of any chemical on the TRI list (*32, 33*). Companies subject to TRI requirements must report the total amounts (including routine releases and accidental spills or leaks) of all listed chemicals that are released directly to the air, water, or land or injected into underground wells (*34*).

Our analytical results were generally consistent across the following categories: all chemicals, all carcinogens, all carcinogens listed in the 1990 Clean Air Act, all hazardous air pollutants listed in the 1990 Clean Air Act that are not carcinogens, all chemicals associated with the synthetic organic chemical manufacturing industry, all metals, all pesticides, and the 17 chemicals listed in the EPA's 33/50 Program (*39*). The following discussion presents results only for (a) all TRI chemicals and (b) the 17 chemicals listed in the EPA's 33/50 program (*40*).

Results

Geographic Distribution of People, TRI Sources, and Air Releases. As shown in Table 1, TRI facilities and racial/ethnic populations are not uniformly distributed across the United States or among EPA regions (see Figure 2A for location of EPA regions). For example, EPA regions 4 and 5 combined contain 46% of all TRI facilities, 46% of the nation's black population, and 37% of the nation's white population. In contrast, almost half of the Asian/Pacific Islanders and other races and a little more than one-third of the Hispanics live in region 9, which accounts for only about one-tenth of all TRI facilities.

Tables 2 and 3 show that household income is not uniformly distributed across the United States, among EPA regions, or between urban and rural counties. For example, compared to the United States as a whole, a larger proportion of the households in regions 2, 4, 6, 7, and 10 are very poor (i.e., annual income less than \$7500). Region 6 has the largest proportion (13.5%) of very poor households. By contrast, regions 1, 8, and 9 have the highest proportion (9.1–10.8%) of wealthy households (income >\$75000). There appears to be no correlation on a regional basis between the median household income and the number of TRI facilities.

Nationally, rural counties have a higher proportion of households with incomes both less than \$7500 and less than \$15000. Urban counties have a higher proportion of households with incomes over \$35000 (Table 3). Rural counties also have a lower median household income (\$25980) compared to urban counties (\$29230) (Table 2). In regions 1 and 3, the proportion of households at all income levels tends to be more evenly distributed between urban and rural counties. In region 8, compared to urban

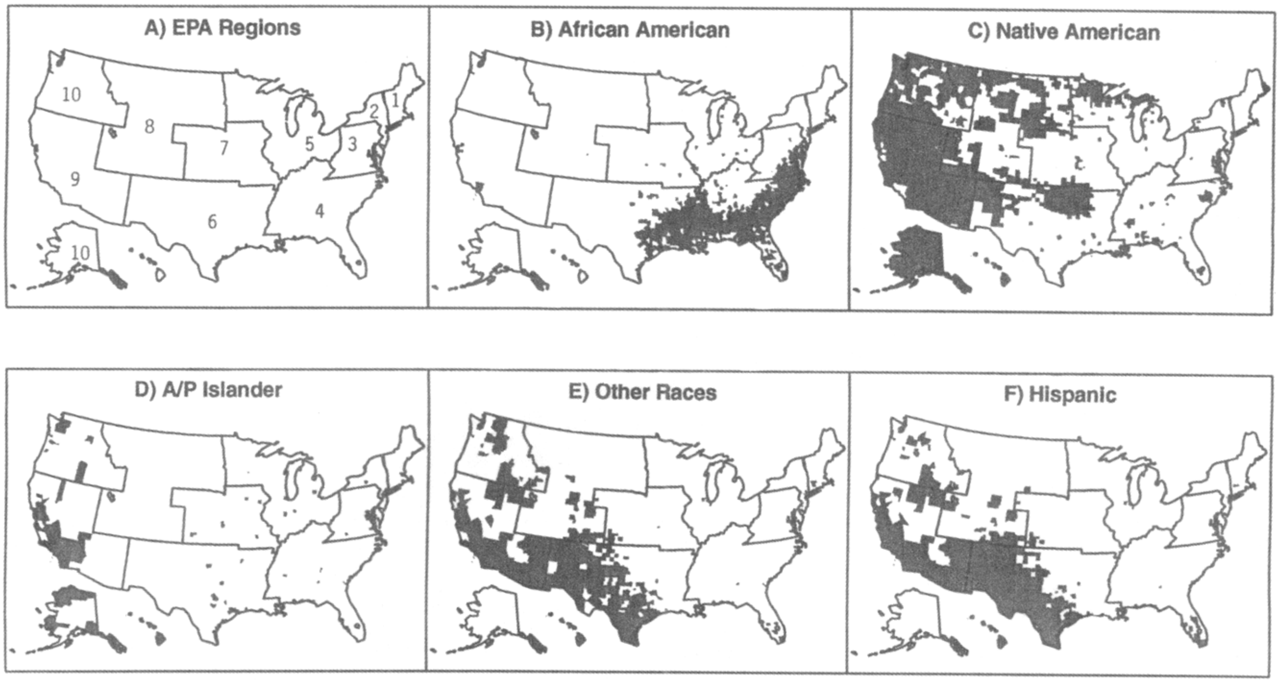


FIGURE 2. Geographic Distribution of 1990 racial/ethnic populations, by county, based on specified minority to white ratios. Shaded areas indicate counties where the specified minority to white ratio is greater than the national ratio. The national ratios (N_{CS}/N_{CW} in eqs 2 and 3) are as follows: 0.15 blacks; 0.01 Native Americans; 0.04 Asian/Pacific Islanders; 0.05 other races; and 0.11 Hispanics. The United States, including Guam, the Virgin Islands, and Puerto Rico, is divided into 10 regions by the Environmental Protection Agency (EPA). The boundaries and locations of the 10 EPA regions are indicated in the upper left panel. Alaska is part of region 10; Guam and Hawaii are part of region 9; the Virgin Islands and Puerto Rico are part of region 2. [Note: This study covers only the 50 states.]

TABLE 2

Distribution of Annual Median Household Income for the United States and EPA Regions in 1990

	HH in U.S.[c] (%)	households in EPA regions[a] (%)									
		1	2	3	4	5	6	7	8	9	10
HH[b] income ($1000)											
<7.5	10.9	7.8	11.6	9.6	12.0	10.8	13.5	12.1	9.8	9.0	11.3
7.5–<10	6.7	6.7	6.6	6.3	7.5	5.9	6.7	7.0	6.9	6.4	6.4
10–<15	9.3	7.6	9.9	8.5	10.0	8.9	10.5	10.1	8.7	8.3	9.4
15–<25	18.6	16.5	20.7	18.1	19.5	18.0	19.9	19.9	17.6	17.5	18.7
25–<35	16.8	15.5	18.7	17.0	16.2	18.1	17.4	17.8	15.9	15.2	17.5
35–<50	17.7	19.8	17.6	18.5	16.6	18.8	16.5	17.2	18.1	17.9	17.9
50–<75	12.6	15.8	10.3	13.6	11.4	12.9	10.2	10.6	13.8	15.0	12.3
>75	7.5	10.4	4.7	8.5	6.9	6.6	5.2	5.2	9.1	10.8	6.5
median HH income[d] for all counties ($1000)	27.8	32.4	25.6	29.5	25.6	28.6	24.7	25.4	29.3	30.8	27.4
median HH income for all urban counties ($1000)[e]	29.2	32.3	26.3	29.5	27.3	30.0	26.6	28.5	29.5	31.6	30.4
median HH income for all rural counties ($1000)[f]	26.0	32.5	23.4	29.4	23.9	26.8	21.8	25.0	29.3	23.7	23.7
no. of HH[g]	93.92M	4721.6K	614.4K	10491.9K	19518.2K	15534.8K	11205.3K	7513.3K	8590.3K	11699.8K	4029.6K
no. TRIs[h]	21864	1528	1671	2033	4286	5843	2072	1356	444	1981	650
(%)		(7.0)	(7.6)	(9.3)	(19.6)	(26.7)	(9.5)	(6.2)	(2.0)	(9.1)	(3.0)

[a] Values for each EPA region represent the percent of households in the region that are within the specified income category. See Figure 2A for location of EPA regions. Each value is based on the total number of households in the specified region. [b] HH is household. [c] Values represent the percent of households within the whole country that are within the specified income category. [d] Values are the median annual household income for the nation ($27800) and each of the regions. [e] Values are the median annual household income for all urban counties in the nation ($29200) and each of the regions. [f] Values are the median annual household income for all rural counties in the nation ($26000) and each of the regions. [g] Values are the total number of households in the country and each region, expressed in millions and thousands, respectively. There are 93.92 million households in the United States. [h] Values are the number of TRI facilities in the country (21864) and each region. The numbers in parentheses are the percent of the total number of facilities in the nation.

counties, rural counties have a much higher proportion of households with incomes over $75000. Compared to the nation as a whole and the other regions, regions 9 and 10 have a higher proportion of the very poorest households (<$7500) in their rural counties.

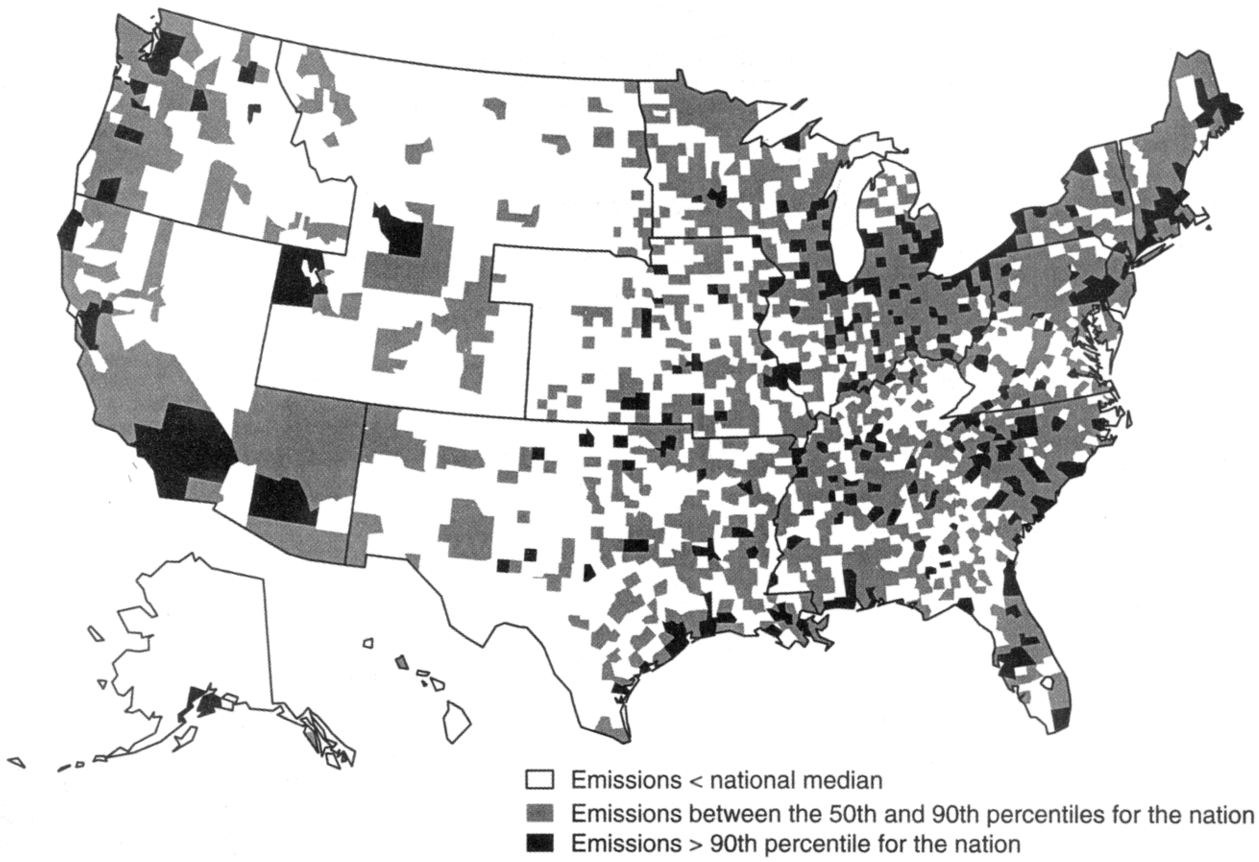
The geographic distribution of racial/ethnic subpopulations by county is shown graphically in Figure 2. The geographic distribution by county of emissions to air of all TRI chemicals is shown in Figure 3. The geographic distribution of air emissions of EPA's 33/50 high-priority

TABLE 3

Comparison of Distribution of Annual Household Income for Urban and Rural Counties for the United States and by EPA Region for 1990

household income ($1000)	ratio of urban:rural HH in U.S.[a] (%)	ratio of proportion of urban:rural households in EPA region[b]									
		1	2	3	4	5	6	7	8	9	10
<7.5	0.8	1.0	0.8	1.0	0.8	0.8	0.8	0.9	0.9	0.7	0.7
7.5−<10	0.8	0.9	0.9	1.0	0.9	0.9	0.7	0.8	0.7	0.8	0.8
10−<15	0.9	1.0	0.9	1.0	0.9	0.9	0.8	0.9	0.9	0.7	0.8
15−<25	1.0	1.0	0.9	1.0	1.0	0.9	1.0	0.9	1.1	0.8	0.9
25−<35	1.0	1.1	1.0	1.0	1.0	1.0	1.1	1.0	1.2	0.9	1.0
35−<50	1.1	1.0	1.1	1.0	1.1	1.1	1.2	1.1	1.1	1.1	1.2
50−<75	1.2	1.0	1.3	1.0	1.2	1.2	1.4	1.3	1.0	1.6	1.6
>75	1.2	1.0	1.4	1.0	1.2	1.2	1.3	1.3	0.7	2.3	2.0
no. of HH in urban counties[c]	50.71M	2670.9K	480.2K	5643.8K	10529.8K	8504.2K	7075.0K	1115.2K	1720.7K	10665.6K	2308.4K
no. of HH in rural counties[d]	43.21M	2050.7K	134.2K	4848.0K	8988.4K	7030.5K	4130.3K	6398.1K	6869.6K	1034.2K	1721.3K

[a] HH is household. The values for the United States are the ratios of the proportion of households in urban counties to households in rural counties within the specified income category. For example, for household incomes <$75000, the proportion of households in urban counties is 20% greater than the proportion of households in rural counties. The Census Bureau defines urban counties as those within metropolitan statistical areas (MSAs). [b] Values for each EPA region are the ratio of the proportion of households in urban counties to the proportion of households in rural counties within the specified income category. See Figure 2A for location of EPA regions. [c] Values are the total number of households in the country (50.71 million) and each EPA region (expressed in thousands) that are located in counties designated as urban by the Census Bureau. [d] Values are the number of households in the country (43.21 million) and each EPA region (expressed in thousands) that are located in counties designated as rural by the Census Bureau.



chemicals is very similar to the pattern of distribution for all TRI chemicals.

Table 4, Section A, provides data on the distribution of county-level air emissions by race/ethnicity for all TRI chemicals, and Table 4, Section B, presents similar data for the 33/50 chemicals. The distributions for both differ markedly among racial/ethnic groups. With the exception of Native Americans, minority groups tend to live in counties where emissions are higher compared to the emissions in counties where whites live. For example, the 50th percentile of county-level emissions for all TRI chemicals and for the 33/50 chemicals is about twice as high for blacks, Asian/Pacific Islanders, and other races as for whites. For blacks, the 90th percentile of county-level emissions for all TRI chemicals and for the 33/50 chemicals is approximately twice the level for whites. The 90th percentile of county-level emissions for Asian/Pacific Islanders, other races, and Hispanics is about four times greater than for whites for all

TABLE 4

1990 Air Emissions ($\times$1000 lb/yr) Distribution by Race/Ethnicity[a]

percentile	white	black	Native American	A/P Islander	other races	Hispanic[b]
			Section A: For All TRI Chemicals			
10	19.0	42.8	0	92.1	75.4	44.4
25	225.9	489.1	45.3	686.9	497.3	476.4
50	1162.0	2066.3	466.1	2204.5	2355.7	1874.4
75	3974.1	5336.6	2148.7	6152.6	25414.5	7839.5
90	7826.4	16484.0	5568.2	28139.4	29789.4	29115.2
100	95212.0	95212.0	95212.0	95212.0	95212.0	95212.0
			Section B: For EPA's 33/50 High-Priority Chemicals			
10	0.01	9.2	0	40.0	13.7	10.7
25	89.5	208.4	0.001	259.3	186.4	186.0
50	543.2	896.5	139.1	973.6	1139.3	896.4
75	2100.0	2974.2	896.2	3478.6	8292.5	4173.3
90	4242.7	7386.2	3249.9	19763.2	20093.7	19901.1
100	20869.1	20869.1	20869.1	20869.1	20869.1	20869.1

[a] See Table 1 for definition of racial/ethnic subpopulations. Nationally, the total population in each subgroup is as follows: whites (199.68M), blacks (29.99M), Native Americans (1.96M), Asian and Pacific Islanders (7.27M), other races (9.80M), and Hispanics (22.35M). [b] Hispanics are counted separately as they are considered to be an ethnic population, not a race, and are counted separately by the Census Bureau.

TRI chemicals and almost five times greater than whites for the 33/50 chemicals.

The geographic distribution of TRI facilities, air emissions, minority populations, and household incomes differ not only by region of the country but also by degree of urbanization. In 1990, of the 3137 counties in the United States, 696 (22%) were urban (i.e., identified by the Census Bureau as being in a metropolitan statistical area); however, they contained 66% (14408) of all TRI facilities, and these facilities were associated with 64% (1.4×10^9 lb/yr) of the total air emissions for all TRI chemicals. In contrast, there were 2441 (78%) rural counties, containing 34% (7456) of all TRI facilities, and these facilities were associated with 36% (7.8×10^8 lb/yr) of the total air emissions for all TRI chemicals.

Emission Index Approach to Analysis. If each person residing in a particular county is assigned a score equal to the total pounds of TRI emissions for one or more chemicals, then it is possible to calculate and compare the distribution of scores by ethnicity/race and/or by SES. We used this approach to calculate a parameter we call the population emission index.

The population emission index (PEI) is defined as follows:

$$\mathrm{PEI}_s = \frac{\sum_{c \in C} R_c n_{cS}}{N_{CS}} \qquad (1)$$

Where R_c is the rate (lb/yr) of TRI chemicals released in county c; n_{cS} is the number of people in subpopulation S (e.g., Asian Americans, income less than \$15000/yr) in county c; C is the set of all counties being considered in the analysis (e.g., total in the United States, total in EPA region 5), and N_{CS} is the total number of people in subpopulation S who reside in the set of all counties C. Thus, the PEI is a single, population group-specific, average air emission value that applies to all members of a specific population subgroup who reside within the counties of interest.

To examine whether emissions differences exist at the county level, it is necessary to compare the PEI for a particular demographic group against some reference or baseline value. For purposes of this analysis, the reference group against which racial/ethnic minorities are compared is the white population of the study area (i.e., total white population in the 50 states). The reference group for SES is households in the study area with annual incomes between \$25000 and \$35000 (i.e., the range that includes the median household income for the United States).

By comparing the PEI for the subpopulation of interest, say Hispanics ($\mathrm{PEI_H}$), to the PEI for the reference group, whites ($\mathrm{PEI_W}$), it is possible to calculate the population emission ratio (PER) for the subpopulation of interest. A PER of 1.0 means that the population subgroup has the same PEI as the reference group and that the average county-level air emissions of TRI chemicals are equivalent for both groups. Values of PER much greater than 1.0 mean that the average member of the population subgroup lives in a county with greater TRI air emissions compared to the average member of the reference group.

PERs were calculated on a national basis for total air emissions of all TRI chemicals and for the 33/50 high-priority chemicals. Figure 4A,B presents the PERs for all TRI chemicals based on race/ethnicity and household income, respectively (the PERs for the 33/50 chemicals were similar). The PERs for all minorities, except Native Americans, were greater than 1.0. For example, the average African American (PER = 1.6) in the United States lives in a county with roughly 60% more TRI air releases than a county in which the average white person lives. The PERs for the different income categories were smaller compared to the PERs for the minority groups and indicated that, on average, households with lower annual incomes (<\$25000) were in counties with lower TRI air releases compared to the counties for the reference group (i.e., households earning \$25000–35000).

We were interested in examining the characteristics of counties that contributed in a similar manner (either positively or negatively) to the PER. To accomplish this, we used eq 1 to develop the following relationship:

$$\mathrm{PER_S} = \frac{\mathrm{PEI_S}}{\mathrm{PEI_W}} = 1 + \frac{\sum_{c \in C} (R_c - R^*)\left[\frac{n_{cS}}{N_{CS}} - \frac{n_{cW}}{N_{CW}}\right]}{\sum_{c \in C} R_c \frac{n_{cW}}{N_{CW}}} \qquad (2)$$

where $\mathrm{PER_S}$ is the population emission ratio for the

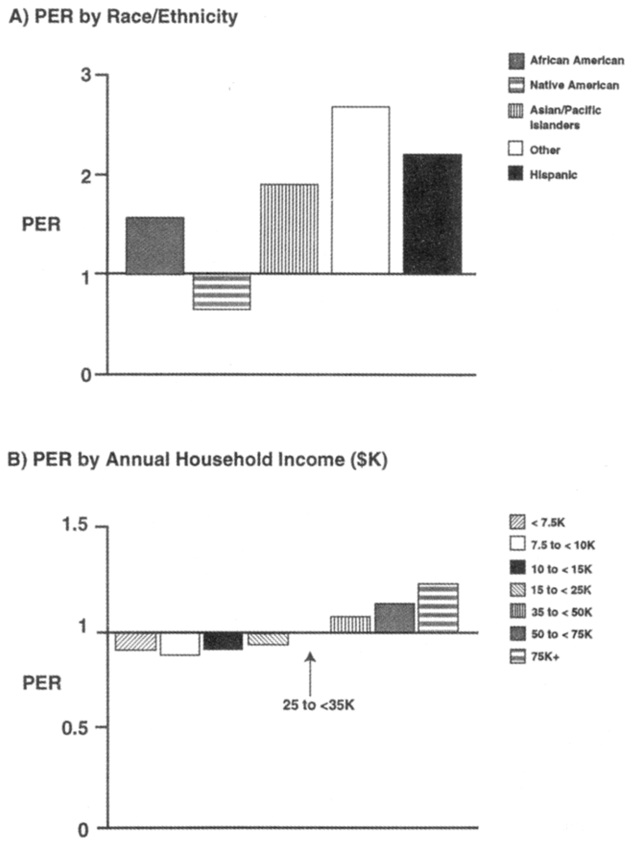


FIGURE 4. National population emission ratios (PERs) based on 1990 data for race and household income. (A) The PER for each race/ethnic subgroup is the ratio of PEI_S/PEI_W. (B) The PER for annual household income is the ratio of $PEI_S/PEI_{\$25-35K}$. PEI_S is the population emission index for the race/ethnic or household income subgroup of interest; PEI_W is the population emission index for the reference group of whites; and $PEI_{\$25-35K}$ is the population emission index for the reference group whose annual household income is \$25–35K. Population emission indices were calculated using eq 1. See Table 1 for definition of race/ethnic groups.

subpopulation S of interest to the PEI for whites; n_{cW} is the number of whites residing in county c; and N_{CW} is the total number of whites residing in the set of counties C. R^* is a reference value for whites for the TRI air release measure in counties *C*. R^* may represent, for example, the median emissions for whites for all counties in the region under study or the median emissions for whites for all counties in the United States. Other terms are as defined for eq 1.

The value of PER_S in eq 2 is unaffected by the value of R^*. In contrast, changing the value of R^* will affect the determination of which individual counties exceed this reference value. For example, the value of R^* can be set so that only counties with much higher than average emissions (e.g., upper 2 percentile) will exceed the reference value.

Since the denominator of the fraction on the right side of eq 2 is always positive, a county makes a positive contribution to the PER whenever its contribution to the numerator is positive. Determination of conditions under which this is true is simplified by noting the following relationship:

$$\frac{n_{cS}}{N_{CS}} - \frac{n_{cW}}{N_{CW}} > 0 \leftrightarrow \frac{n_{cS}}{n_{cW}} > \frac{N_{CS}}{N_{CW}} \tag{3}$$

That is, the mathematical operation on the left side of the equivalency sign in eq 3 yields a positive value for a given county c, if and only if, the ratio in county *c* of subpopulation S residents to reference group W residents is greater than the same ratio for the entire region under study.

Thus, a particular county increases the PER by satisfying either of two conditions: (a) the county has large emissions relative to the reference emission value ($R_c > R^*$) *and* a large subpopulation (n_{cS}) relative to the reference group (n_{cW}) such that $n_{cS}/n_{cW} > N_{CS}/N_{CW}$ (i.e., both terms in the numerator are positive); or (b) the county has low emission levels ($R_c < R^*$) *and* a small subpopulation relative to the reference group such that $n_{cS}/n_{cW} < N_{CS}/N_{CW}$ (i.e., both terms in the numerator are negative). Keeping in mind that we have made the simplifying assumption that all residents of a particular county have the same PEI, it follows that the above two conditions are complements of each other. Condition a increases the PER because minorities are overrepresented in counties having high emissions relative to R^*. Condition b increases the PER because minorities are underrepresented in counties having low emissions relative to R^*.

Table 5, Sections A (all TRI chemicals) and B (the 33/50 chemicals), show the number of counties, either urban or rural, that increase the PER by satisfying condition a, that is, in which the specified minority to white ratio exceeds the national ratio (i.e., N_{CS}/N_{CW}) *and* in which TRI airborne emissions exceed the national median for whites (i.e., R^*). These data show that, for the R^* and N_{CS}/N_{CW} we have selected, relatively few (e.g., less than 10%) of the 3137 counties in the United States satisfy condition a for any ethnic/racial group, and of those that do, most are urban. However, more than 43% of blacks, Asian/Pacific Islanders, other races, and Hispanics reside in these counties.

The spread of the data (i.e., for the 3137 United States counties) around the baseline values, $R^* = 10^6$ lb/yr and $n_{cs}/N_{CS} - n_{cW}/N_{CW} = 0$, is summarized graphically in Figure 5 for African Americans and Native Americans (results were generally similar for the other minority groups). Total TRI air emissions (lb/yr) span 8 orders of magnitude, with most counties in the range of 10^5–10^7 lb/yr. The difference between the minority to white ratio in the county versus that in the United States is near zero for the vast majority of counties.

Those counties in the upper right quadrant of each graph are the same as those listed in Table 5, Section A; that is, the counties that have both total air emissions exceeding the national median for whites and minority to white ratios exceeding the national ratio. Only a very small number of counties exceed both baseline values by a noticeable margin. In the case of African Americans (as well as Asian/Pacific Islanders, other races, and Hispanics), a relatively large percentage of the population resides in these few counties, which tend to drive the calculated group-specific PEIs and PERs. It is also worth noting that, compared to African Americans, Native Americans exhibit more values in the lower right quadrant and fewer in the upper right quadrant. This is consistent with the fact that only Native Americans had a calculated national PER less than 1.0 (see Figure 4A).

Discussion

By calculating population emission indices (PEIs) and population emission ratios (PERs), we have examined whether ethnicity/race or household income is associated with county-level emissions of certain industrial air pol-

TABLE 5

Counties in 1990[a] Where the Ratio of Minority to White Exceeds the National Ratio[b] and Where Total Air Releases Exceed the National Median for Whites

	rural counties				urban counties[h]			
			% national population				% national population	
minority[c]	no. of counties[d]	population in counties (×1000)[e]	minority[f]	white[g]	no. of counties[d]	population in counties (×1000)[e]	minority[f]	white[g]
Section A: All TRI Chemicals								
black	45	571.1	1.9	0.7	92	13168.4	43.9	18.9
Native American	18	37.9	1.9	0.4	35	274.2	14.0	7.6
A/P Islander	1	0.6	0	0	34	3139.9	43.2	15.2
other races	10	40.2	0.4	0.2	34	4779.7	48.7	15.0
Hispanic	5	56.8	0.3	0.1	32	10337.3	46.2	14.7
total	64[i]	N/A[j]	N/A	N/A	140[i]	N/A	N/A	N/A
Section B: EPA's 33/50 Chemicals								
black	36	524.6	1.7	0.6	89	14372.8	47.9	20.1
Native American	11	14.2	0.7	0.2	27	238.3	12.2	6.6
A/P Islander	0	0.0	0	0	37	3405.3	46.8	16.3
other races	1	2.3	0	0	32	5191.2	52.9	15.9
Hispanic	1	3.8	0	0	31	11211.8	50.2	15.7
total	43[i]	N/A	N/A	N/A	130[i]	N/A	N/A	N/A

[a] Median emissions for whites are approximately 10^6 lb/yr for all TRI chemicals and 543000 lb/yr for the 33/50 chemicals (see Table 4, Sections A and B). [b] National ratios of minority to white (e.g., N_{CS}/N_{CW} in eqs 2 and 3) are as follows: 0.15 (blacks), 0.01 (Native Americans), 0.04 (Asian and Pacific Islanders, 0.05 (other races) and 0.11 (Hispanics). [c] See Table 1 for definition of minority populations. [d] Values indicate the number of counties satisfying both criteria (i.e., ratio of minority to white exceeds the national ratio and total air releases exceed the national median for whites) for the specified minority group. [e] Total population of specified minority within those counties satisfying both criteria. [f] Percent of national population of specified minority who live in those counties satisfying both criteria. [g] Percent of national population of whites who live in those counties satisfying both criteria. [h] Counties are considered urban if they are within a metropolitan statistical area (MSA), as defined by the Census Bureau. [i] Totals indicate the number of counties satisfying both criteria for at least one minority. [j] N/A means not applicable.

lutants. The PER analysis indicates that on a national basis members of several racial/ethnic groups (i.e., blacks, Asian/Pacific Islanders, other races, and Hispanics) are more likely, on average, to live in a county with higher TRI air releases than the median value for whites (Figure 4A). The PERs also suggest that, on average, annual household income tends to be higher in counties with higher TRI air releases compared to counties where household incomes are between \$25000 and \$35000 (e.g., median household income for the nation) (Figure 4B).

This seemingly incongruous finding, that both a higher percentage of minorities and higher household income are positively associated with TRI emissions, underscores the problem of using data aggregated at the county level. Although only 22% (696) of the 3137 counties in the United States are classified as urban, they contain 66% (14408) of the TRI facilities, and these facilities account for 64% (1.4×10^9 lb/yr) of the total TRI air releases. Urban counties also tend to have a higher proportion of both minorities and households earning more than \$35000 per year. The confounding effect of assuming that everyone in the same county has the same PEI may lead to the seemingly anomalous result that higher PERs are associated with minority status and with higher household income; a finding consistent with Gelobter (*14*), who found higher levels of some ambient air pollutants at the county level associated with higher incomes.

Another important factor in the interpretation of PERs relates to the reference (baseline) values used in eq 2. The PER value is affected directly by the choice of which population is chosen as the basis for comparison (e.g., non-Hispanic whites, both Hispanic and non-Hispanic whites, whites or other racial groups). Although selection of the value for R^* does not affect the calculated PER, it does affect how many and which counties will exceed this reference value. Analyses using the PEI/PER approach should be explicit about which reference values were used and why.

The uneven geographic distribution of ethnic/racial groups (Figure 2; Table 1), household income (Table 2), household income for urban and rural counties (Tables 2 and 3), and TRI air emissions (Figure 3; Table 1) means that national statistics (e.g., PEI, PER) mask potentially important regional and local differences and must be interpreted with caution. Using the PEI/PER approach described earlier, only 204 (6.5%) of the 3137 counties have both (a) a minority to white ratio that exceeds the national ratio *and* (b) total air emissions of all TRI chemicals that exceed the national median for whites (173 counties met these two conditions for the 33/50 chemicals). Of these 204 counties, 69% (140) are classified as urban (75% or 130 are classified as urban for the 33/50 chemicals). These data indicate that a relatively small number of mostly urban counties drives the national PERs calculated according to eq 2. Nevertheless, the minority population residing in these urban counties may be substantial. As indicated in Table 5, Sections A and B, almost half the United States population of blacks, Asian/Pacific Islanders, other races, and Hispanics live in these urban counties. Of course, by definition, a smaller percentage of the nation's white population lives in these same counties; however, what is noteworthy is the magnitude of the difference in the percentage of minorities and whites.

Summary and Conclusions

Environmental justice can be broadly defined as adequate protection from the harmful effects of environmental agents for everyone, regardless of age, culture, ethnicity, gender, race, or socioeconomic status. Although there is widespread agreement about the appropriateness of environmental justice as a national goal, there is no consensus about (a) its operational definition, (b) standard evaluation methods, or (c) how to achieve it. Much of the ongoing debate is about values, what kind of a society do we want, and how should we balance trade offs between equity and efficiency?

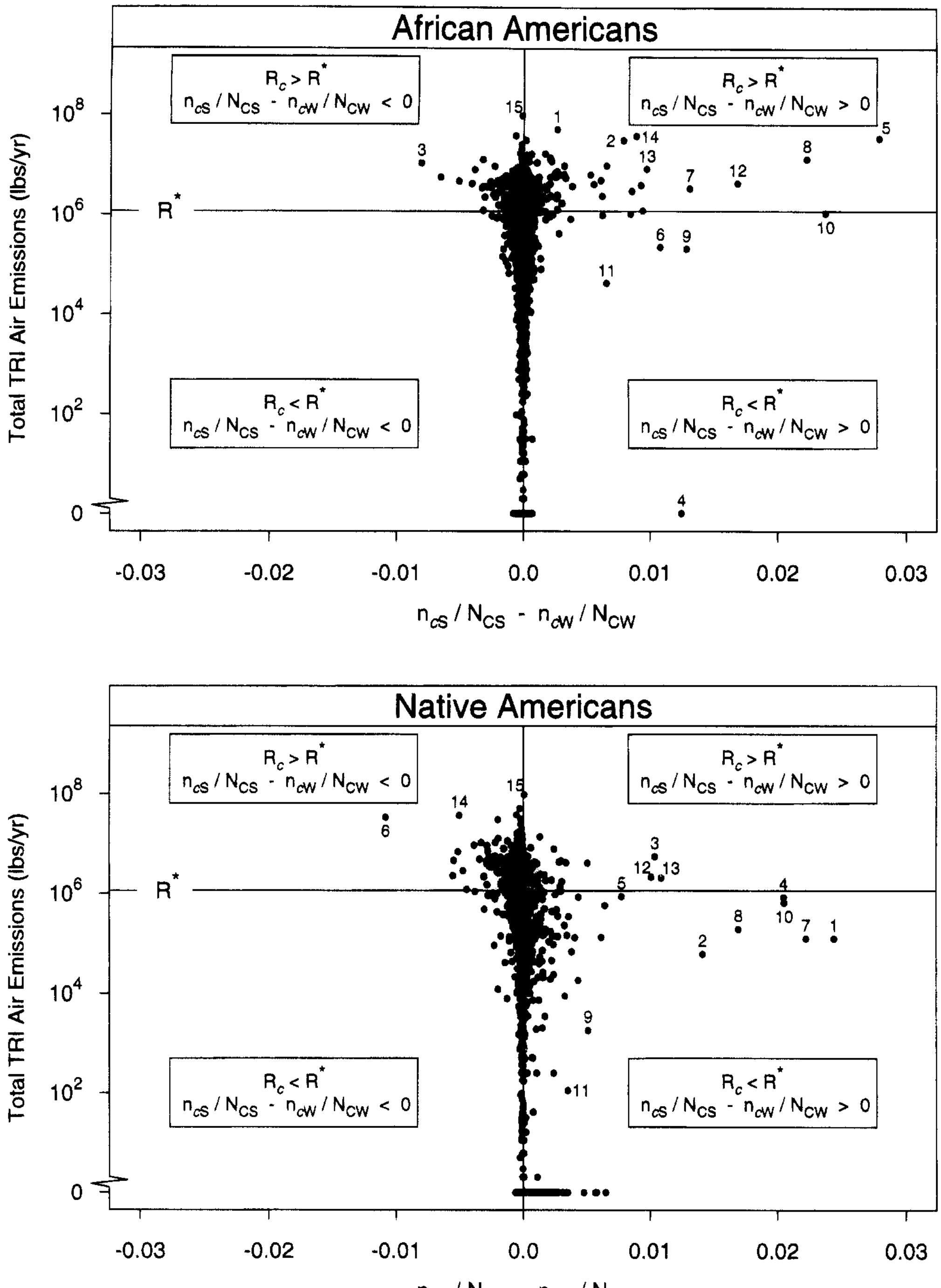


FIGURE 5. Comparisons of county-level total TRI air emissions and differences between the proportion of a minority population in the county and in the United States. R^* is the national median air emission level for all TRI chemicals for whites (1.2×10^6 lb/yr, see Table 4, Section A). R_c is the amount (lb/yr) of all TRI chemicals released in any county *c*. $n_{cS}/N_{CS} - n_{cW}/N_{CW}$ (eqs 2 and 3) indicates, for a given county c and subpopulation S (African Americans, Native Americans), the size of the subpopulation in c relative to the size of the subpopulation in all the counties C in the country compared to the size of the reference group of whites, W, in the county relative to the size of the reference group in all counties. Each point represents an individual county (or county equivalent) and all counties in the United States are displayed. Numbered counties are as follows: *African Americans*: 1, Mobile, AL; 2, Los Angeles, CA; 3, Orange, CA; 4, Washington, DC; 5, Cook, IL; 6, Prince George, MD; 7, Baltimore City, MD; 8, Wayne, MI; 9, Bronx, NY; 10, Kings, NY; 11, New York, NY; 12, Philadelphia, PA; 13, Shelby, TN; 14, Harris, TX; 15, Tooele, UT. *Native Americans*: 1, Apache, AZ; 2, Coconino, AZ; 3, Maricopa, AZ; 4, Navaho, AZ; 5, Pima, AZ; 6, Cook, IL; 7, McKinley, NM; 8, San Juan, NM; 9, Valencia, NM; 10, Robeson, NC; 11, Deleware, OK; 12, Oklahoma, OK; 13, Tulsa, OK; 14, Harris, TX; 15, Tooele, UT.

Within this context, environmental justice raises many legitimate and important scientific issues.

In general, there is a scarcity of scientific evidence documenting differences by ethnicity/race and socioeconomic status for exposures to environmental agents, associated internal doses, and related health effects. Yet despite the fact that much of the evidence is anecdotal and circumstantial, there are mounting concerns that certain environmental health risks are borne disproportionately by economically disadvantaged populations, many of whom are ethnic and racial minorities. For example, the limited data on hand appear to support the contention that poor people, particularly African Americans and Hispanics, routinely encounter higher than average exposures to air pollution (*31*).

This study has explored some of the methodological issues related to evaluating the national and regional distribution of certain industrial air pollution emissions by ethnicity/race and socioeconomic status. We have emphasized that decisions about statistical tests, geographic units of analysis, exposure estimators, and comparison (reference) groups are critical to the design and interpretation of studies focusing on issues of environmental justice.

An important finding, with potentially significant implications for future investigations of environmental justice issues, is the uneven distribution in the United States and EPA regions of (a) ethnic/racial populations, (b) household incomes, (c) population subgroups living in urban and rural counties, (d) industrial facilities, and (e) industrial air emissions. The data show that regional variations are substantial and suggest that analyses looking only at the national picture will miss important information, which may lead to erroneous conclusions.

Population emission indices (PEIs) and population emission ratios (PERs) are used as indicators of differences in county-level air emissions across population subgroups. Using estimates of industrial airborne emissions from the Toxic Release Inventory, we examined national and regional PERs across specific ethnic/racial and income groups. Our analysis showed differences in county-level TRI air emissions by ethnicity/race and to a lesser extent by household income. It also pointed to some of the problems with this approach, especially the confounding effects of using data aggregated at the county level.

Also noteworthy was the finding that, based on our PEIs/PERs, fewer than 7% of the 3137 counties in the United States had both (a) a minority to white ratio that exceeded the national ratio *and* (b) TRI air emissions that exceeded the national median value for whites. Moreover, most of these counties (69%) were urban and contained a substantial proportion of the nation's minorities (almost 50% of the blacks, Asian/Pacific Islanders, other races, and Hispanics). An even smaller number of counties exceeded either of our selected reference values by a substantial margin.

Our analysis highlights the need to identify and understand key methodological issues associated with questions of environmental justice. Subsequent studies should focus on how decisions about statistical tests, geographic units of analysis, exposure estimators, and reference populations influence the outcome and interpretation of results. The value of the PEI/PER approach should be evaluated further, and results at the county-level should be compared with results obtained using less aggregated units of analysis (e.g., block groups, concentric circles around emission sources). Especially important is the critical need to investigate the nature of the relationship, if any, between TRI emission estimates and actual exposures in nearby communities. This will necessitate conducting well-designed human exposure studies, including personal exposure monitoring and human tissue monitoring, to test whether differences in TRI emissions correspond to measurable exposure differences.

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