Disparities in Distribution of Particulate Matter Emission Sources by Race and Poverty Status

Ihab Mikati, BS, Adam F. Benson, MSPH, Thomas J. Luben, PhD, MSPH, Jason D. Sacks, MPH, and Jennifer Richmond-Bryant, PhD

Objectives. To quantify nationwide disparities in the location of particulate matter (PM)-emitting facilities by the characteristics of the surrounding residential population and to illustrate various spatial scales at which to consider such disparities.

Methods. We assigned facilities emitting PM in the 2011 National Emissions Inventory to nearby block groups across the 2009 to 2013 American Community Survey population. We calculated the burden from these emissions for racial/ethnic groups and by poverty status. We quantified disparities nationally and for each state and county in the country.

Results. For PM of 2.5 micrometers in diameter or less, those in poverty had 1.35 times higher burden than did the overall population, and non-Whites had 1.28 times higher burden. Blacks, specifically, had 1.54 times higher burden than did the overall population. These patterns were relatively unaffected by sensitivity analyses, and disparities held not only nationally but within most states and counties as well.

Conclusions. Disparities in burden from PM-emitting facilities exist at multiple geographic scales. Disparities for Blacks are more pronounced than are disparities on the basis of poverty status. Strictly socioeconomic considerations may be insufficient to reduce PM burdens equitably across populations. (*Am J Public Health.* 2018;108:480–485. doi:10.2105/AJPH.2017.304297)

See also Houston, p. 441.

The inequitable distribution of hazardous sites such as landfills and industrial facilities is one of the longest-standing concerns in the field of environmental justice. More than 3 decades ago in one of the earliest environmental justice studies, the US government reported a disproportionately high representation of socially disadvantaged populations residing in communities near landfills.[1] Disparities in residential proximity to pollution sources have been evaluated in terms of income level and poverty as well as race/ethnicity. A nationally representative 1986 sample found that Blacks were 1.54 times more likely than were Whites to live within 1 mile of a facility listed in the Toxics Release Inventory—a gap that remained statistically significant even after accounting for income and education level.[2] The distributions of specific air pollutants, and not just the facilities emitting them, also reflect racial disparities. For example, mean residential ambient nitrogen dioxide concentrations in 2010 were about 7% higher for those in poverty than for those above the poverty line, whereas the disparity for non-Whites (37% higher concentrations than for Whites) was substantially greater.[3]

There is considerable evidence concerning human health impacts of residential proximity to facilities emitting air pollutants.[4] One such pollutant is particulate matter (PM), a mixture of solid and liquid particles suspended in the air.[5] Exposure to PM_{10} ($PM \leq 10$ µm in diameter) and especially to $PM_{2.5}$ ($PM \leq 2.5$ µm in diameter) has been associated with a number of health effects, including respiratory and cardiovascular diseases as well as premature mortality.[6–8] Although proximity to facilities emitting PM is not a direct measure of exposure, it is a valuable metric. Unlike natural events that contribute to ambient PM, such as wildfires, the siting of a facility is the result of a decision-making process. Disparities in siting may indicate underlying disparities in the power to influence that process. For example, an Environmental Protection Agency (EPA) investigation in Flint, Michigan, found a direct link between racial discrimination and the permitting of a power station there, stating, "The preponderance of evidence supports a finding of discriminatory treatment of African Americans by [the Department of Environmental Quality] in the public participation process."[9]

We aimed to quantify nationwide disparities in the distribution of PM-emitting facilities by the characteristics of the surrounding residential populations and to illustrate various spatial scales at which to consider such disparities. Previous literature has shown that non-Whites and below-poverty individuals are more likely to reside near stationary sites of $PM_{2.5}$ emissions[10]; we sought to update and expand on these findings.

METHODS

We combined facility emissions data with demographic data to investigate racial/ethnic and economic disparities in residential proximity to sources of air pollution.

ABOUT THE AUTHORS

Ihab Mikati and Adam F. Benson are participants in the Oak Ridge Institute for Science and Education research training program stationed with the National Center for Environmental Assessment, Office of Research and Development, US Environmental Protection Agency, Research Triangle Park, NC. Thomas J. Luben, Jason D. Sacks, and Jennifer Richmond-Bryant are staff members with the National Center for Environmental Assessment, Office of Research and Development, US Environmental Protection Agency, Research Triangle Park, NC.

Correspondence should be sent to Ihab Mikati, ORISE Program participant at the National Center for Environmental Assessment, Office of Research and Development, US Environmental Protection Agency—109 T.W. Alexander Drive, Research Triangle Park, NC 27709 (e-mail: mikati.ihab@epa.gov; please cc: mikati.ihab@gmail.com to ensure receipt). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

This article was accepted December 16, 2017.
doi: 10.2105/AJPH.2017.304297

Data Sources

We accessed population data via the US Census Bureau's 2009 to 2013 American Community Survey (ACS).[11] The ACS provides self-reported data on racial/ethnic identification and poverty status at the census block group level for all 50 states and Washington, DC. The block group is a single level of resolution finer than the census tract and commonly contains 600 to 3000 residents.

For our analyses, "White" refers to only non-Hispanic Whites; "non-White" refers to all others. Included in the latter group are Black (non-Hispanic) and Hispanic (any race). The Census Bureau determines poverty status by comparing household income to a threshold that varies by household size and composition.[12]

Because there are differences between rural and urban areas both in industrialization and in demographic composition, we also noted rural–urban status for all block groups. We made rural–urban status determinations from the US Department of Agriculture's rural–urban commuting area (RUCA) codes for 2010.[13] These codes are determined on the basis of census tract–level population density, urbanization, and daily commuting levels; they can be used to distinguish between metropolitan and micropolitan urban centers, commuting (suburban) areas, small towns, and rural areas.[13]

We collected emissions data on stationary human-made point sources from the US EPA National Emissions Inventory (NEI) "Facility-level by Pollutant" files for 2011, the year most closely aligned to the census data we used for our analysis.[14] This data source allowed us to consider not just the presence or absence of a facility but also the amount of the pollutant emitted. We considered annual NEI totals, in tons per year, for primary $PM_{2.5}$ and primary PM_{10}.

Data Analysis

The spatial size (i.e., land area) of block groups can vary substantially between urban and rural areas because of the block group's restricted population range. As population densities increase and block groups shrink in urban areas, assignment via "unit–hazard coincidence" (the matching of a site to its host unit and no others, regardless of proximity) may underestimate the number of nearby hazards relative to those in large rural tracts.[15] To address this, we used a distance-based "centroid-containment" assignment instead.[15] We assigned each facility and its corresponding emissions (in tons per year) to all census block groups containing a centroid within a set radius of the facility's geographic coordinates. We analyzed radii ranging from 0.5 to 5.0 miles; in our main analysis, we used a 2.5-mile radius, following the NEI facility assignment of Boyce and Pastor.[10] We assigned facilities and emissions meeting the centroid-containment criteria for a block group to the population residing within that block group.

We measured the between-group differences in residential proximity to facilities and facility emissions by using 2 metrics: the absolute burden (i.e., the average number of facilities or average amount of PM, in tons/year, emitted within a set distance from an individual's block group centroid) and the proportional burden (i.e., the ratio between a demographic subgroup's average burden and that of the overall population).

To determine average absolute burden (Equation 1) for demographic subgroups, we multiplied the emissions (or total number of facilities) assigned to each block group by the subgroup's population size. We divided the sum of this value across block groups by the total subgroup population, similar to previous studies.[10,16,17]

$$(1)\quad \text{Absolute Burden} = \frac{\sum(\text{Population}_{\text{BlockGroup}} \times \text{Emissions}_{\text{BlockGroup}})}{\sum \text{Population}_{\text{BlockGroup}}}$$

We calculated proportional burdens (Equation 2) by dividing the absolute burden in a subgroup of the population by the absolute burden in the overall population. Scores above 1.0 indicate that the subgroup experienced higher burden than would be expected in a perfectly equitable scenario.

$$(2)\quad \text{Proportional Burden}_{\text{Subgroup}} = \frac{\text{Absolute Burden}_{\text{Subgroup}}}{\text{Absolute Burden}_{\text{Overall}}}$$

We carried out all data management and analysis by using R software version 3.1.2 (R Foundation for Statistical Computing, Vienna, Austria; packages used: dplyr, tidyr, bit64, data.table for data management; tigris for block group coordinates; Hmisc for calculation of correlations).

Sensitivity Analyses

We conducted several sensitivity analyses to address the potential for small methodological changes to bias our results. To examine whether disparities were consistent at various distances from emissions sources, we used assignment radii at 0.50, 1.25, and 5.00 miles as alternatives to the 2.50-mile centroid-containment radius in the main analysis. To address whether the reported disparities were driven by assignments in extremely sparse or dense areas, we repeated the main analysis after eliminating the largest and smallest decile of block groups (by area). An additional analysis ensured that facilities were always assigned to their host block group by combining the centroid-containment assignment with the traditional unit–hazard coincidence; this helped us address concerns that centroid-containment assignment could underestimate the burden in rural areas, where facilities may be far from their host block group's centroid.

We repeated the main analysis using racial/ethnic population data from the 2010 Decennial Census (poverty data unavailable for this data set) to show that disparities were not specific to the census methodology of the ACS. We considered recent shifts in pollution data by substituting the 2008 or 2014 NEI in place of the 2011 data set. To gauge general applicability to other emissions, we also analyzed other criteria air pollutants available in the NEI: carbon monoxide (CO), lead (Pb), oxides of nitrogen (NO_X), and sulfur dioxide (SO_2).

RESULTS

On average, there are 5.7 NEI facilities within 2.5 miles of an individual's census block group centroid (i.e., a facility burden of 5.7). For an individual in the overall US population, the mean absolute burden of $PM_{2.5}$ and PM_{10} emitted from nearby facilities is 22.4 and 29.2 tons per year, respectively. As reported in Table 1, non-Whites and those living in poverty face a disproportionate burden from PM-emitting facilities. Blacks in particular are likely to live in high-emission areas; the average $PM_{2.5}$ burden in this group is 1.54 times that of the population overall. It is notable that this racial

TABLE 1—Mean Absolute and Proportional Burdens From Facilities Emitting PM in the 2011 National Emissions Inventory, Selected Subgroups: American Community Survey, United States, 2009–2013

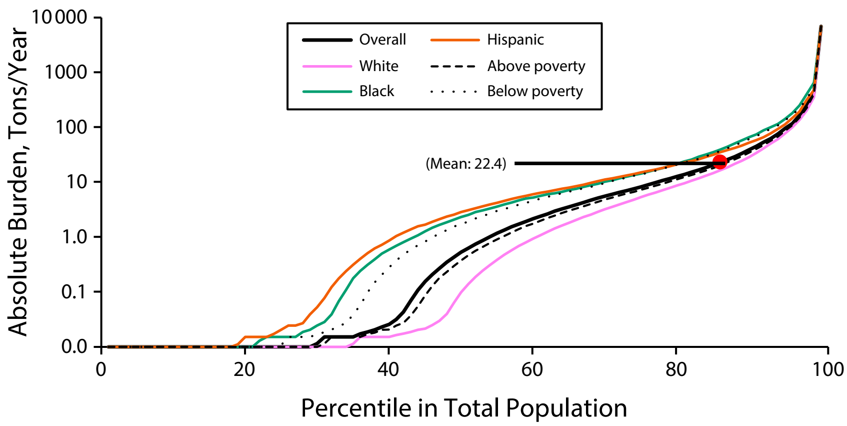
Variable	Proportion of Population, %	$PM_{2.5}$ Burden, Absolute (Proportional)	PM_{10} Burden, Absolute (Proportional)	Facility Burden, Absolute (Proportional)
Overall population	1.00	22.4 (. . .)	29.2 (. . .)	5.7 (. . .)
Race/ethnicity[a]				
White	0.63	18.8 (0.84)	24.7 (0.85)	4.1 (0.72)
Non-White	0.37	28.6 (1.28)	37.0 (1.27)	8.5 (1.49)
Black	0.12	34.5 (1.54)	43.6 (1.49)	6.2 (1.09)
Hispanic	0.17	26.9 (1.20)	35.9 (1.23)	9.8 (1.70)
Poverty level				
Above poverty	0.85	20.9 (0.93)	27.2 (0.93)	5.5 (0.95)
Below poverty	0.15	30.3 (1.35)	39.3 (1.35)	7.2 (1.26)

Note. PM = particulate matter; PM2.5 = PM of ≤ 2.5 µm in diameter; PM10 = PM of ≤ 10 µm in diameter. Poverty level determined by the US Census Bureau in 2013. Burdens represent the PM emissions or the number of facilities in the 2011 National Emissions Inventory that are near the block group of residence for an average individual in the 2009–2013 American Community Survey population. Absolute burden units for PM emissions are tons/year; for facilities, they are the total number. Proportional burden is the ratio of subgroup burden to overall population burden.

[a]"White" refers to only non-Hispanic Whites; "non-White" refers to all others. Included in the latter group are Black (non-Hispanic) and Hispanic (any race).

disparity is larger than is the poverty-based $PM_{2.5}$ disparity (1.35 times the overall population average). Proportional burdens for $PM_{2.5}$ are highly similar to those for PM_{10}, but this is not true for proportional burdens in the total number of facilities. This difference suggests that the magnitude of emissions from a facility, and not simply its presence or absence, is valuable information when characterizing burden.

Figure 1 illustrates the population-wide distribution of absolute $PM_{2.5}$ burden for the overall population as well as for several subgroups. Because of a highly nonnormal distribution, individuals residing in block groups with emissions above the overall mean are among the top 15% most burdened. Across the distribution, the gap in burden between those above and those below the poverty line is smaller than is the gap between Whites and non-Whites. At the 50th percentile, Whites have an absolute $PM_{2.5}$ burden below 0.1 tons per year—more than an order of magnitude below the burden of any of their non-White counterparts. At the 80th percentile, the absolute burden for Whites (8.7 tons/year) is less than is half the absolute burden for equivalent non-Whites (20.1 tons/year).



Note. PM2.5 = particulate matter of 2.5 micrometers in diameter or less. Burden scale (y-axis) is displayed logarithmically. Poverty level determined by the US Census Bureau in 2013.

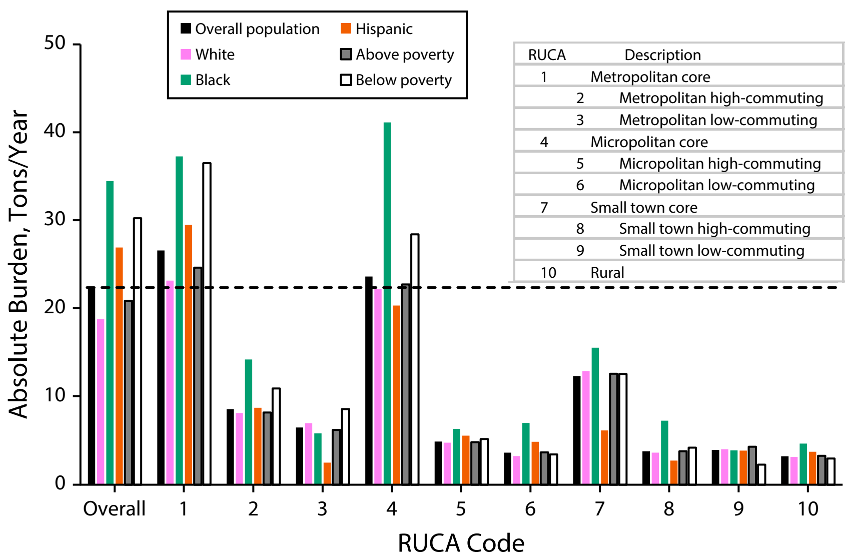
FIGURE 1—Distribution of Absolute Burdens of $PM_{2.5}$ Emissions From Nearby Facilities in the 2011 National Emissions Inventory, Stratified by Race/Ethnicity and Poverty Status: American Community Survey, United States, 2009–2013

The proportional $PM_{2.5}$ burden for non-Whites at the national level is 1.28 (Table 1). This indicates that high non-White populations coincide with high emissions nationally. Burdens can also be considered within finer spatial scales—for example, the ratio of burdens between non-Whites and the overall population in a particular state or county. Disparities operate in different ways at each scale, yet overall higher burdens for non-Whites are a consistent outcome at both state (Figure A, part a [available as a supplement to the online version of this article at http://www.ajph.org]) and county (Figure A, part b) levels. All but 4 states (Maryland, New Mexico, North Dakota, and West Virginia) and Washington, DC, have an elevated mean $PM_{2.5}$ burden for the non-White population (i.e., proportional burdens > 1.0). Comparing the White and non-White burdens across all states confirms a statistically significant overall difference in absolute $PM_{2.5}$ burdens (paired t test mean of differences = –11.04 (–15.30, –6.79); $t(50) = –5.22$; $P < 10^{-5}$). Likewise, the majority of counties have higher absolute $PM_{2.5}$ burdens for their non-White residents (paired t test mean of differences = –3.43 (–4.37, –2.48); $t(3140) = –7.12$; $P < 10^{-11}$).

We recognized rural–urban status as a potential modifier because of the industrialization of cities combined with the high representation of non-Whites in population-dense centers. For this reason, we used the RUCA codes to characterize and stratify block groups by rural–urban status (Table A [available as a supplement to the online version of this article at http://www.ajph.org]). As shown in Figure 2, the overall national burdens are largely driven by high emissions in the metropolitan and micropolitan cores (those with populations of at least 50 000 and those with populations of at least 10 000 but less than 50 000, respectively). Although those living above the poverty line do experience a lower burden than do those below it within these urban areas, the disparities in emissions are especially pronounced for Blacks—reinforcing the overall finding that racial disparities appear to be markedly higher than are poverty-based disparities.

We also explored recent changes in emission distributions by considering available NEI year data for a 6-year range (Table B [available as a supplement to the online version of this article at http://www.ajph.org]). Absolute $PM_{2.5}$ burden dropped for all examined subgroups between the 2008 and 2014 NEI by a mean of 11.7 tons per year in the overall population (i.e., a 38% drop over the 6-year interval). This drop was slightly smaller (33%) for Blacks and slightly greater (41%) for Hispanics. Despite large drops in absolute burden for all groups, proportional burdens appear stagnant. The proportional $PM_{2.5}$ burden of 1.61 for Blacks in the 2014 NEI is higher than are the proportional burdens in the 2011 NEI (1.54; Table 1) and the 2008 NEI (1.50; Table B). Data are also provided using the 2012 to 2016 ACS and 2014 NEI (Table B). However, because comparison of overlapping ACS data sets is advised against,[18] this analysis is limited in that it considers only changes in $PM_{2.5}$ emissions and not changes in demographics during this time span. It is not possible to determine a causal relationship for changes over time from this analysis. Although there is evidence that lower property values attract minority populations after siting, high representation of those groups generally also exists before the siting of a facility in an area.[19]

We performed sensitivity analyses by repeating the main analysis after adjusting the centroid-containment radius; removing the smallest and largest decile of block groups; including all facilities hosted in a block group, regardless of distance to centroid; and using 2010 Decennial Census data instead of the 2009 to 2013 ACS. The results of these analyses were largely consistent with the original analysis, suggesting robustness in results despite alterations in methodology (Table C [available as a supplement to the online version of this article at http://www.ajph.org]). Extending the analysis to other criteria pollutants tracked by the NEI (CO, Pb, NO_X, and SO_2) also remained largely consistent with PM results with few exceptions (Table D [available as a supplement to the online version of this article at http://www.ajph.org]). The block group Spearman correlation of CO, Pb, NO_X, and SO_2 to $PM_{2.5}$ assignments were 0.92, 0.77, 0.94, and 0.93, respectively (Table E [available as a supplement to the online version of this article at http://www.ajph.org]); the amount of $PM_{2.5}$ emitted near a block group is likely a general indicator of the overall emissions in that area.



Note. PM2.5 = particulate matter of 2.5 micrometers in diameter or less; RUCA = rural–urban commuting area. Dashed line indicates mean overall burden for all groups in the United States (22.4 tons/year). The US Department of Agriculture defines and assigns RUCA codes. Poverty level determined by the US Census Bureau in 2013.

FIGURE 2—RUCA-Stratified Absolute Burdens of $PM_{2.5}$ Emissions From Nearby Facilities in the 2011 National Emissions Inventory, Further Stratified by Race/Ethnicity and Poverty Status: American Community Survey, United States, 2009–2013

DISCUSSION

We characterized the populations residing near NEI facilities to determine whether individuals from certain subgroups face disproportionately high burden from nearby PM emissions. We observed disproportionately high burdens for non-Whites and those living in poverty (Table 1; Figure 1). Disparities for non-Whites persist at multiple scales: nationally, in the vast majority of states (Figure A, part a) and in the majority of individual counties (Figure A, part b). The lack of individual-level data on the intersection of racial/ethnic identification and poverty status limited our ability to make direct comparisons; however, overall, racial disparities for both $PM_{2.5}$ and PM_{10}—specifically between Blacks and Whites—are stronger than are poverty-based disparities (Table 1). This is a consistent observation even when considering urban Whites and Blacks alone (Figure 2). $PM_{2.5}$ and PM_{10} disparities for Hispanics are less pronounced or consistent but still present. The diversity within the Hispanic population, which includes both native-born persons and recent immigrants from a variety of countries, has made the catchall "Hispanic" designation vexing for public health research.[20,21]

Our main finding of national disparities in $PM_{2.5}$ burdens by race is consistent with that of Boyce and Pastor,[10] who carried out a similar analysis on $PM_{2.5}$ using the 2008 NEI and reported results equivalent to a proportional burden of 1.25 for non-Whites (compared with our finding of 1.28). Such disparities in residential proximity to sites of pollution potentially correspond to disparities in a range of health outcomes.[22–24]

Exposure to $PM_{2.5}$ has been linked to increased morbidity and mortality.[6–8] Although our study focused on point source emissions and not on ambient $PM_{2.5}$, the racial disparity in burdens from nearby facilities parallels the disparities seen in both modeled[16] (Table F [available as a supplement to the online version of this article at http://www.ajph.org]) and monitored[17] ambient $PM_{2.5}$ concentration data. Disparities in exposure between Blacks and Whites have been reported to be greater than are disparities on the basis of poverty status,[16] whether considering only urban, suburban, or rural census tracts.[17] This potential increase in exposure for the Black population coupled with higher prevalence of conditions such as cardiovascular disease mortality[25] and asthma,[26] which are known to be linked to PM exposure, makes for a population of concern. Equivalent increases in $PM_{2.5}$ have been linked to statistically significantly higher associations in Blacks than in Whites for health outcomes ranging from asthma attacks[27] to overall mortality.[28] In the US Medicare population, Blacks who are not eligible for Medicaid (a proxy for higher economic status) have higher $PM_{2.5}$-related mortality risk than do Whites who are eligible.[28]

Our analysis considered disparities at various scales. Racial disparity at the national scale is driven by high emissions in areas with high non-White populations. However, areas with a proportionately higher White population may still be internally inequitable. The few non-Whites who do reside in such an area are disproportionately likely to live near a source of PM emissions. Figure A, part a highlights such areas; the largely White Midwestern states contain some of the most disproportionately high internal $PM_{2.5}$ burden for non-Whites. Indiana, for instance, is more than 80% White, but the disproportionality in non-White burden is greater there than in any other state. Mohai et al.[2] found a disproportionately high number of Black residences near polluting facilities in Midwestern metropolitan areas—much more so than in Southern cities and in rural areas. No single scale can be considered best for grouping populations. In this case, results at national, state, and county scales all indicate that non-Whites tend to be burdened disproportionately to Whites.

Strengths and Limitations

Our methodology has advantages as well as limitations. We relied on proximity to stationary, human-made point sources of primary PM emissions rather than ambient concentrations. Because there is a collection of other factors that may affect ambient PM concentrations—including natural events, roadway activity, and the formation of secondary PM from precursor pollutants—this metric should not be interpreted as a direct measure of PM exposure. Aggregation of burdens to the census tract level allowed us to compare our absolute burden assignments to EPA's Fused Air Quality Surface Using Downscaling[29] model of $PM_{2.5}$ daily concentration averages for 2011. Despite the presence of small racial disparities in residential ambient $PM_{2.5}$ for the contiguous United States (Table F), mean ambient $PM_{2.5}$ concentration and tract $PM_{2.5}$ burden from emissions were only weakly correlated (Spearman $\rho = 0.30$). However, there are benefits to understanding proximity that go beyond direct health impacts, including monetary reasons. Nearby pollution-generating sites are a tangible and accessible marker of pollution, and residents' awareness of such sites is demonstrated by the negative effect on housing values.[30]

Our method of assignment was to link facilities to all block groups that had a centroid within a set radius of the coordinates given in the NEI. Centroid-containment and other distance-based methods employing circular buffers are better equipped than is unit–hazard coincidence (i.e., the assignment of point sources to only their host census unit) in assigning nearby hazards to a population.[15,31] Unit–hazard coincidence inherently deemphasizes the impact of facilities near borders, which becomes increasingly important in small, dense, urban block groups. The result is an overrepresentation of large, rural areas. Because of the higher representation of the non-White population in urban areas, centroid containment offers a more appropriate characterization of Black burdens nationally. We took several sensitivity measures to address the potential resulting underestimates of burdens in rural areas. In one analysis, we combined unit–hazard coincidence with centroid containment to calculate burdens; in others, we varied the containment radius between 0.5 and 5.0 miles. Neither of these alterations to the methodology substantially changed the values reported in the main analysis, suggesting a robust result (Table C). Furthermore, even limiting analysis only to urban areas, a Black individual living in a metropolitan or micropolitan core has a higher burden than does her urban White counterpart (Figure 2).

An additional strength of our analysis is the inclusion of the total amount of pollutants emitted at each site, as opposed to only the presence or absence of a nearby facility. As seen in Table 1, the proportional burden in facility number for Blacks is only 1.09; the proportional burdens in total $PM_{2.5}$ (1.54) and PM_{10} (1.49) are much higher. This is consistent with studies suggesting that scaling sites by the amount of pollution emitted can further reinforce findings of inequity.[32] The difference between disparities in facility number and disparities in total PM implies that the few extra facilities near the average Black residence tend to be among the highest emitters. The distribution shown in Figure 1 suggests that a relatively small proportion of the US population bears the vast majority of burden from $PM_{2.5}$ emissions. Analysis on the basis of the EPA's Toxic Release Inventory shows that extremely high-polluting "toxic outliers" tend to exist in places with higher non-White and low-income populations.[33]

Public Health Implications

This research demonstrates an aspect of a multifaceted public health problem faced by marginalized groups. As was exemplified in the EPA's investigation of racially discriminatory treatment in a public participation process,[9] the lack of political capital is an obstacle to obtaining more desirable living conditions. In addition, social and economic challenges can lead marginalized people to further populate an area made less desirable by proximity to sources of pollution.[19] The potential health effects of the resulting environmental burdens on these groups should be considered in conjunction with existing health disparities: access to health care has well-documented disparities by race/ethnicity,[34] and the prevalence of certain diseases is notably higher in non-White populations.[25,26] Along with other inequitable social and physical determinants of health, these interlocking mechanisms must all be addressed to establish environmental and public health justice.

We have presented a framework with which to consider the racial and economic disparities in residential proximity to sources of pollution in the United States. We have shown that a focus on poverty to the exclusion of race may be insufficient to meet the needs of all burdened populations. Application of this knowledge can be a valuable resource in improving equity. Disparity persists at multiple scales of observation, and this suggests that solutions can also be approached on multiple levels. AJPH

CONTRIBUTORS

I. Mikati led project design, data analysis, and writing. A. F. Benson contributed to design, writing, and data visualization. T. J. Luben, J. D. Sacks, and J. Richmond-Bryant supported project design and writing.

ACKNOWLEDGMENTS

This research was supported in part by an appointment to the Research Participation Program for the US Environmental Protection Agency (EPA), Office of Research and Development, administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the US Department of Energy and the EPA.

We thank Julian Marshall for his suggestions on strengthening the study design and Danelle Lobdell and Jen Nichols for their helpful comments on the article.

Note. This document was reviewed in accordance with EPA policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. The views expressed in this article are those of the authors and do not necessarily reflect the views or policies of the EPA.

HUMAN PARTICIPANT PROTECTION

No protocol approval was necessary because all data were obtained from publicly available secondary sources.

REFERENCES

1. US General Accounting Office. Siting of hazardous waste landfills and their correlation with racial and economic status of surrounding communities. 1983. Available at: http://www.gao.gov/products/RCED-83-168. Accessed March 13, 2017.

2. Mohai P, Lantz PM, Morenoff J, House JS, Mero RP. Racial and socioeconomic disparities in residential proximity to polluting industrial facilities: evidence from the Americans' Changing Lives Study. *Am J Public Health*. 2009;99(suppl 3):S649–S656.

3. Clark LP, Millet DB, Marshall JD. Changes in transportation-related air pollution exposures by race-ethnicity and socioeconomic status: outdoor nitrogen dioxide in the United States in 2000 and 2010. *Environ Health Perspect*. 2017;125(9):097012.

4. Brender JD, Maantay JA, Chakraborty J. Residential proximity to environmental hazards and adverse health outcomes. *Am J Public Health*. 2011;101(suppl 1): S37–S52.

5. US Environmental Protection Agency. Particulate matter (PM) basics. Available at: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics. Accessed April 6, 2017.

6. Franklin M, Zeka A, Schwartz J. Association between PM2.5 and all-cause and specific-cause mortality in 27 US communities. *J Expo Sci Environ Epidemiol*. 2006;17(3): 279–287.

7. Pope CA, Dockery DW. Health effects of fine particulate air pollution: lines that connect. *J Air Waste Manag Assoc*. 2006;56(6):709–742.

8. Brook RD, Rajagopalan S, Pope CA, et al. Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association. *Circulation*. 2010;121(21):2331–2378.

9. US Environmental Protection Agency. 01R-94-R5 MDEQ closure letter. 2017. Available at: https://www.epa.gov/ocr/01r-94-r5-mdeq-closure-letter. Accessed March 24, 2017.

10. Boyce JK, Pastor M. Clearing the air: incorporating air quality and environmental justice into climate policy. *Clim Change*. 2013;120(4):801–814.

11. US Census Bureau. American Community Survey (ACS). Available at: https://www.census.gov/programs-surveys/acs. Accessed April 17, 2017.

12. US Census Bureau. How the census bureau measures poverty. Available at: https://www.census.gov/topics/income-poverty/poverty/guidance/poverty-measures.html. Accessed August 1, 2017.

13. US Department of Agriculture. 2010 rural–urban commuting area (RUCA) codes documentation. Available at: https://www.ers.usda.gov/data-products/rural–urban-commuting-area-codes/documentation. Accessed April 17, 2017.

14. US Environmental Protection Agency. 2011 National Emissions Inventory (NEI) data. Available at: https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data. Accessed April 17, 2017.

15. Mohai P, Saha R. Reassessing racial and socioeconomic disparities in environmental justice research. *Demography*. 2006;43(2):383–399.

16. Bell ML, Ebisu K. Environmental inequality in exposures to airborne particulate matter components in the United States. *Environ Health Perspect*. 2012;120(12): 1609–1704.

17. Bravo MA, Anthopolos R, Bell ML, Miranda ML. Racial isolation and exposure to airborne particulate matter and ozone in understudied US populations: environmental justice applications of downscaled numerical model output. *Environ Int*. 2016;92–93:247–255.

18. US Census Bureau. Comparing ACS data. Available at: https://www.census.gov/programs-surveys/acs/guidance/comparing-acs-data.html. Accessed April 11, 2017.

19. Mohai P, Saha R. Which came first, people or pollution? Assessing the disparate siting and post-siting demographic change hypotheses of environmental injustice. *Environ Res Lett*. 2015;10:115008.

20. Borrell LN. Racial identity among Hispanics: implications for health and well-being. *Am J Public Health*. 2005;95(3):379–381.

21. Palloni A, Arias E. Paradox lost: explaining the Hispanic adult mortality advantage. *Demography*. 2004; 41(3):385–415.

22. Maantay J. Asthma and air pollution in the Bronx: methodological and data considerations in using GIS for environmental justice and health research. *Health Place*. 2007;13(1):32–56.

23. Kouznetsova M, Huang X, Ma J, Lessner L, Carpenter DO. Increased rate of hospitalization for diabetes and residential proximity of hazardous waste sites. *Environ Health Perspect*. 2007;115(1):75–79.

24. Choi HS, Shim YK, Kaye WE, Ryan PB. Potential residential exposure to toxics release inventory chemicals during pregnancy and childhood brain cancer. *Environ Health Perspect*. 2006;114(7):1113–1118.

25. Mensah GA, Mokdad AH, Ford ES, Greenlund KJ, Croft JB. State of disparities in cardiovascular health in the United States. *Circulation*. 2005;111(10):1233–1241.

26. Centers for Disease Control and Prevention. Trends in asthma prevalence, health care use, and mortality in the United States, 2001–2010. 2012. Available at: https://www.cdc.gov/nchs/products/databriefs/db94.htm. Accessed April 17, 2017.

27. Nachman KE, Parker JD. Exposures to fine particulate air pollution and respiratory outcomes in adults using two national datasets: a cross-sectional study. *Environ Health*. 2012;11:25.

28. Di Q, Wang Y, Zanobetti A, et al. Air pollution and mortality in the Medicare population. *N Engl J Med*. 2017; 376(26):2513–2522.

29. US Environmental Protection Agency. RSIG-related downloadable data files. Available at: https://www.epa.gov/hesc/rsig-related-downloadable-data-files. Accessed April 17, 2017.

30. Davis LW. The effect of power plants on local housing values and rents. *Rev Econ Stat*. 2011;93(4):1391–1402.

31. Chakraborty J, Maantay JA, Brender JD. Disproportionate proximity to environmental health hazards: methods, models, and measurement. *Am J Public Health*. 2011;101(suppl 1):S27–S36.

32. McMaster RB, Leitner H, Sheppard E. GIS-based environmental equity and risk assessment: methodological problems and prospects. *Cartogr Geogr Inform*. 1997; 24(3):172–189.

33. Collins MB, Munoz I, JaJa J. Linking "toxic outliers" to environmental justice communities. *Environ Res Lett*. 2016;11(1):015004.

34. Smedley BD, Stith AY, Nelson AR, eds. *Unequal Treatment: Confronting Racial and Ethnic Disparities in Health Care*. Washington, DC: National Academies Press; 2003.