RESEARCH REPORT

Children at risk: measuring racial/ethnic disparities in potential exposure to air pollution at school and home

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Study objective: This paper addresses the environmental justice implications of children's health by exploring racial/ethnic disparities in potential exposure to air pollution, based on both school and home locations of children and three different types of pollution sources, in Orange County, Florida, USA.
Methods: Using geocoded school and residence locations of 151 709 children enrolled in the public school system, distribution functions of proximity to the nearest source are generated for each type of air pollution source in order to compare the exposure potential of white, Hispanic, and black children. Discrete buffer distances are utilised to provide quantitative comparisons for statistical testing.
Main results: At any given distance from each type of pollution source, the cumulative proportion of Hispanic or black children significantly exceeds the corresponding proportion of white children, for both school and home locations. Regardless of race, however, a larger proportion of children are potentially exposed to air pollution at home than at school.
Conclusions: This study addresses the growing need to consider both daytime and nighttime activity patterns in the assessment of children's exposure to environmental hazards and related health risks. The results indicate a consistent pattern of racial inequity in the spatial distribution of all types of air pollution sources examined, with black children facing the highest relative levels of potential exposure at both school and home locations.

Environmental justice provides a framework for public policy debates on the challenging question of whether disparities in exposure to environmental pollution and health hazards have played a causal role in the persistent patterns of disparate health status among minority and low-income populations in the United States.[1 2] Whereas environmental justice analysis has focused primarily on assessing racial/ethnic or socioeconomic inequities in the distribution of environmental hazards among the general population,[3] recent studies have begun to examine the burdens of exposure borne by particularly vulnerable groups, such as young children. A substantial amount of scientific evidence indicates that children are more susceptible to the effects of environmental pollution than adults.[4–9] Air pollution from potentially hazardous facilities and roadways, in particular, has been documented to play a significant role in causing a variety of health problems among school-age children.[10–15]

The growing need to examine the environmental justice consequences of children's exposure to air pollutants and related health outcomes has been emphasised by several researchers.[1 16 17] Recent studies have analysed potential exposure to toxic air emissions at school locations based on race, ethnicity, or socioeconomic status, following concerns that children are confined to schools for extended periods of time during the day.[18–20] Time–activity databases such as the National Human Activity Pattern Survey indicate, however, that US youths aged from 11 to 17 years spend approximately 61% of their time indoors at home and only 14% inside a school or other public building.[21] It is necessary, therefore, to investigate whether children are disproportionately exposed to pollution not only at schools, but also at their places of residence, and thus examine inequities for both their daytime and nighttime locations.

This paper extends research on children's environmental health and its environmental justice implications by exploring racial/ethnic disparities in the distribution of potential exposure to air pollution at both the school and home locations of children, based on a case study in a large metropolitan region (Orange County, Florida, USA). The environmental injustice hypothesis is investigated by comparing the exposure distributions of white children, at home and at school, with the corresponding distributions of Hispanic and black children.

Three different types of urban air pollution sources are examined in this study: industrial facilities from the Environmental Protection Agency's (EPA) toxic release inventory (TRI), small facilities with air releases from the EPA aerometric information retrieval system (AIRS), and major roads. TRI sites represent large point sources of air pollution with some clustering in industrial areas. AIRS facilities represent smaller and more dispersed point sources of air pollution. Major roads, in contrast, are a source of vehicular traffic emissions and thus represent a mobile source of air pollution. Residential proximity to busy roadways has been documented by earlier studies to cause adverse health outcomes among young children.[19 22–24] The use of three different types of air pollution sources provides an opportunity to explore the variability in the results and to reduce the possible bias introduced by a unique spatial pattern of a single category of sources.

METHODS

Locations of public schools and children

The locations of all 153 public schools in Orange County were provided by the Orange County Schoolboard. Enrollment records for 2005 were obtained and the home residences were geocoded using StreetMap USA for ArcGIS 9. Of a total of 163 886 records, 95.1% were reliably geocoded. Student records that did not allow for a determination of the school they attended were removed, resulting in a final set of 151 709 geocoded home residences. Racial classification was based on self-reporting by children or their parents, and included the following mutually exclusive categories: black, Hispanic, white, and other. Of the 151 709 children in our sample, 27.05% are black, 29.55% are Hispanic,

Abbreviations: AIRS, aerometric information retrieval system; CDF, cumulative distribution function; EPA, Environmental Protection Agency; TRI, toxic release inventory

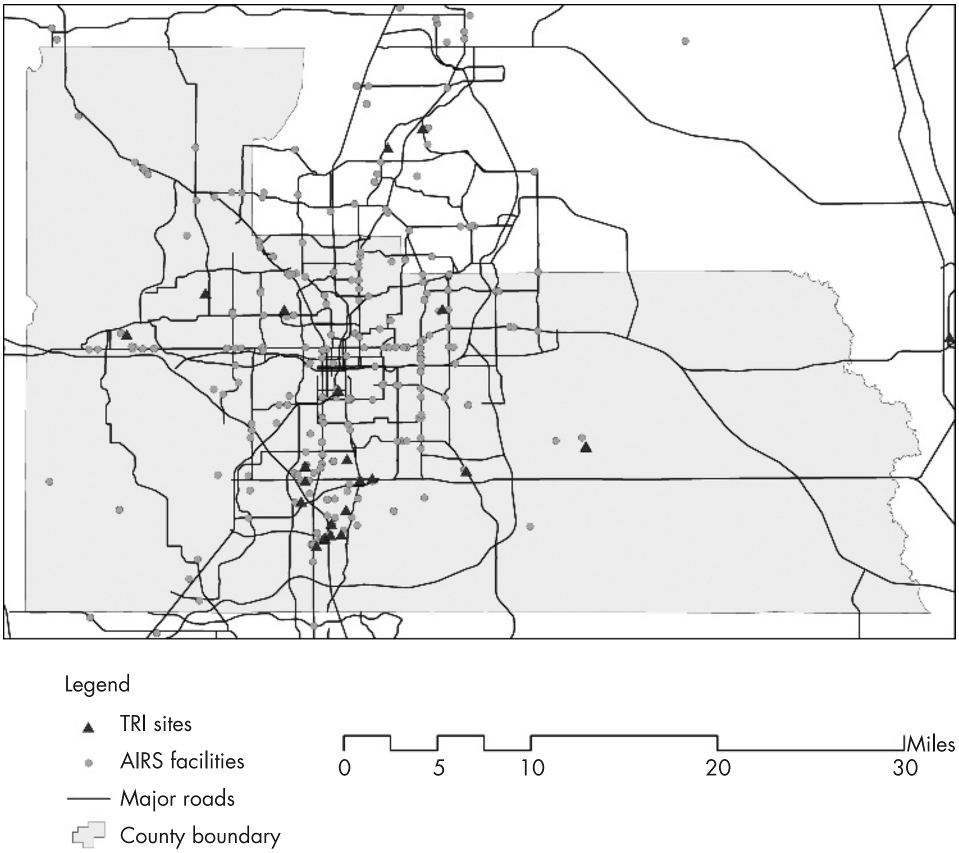

Figure 1 Locations of three types of air pollution sources in Orange County, Florida, USA. In some areas aerometric information retrieval system (AIRS) facilities are located in very close proximity to each other and consequently all individual locations are not clearly visible at this scale.
TRI, Toxic release inventory.

and 36.49% are white. The remaining 6.91% belonging to the other category were excluded from the study.

Geocoded student records were used to determine the enrollment total of each school in order to avoid potential biases in geocoding match rate across the study area and allow a direct comparison of the student population at home with those at school. Racial composition varied greatly among the schools. For example, only 27.05% of the student population was black, but 38 of the 153 schools had an enrollment of 50% or more black children and eight schools indicated an enrollment of 90% or more black children. This variation in racial composition of the schools reflects the racially segregated distribution of the general population in Orange County, Florida.

As in many other metropolitan areas in the United States, race is strongly related to socioeconomic status and educational attainment in Orange County, Florida. For example, Census 2000 data indicate that the proportion of unemployed individuals above 16 years of age in the labor force is 4.1% for white, 6.9% for Hispanic and 8.2% for black individuals. The proportion of adults above 25 years of age without a high school diploma is 14.4% for white, 29.1% for Hispanic and 30.8% for black individuals. Finally, the percentage of families with related children under the age of 18 years that are below the poverty line is 7.0% for white, 14.3% for Hispanic and 21.1% for black individuals.

Locations of air pollution sources

Information on industrial facilities releasing toxic chemicals was obtained from the EPA TRI database for the time period 2000–2003. All industrial facilities reporting point source air emissions of at least 1000 pounds for the entire four-year period (2000–2003) to the TRI were selected for our study. A total of 27 such facilities were identified within Orange County or within 5 miles of its boundary. The most common types of operations at these facilities include boat building and repair (n = 4), plastic products manufacturing (n = 4), and paint manufacturing (n = 3).

Data on facilities with air releases were obtained from the EPA AIRS for 2005. This database contains smaller stationary facilities that do not fall under the TRI reporting requirements. A total of 282 AIRS facilities were identified within Orange County or 5 miles of its boundary. These facilities include automobile repair shops, dry cleaners, hospitals, and small manufacturing facilities.

Locations of TRI sites and AIRS facilities were geocoded using StreetMap USA for ArcGIS 9.

A detailed linear network of major roads at a scale of 1 : 24 000 for Florida (2005) was obtained from the Florida Department of Transportation. From this network, only the urban and rural arterial roads were selected for this study. The total length of these arterial roads within Orange County is 954 km.

Figure 1 shows the locations of all TRI sites, AIRS facilities, and major roadways in Orange County and surrounding areas.

Proximity analysis

Distance to the nearest air pollution source of each type (TRI sites, AIRS facilities, and major roads) was determined in the appropriate state plane coordinate system for schools and children's home residences and these values were rounded to the nearest foot. These distances were summarised with a cumulative distribution function (CDF), which represents a plot of the number of observations falling below every threshold value. CDF are particularly well suited for the proximity-based analysis of potential exposure because they overcome the limitations of choosing arbitrary discrete buffer distances.[25 26] To compare the exposure distribution of white, Hispanic, and black children, CDF were created for each type of pollution source, plotting the cumulative number of children within each racial category as a percentage of the total number versus distance to the nearest pollution source. Schools were weighted with the number of children in each racial category associated with each school. The cumulative number of children in each racial category was also

Table 1 Cumulative percentage of white, Hispanic, and black students at fixed distances from air pollution sources†

Buffer radius (miles)	% White students	% Hispanic students	% Black students	% Difference Hispanic–white	% Difference Black–white
TRI sites					
School					
0.25	0.1	0.1	0.5	0.0*	0.4*
0.50	0.3	1.4	0.8	1.1*	0.5*
1.00	2.7	8.1	8.5	5.4*	5.8*
2.00	23.7	29.6	40.5	5.9*	16.8*
4.00	60.9	74.7	80.7	13.7*	19.8*
Home					
0.25	0.3	0.4	0.4	0.1*	0.1*
0.50	1.1	1.9	1.7	0.8*	0.6*
1.00	5.9	9.3	8.5	3.4*	2.6*
2.00	19.4	29.1	40.4	9.7*	21.0*
4.00	59.2	73.2	84.2	14.0*	25.0*
AIRS facilities					
School					
0.25	4.7	5.4	7.2	0.7*	2.5*
0.50	12.1	17.4	23.3	5.3*	11.2*
1.00	42.9	54.4	69.1	11.5*	26.2*
2.00	80.5	81.7	93.5	1.2*	13.0*
4.00	96.5	98.3	99.5	1.8*	3.0*
Home					
0.25	4.6	7.8	9.0	3.2*	4.4*
0.50	18.0	27.4	33.3	9.4*	15.3*
1.00	45.4	56.7	72.1	11.3*	26.7*
2.00	74.7	82.3	94.2	7.6*	19.5*
4.00	95.9	98.6	99.6	2.7*	3.7*
Arterial roads					
School					
0.25	38.3	45.7	45.7	7.4*	7.4*
0.50	62.1	66.7	72.2	4.6*	10.1*
1.00	82.8	91.7	92.6	8.9*	9.8*
2.00	94.3	97.2	99.0	2.9*	4.7*
4.00	100.0	100.0	100.0	0.00	0.0
Home					
0.25	37.9	47.9	46.3	10.0*	8.4*
0.50	63.3	77.3	79.3	14.0*	16.0*
1.00	83.5	93.8	96.7	10.3*	13.2*
2.00	95.7	98.4	99.4	2.7*	3.7*
4.00	99.9	100.0	100.0	0.1	0.1

AIRS, aerometric information retrieval system; TRI, toxic release inventory.
*$p<0.001$.
†z-Test results.

determined using discrete distances of 0.25, 0.5, 1, 2 and 4 miles. These values represent the most widely used buffer radii in proximity-based analyses of environmental exposure for point sources of air pollution;[27–31] buffers of 0.25–1 mile are commonly used for vehicular sources of air pollution.[32–35]

Statistical analysis

The CDF were plotted against the distance from each pollution source to identify and compare general patterns of exposure among racial categories and between home and school locations. The percentages of children at home and at school for various discrete buffer distances were compared using a two-sample z-test of proportions. The environmental injustice hypothesis was investigated by comparing the black with the white student population, and the Hispanic with the white student population; this was repeated for each of the pollution sources and for school and home locations independently, for a total of 60 z-tests. Comparisons were also made between the home and school student populations; these were repeated for each type of pollution source and racial category, for a total of 45 z-tests.

RESULTS

The CDF representing exposure distributions of white, Hispanic, and black children, respectively, at school and home, are presented in fig 2 for each type of pollution source. The CDF indicate how the proportion of the student population in each racial category increases with distance to the nearest pollution source. Almost 100% of children in all three categories can be found within 50 000 feet from the TRI sites, 25 000 feet from AIRS facilities, and only 15 000 feet from a major road. These differences reflect the fact that there are fewer TRI sites than AIRS facilities, and also that TRI sites are more spatially clustered (fig 1). The curves for school locations reveal a more stepwise and less continuous pattern than those based on home locations; each step in these curves represents one of the 153 schools in Orange County, with the step height determined by student enrollment in each racial category at that school.

Several observations regarding racial disparities can be made from the CDF shown in fig 2. For all three types of air pollution sources, the curves for Hispanic and black children are higher than the curve for white children, both at school and at home. This implies that the percentage of Hispanic and black children within any given distance from these pollution sources is always larger than the corresponding percentage of white children. In addition, the curves representing black children are higher than the curves representing Hispanic children for both TRI sites and AIRS facilities, which suggests that a higher proportion of black children are potentially exposed than Hispanic children. For

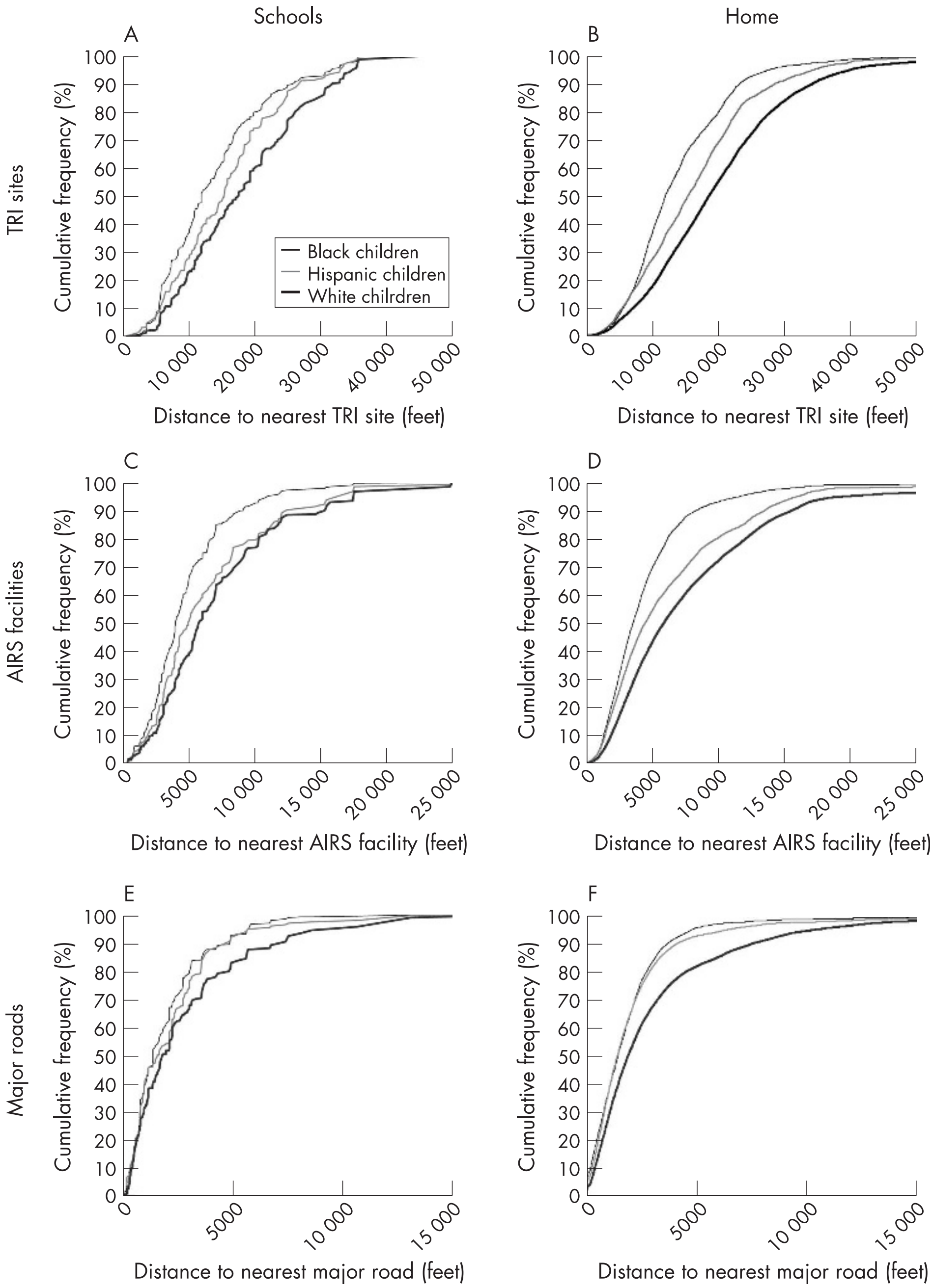

Figure 2 Cumulative distribution functions of exposure potential of school children. The vertical axis in each graph depicts the cumulative number of children as a percentage of the group total. The horizontal axis in each graph depicts the distance to the nearest pollution source.
AIRS, aerometric information retrieval system; TRI, toxic release inventory.

major roads, however, the gap between the curves representing black and Hispanic children is considerably smaller.

A statistical assessment of racial disparities in the distribution of potential exposure can be made from table 1, which presents z-test results for discrete buffer distances. At each given distance, the cumulative percentage of white, black, and Hispanic children inside the buffer zone was derived for both school and home locations from the CDF in fig 2. The z-tests are based on the difference between the proportion of white and Hispanic children, and white and black children, respectively. As shown in table 1, 58 of the 60 comparisons revealed statistically significant differences at the 0.001 level, confirming the consistent pattern of racial disparities observed visually in fig 2.

Table 1 also highlights some of the differences between the patterns observed for each type of pollution source. For TRI sites, the cumulative proportion of children in all racial categories is less than 10% within 1 mile and less than 2% within 0.5 mile, both at school and home. Consequently, the largest racial disparities (white–Hispanic or white–black) for TRI sites can be observed only at buffer distances of 2 or 4 miles. For AIRS facilities, which are more numerous than TRI sites, the proportion of children within the 0.5 or 1 mile buffer is considerably higher, resulting in larger racial disparities at smaller buffer distances. For all buffer distances from a major road, the proportions of children are substantially higher compared with other pollution sources. Both at school and at home, more than 60% of children in any racial category can be found inside the 0.5 mile buffer zone.

A more direct comparison of potential exposure at school and home can be made for the same buffer distances in table 2. The z-tests here are based on the difference between the proportion of children at school and home locations. A negative difference indicates that the percentage of children at home is higher than those at school, and a positive difference indicates the opposite. As shown in table 2, 33 of these 45 z-tests show statistically significant differences at the 0.01 level, and 28 of these 33 significant differences are negative. This implies that a larger proportion of children are potentially exposed to air pollution sources at their place of residence compared with school locations,

Table 2 Comparing potential exposure at school and home locations: cumulative percentages of students at fixed distances from air pollution sources†

Buffer (miles)	% White students			% Hispanic students			% Black students		
	School	Home	Difference	School	Home	Difference	School	Home	Difference
TRI sites									
0.25	0.1	0.3	−0.2*	0.1	0.4	−0.3*	0.4	0.4	0.0
0.50	0.3	1.1	−0.8*	1.4	1.9	−0.5*	0.8	1.7	−0.9*
1.00	2.7	5.9	−3.2*	8.1	9.3	−1.2*	8.5	8.5	0.0
2.00	23.7	19.4	4.3*	29.6	29.1	0.5*	40.5	40.4	0.1
4.00	60.9	59.2	1.7*	74.7	73.2	1.5*	80.7	84.2	−3.5*
AIRS facilities									
0.25	4.7	4.6	0.1*	5.4	7.8	−2.4*	7.2	9.0	−1.8*
0.50	12.1	18.0	−5.9*	17.3	27.4	−10.1*	23.3	33.3	−10.0*
1.00	42.9	45.4	−2.5*	54.4	56.7	−2.3*	69.1	72.1	−3.0*
2.00	80.5	74.7	5.8*	81.7	82.3	−0.6*	93.5	94.2	−0.7*
4.00	96.5	95.9	0.6*	98.3	98.6	−0.3*	99.5	99.6	−0.1
Arterial roads									
0.25	38.3	37.9	0.4*	45.7	47.9	−2.2*	45.7	46.3	−0.6*
0.50	62.1	63.3	−1.2*	66.7	77.3	−10.4*	72.2	79.3	−7.1*
1.00	82.8	83.5	−0.7*	91.7	93.8	−2.1*	92.6	96.7	−4.1*
2.00	94.3	95.7	−1.4*	97.2	98.4	−1.2*	99.0	99.4	−0.4*
4.00	100.0	99.9	0.1	100.0	100.0	0.0	100.0	100.0	0.0

AIRS, aerometric information retrieval system; TRI, toxic release inventory.
*$p<0.01$.
†z-Test results.

regardless of race. Minor exceptions are observed for black children at distances of less than 2 miles from TRI sites, but these can be partly explained by the relatively small percentage of children and schools located in close proximity to TRI sites. The five positive differences that are significant either occur at very large buffer distances (2 or 4 miles), or are smaller than 1% in magnitude.

DISCUSSION

The intersection of environmental justice and children's health has emerged as a critically important area of academic enquiry and policy making in the United States. The racial/ethnic implications of children's potential exposure to air pollution are addressed in our study through the analysis of proximity to multiple air pollution sources in Orange County, Florida. Unlike earlier studies on this topic that have examined a single type of pollution source or facility, our analyses encompass three types of air pollution sources. Our results indicate a persistent pattern of racial inequity in the spatial distribution of these pollution sources. At any given distance from these sources, the cumulative proportion of black or Hispanic children always exceeds the corresponding proportion of white children. In addition, the percentage of black children in close proximity to point sources of air pollution (TRI sites and AIRS facilities) is higher than the corresponding percentage of Hispanic children, suggesting that black school-age children are burdened with the highest relative levels of potential exposure. Our results are consistent with findings from recent studies that indicate that non-white children are more likely to attend schools near hazardous facilities or busy roads, and are disproportionately exposed to airborne toxic hazards at school locations.[2 18–20]

Compared with studies that focus only on schools and daytime risk, our study provides a more comprehensive view of the risk burden imposed on young children by examining potential exposure at both school and home locations. The comparison between home and school locations reflects a long-standing interest to consider both daytime and nighttime patterns in exposure assessment.[36 37] Our findings indicate that a significantly larger proportion of children are closer to air pollution sources at home compared with their school locations, within all three racial categories. This pattern could be the consequence of stricter environmental standards that have been used to locate new suburban schools in areas that are not proximate to pollution sources or hazardous facilities. Whereas earlier studies have demonstrated the role of zoning in creating environmental inequities and health problems,[31 38] more research is clearly necessary to understand the sociospatial processes that have caused the patterns observed in Orange County.

Despite specific differences between the results at school and home locations, the general pattern in exposure potential as characterised by the CDF is broadly similar at home and school for all air pollution sources considered. This similarity can be explained partly by the fact that a majority of children attend the school closest to their home address.

A strength of this study is the use of individual geocoded locations of children's home residences. This provides a more accurate characterisation of the exposed population and reliable comparisons among subgroups, compared with studies relying on aggregated data at the level of census enumeration units.[25] Another strength of our study is the application of CDF to characterise proximity-based exposure potential instead of discrete buffer distances that introduce substantial bias.[25] Although discrete buffer distances were used for statistical testing, these are complemented by the CDF, and the selected buffer radii represent a broad range of distances of interest.

Among the limitations of the study is the use of proximity as a measure of exposure potential. Although distance to a pollution source is widely used as a surrogate for exposure, the actual extent and magnitude of exposure may not be a simple function of distance. Proximity is used in this study to focus attention on how to summarise comparisons rather than measure the exact nature or degree of exposure. A second limitation is the potential error in the geocoding of schools, children, and pollution sources. Geocoding match rates, however, were generally high and the typical positional error for this kind of geocoding is much smaller than the shortest buffer distance of 0.25 miles used in the analysis.[39–41] Another limitation is the use of only arterial roads as air pollution sources, which could affect the distribution of distances to the nearest roadway. Traffic densities on non-arterial roads in Orange County are, however, relatively low (less than 10 000 vehicles/day) compared with arterial roads that have traffic densities between 25 000 and 100 000 vehicles per day. The exclusion of private schools for which individual address information was unavailable is another limitation. Total

What is already known on this subject

Previous studies on the environmental justice consequences of children's exposure to environmental pollution and related health risk have focused primarily on examining: (a) school locations or daytime exposure; and (b) a single type of air pollution source, such as roadways or industrial facilities.

What this study adds

Our results indicate a consistent pattern of racial inequity in the distribution of three different types of air pollution sources (stationary and mobile), with Hispanic and black children facing significantly higher levels of potential exposure than white children, at both school and home. We also found a larger proportion of children to be potentially exposed to air pollution at home than school, regardless of race.

enrollment at private schools (grade K-12) in Orange County is 18 293 for the 2003/2004 school year according to the National Center for Education Statistics, representing a relatively small number compared with those enrolled in the public school system. Finally, our analysis focuses only on race/ethnicity because additional socioeconomic data on individual children are unavailable. Given its strong correlation with socioeconomic status in Orange County, race may be a confounding factor masking the association between poverty and exposure to pollution.

Within these limitations, this study provides strong evidence of racial inequity in potential exposure to air pollution for a large metropolitan area. This inequity is consistent between children's home residences and school locations, and across different types of air pollution sources. Although more research is necessary to characterise the actual health effects of exposure to different pollutants, our study represents an important step in the consideration of both daytime and nighttime activity patterns in the assessment of children's exposure to environmental risk and related inequities.

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