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Paul Mohai

University of Michigan - Ann Arbor, pmohai@umich.edu

Robin Saha

University of Montana - Missoula, robin.saha@umontana.edu

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LETTER

Which came first, people or pollution? Assessing the disparate siting and post-siting demographic change hypotheses of environmental injustice

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Paul Mohai^{1,3} and Robin Saha²¹ School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI 48109 734-763-4598, USA² Department of Environmental Studies, University of Montana, Missoula, MT 59812 406-243-6285, USA³ Author to whom any correspondence should be addressed.E-mail: pmohai@umich.edu and robin.saha@mso.umt.edu**Keywords:** environmental justice, environmental racism, environmental disparities, racial disparities, longitudinal studies, environmental justice theory, environmental justice evidenceSupplementary material for this article is available [online](#)**Abstract**

Although a large body of quantitative environmental justice research exists, only a handful of studies have examined the processes by which racial and socioeconomic disparities in the location of polluting industrial facilities can occur. These studies have had mixed results, we contend, principally because of methodological differences, that is, the use of the unit-hazard coincidence method as compared to distance-based methods. This study is the first national-level environmental justice study to conduct longitudinal analyses using distance-based methods. Our purposes are to: (1) determine whether disparate siting, post-siting demographic change, or a combination of the two created present-day disparities; (2) test related explanations; and (3) determine whether the application of distance-based methods helps resolve the inconsistent findings of previous research. We used a national database of commercial hazardous waste facilities sited from 1966 to 1995 and examined the demographic composition of host neighborhoods around the time of siting and demographic changes that occurred after siting. We found strong evidence of disparate siting for facilities sited in all time periods. Although we found some evidence of post-siting demographic changes, they were mostly a continuation of changes that occurred in the decade or two prior to siting, suggesting that neighborhood transition serves to attract noxious facilities rather than the facilities themselves attracting people of color and low income populations. Our findings help resolve inconsistencies among the longitudinal studies and builds on the evidence from other subnational studies that used distance-based methods. We conclude that racial discrimination and sociopolitical explanations (i.e., the proposition that siting decisions follow the ‘path of least resistance’) best explain present-day inequities.

Most quantitative analyses of environmental disparities by race and socioeconomic status have been cross-sectional, employing data about hazardous site locations and demographic characteristics from the US Census at only one point in time (Mohai and Saha 2015). These studies, conducted over the past several decades, have established clear patterns of racial and socioeconomic disparities in the distribution of a large variety of environmental hazards. Although a limited number of hypotheses about the causes of present-day

disparities can be tested using cross-sectional data, longitudinal data are essential to identify the processes by which present-day environmental disparities have come about. As we point out in our companion review article (Mohai and Saha 2015), there are only two possible processes for explaining present-day disparities: (1) there has been a pattern, at the time of siting, of placing hazardous waste sites, polluting industrial facilities, and other locally unwanted land uses (LULUs) disproportionately in low-income and

people of color communities, or (2) demographic changes after siting have led to disproportionately high concentrations of low-income and people of color around hazardous sites. These two processes have been termed respectively as 'disparate siting' and 'post-siting demographic change'. Which of these two processes has occurred, or whether both have, has not been firmly established. This is because relatively few longitudinal environmental justice analyses have been conducted. Furthermore, those longitudinal studies that exist have led to confusing and even contradictory findings. The conflicting findings may be the result of the varying geographic scopes of these studies; some have been nation-wide (Oakes *et al* 1996, Been and Gupta 1997, Hunter *et al* 2003) while others have been state-wide (Saha and Mohai 2005) or metropolitan-wide (Shaikh and Loomis 1999, Pastor *et al* 2001, Hipp and Lakon 2010). However, the inconsistent findings may also be the result of these studies employing differing methods; some have employed the unit-hazard coincidence method while others have employed distance-based methods. The differences between the unit-hazard coincidence and distance-based methods have been described in detail by Mohai and Saha (2006, 2007) and others (see, e.g., Chakraborty *et al* 2011, and Mohai and Saha 2015).

Briefly, the unit-hazard coincidence method compares the demographic characteristics of host geographic units, such as counties, zip code areas, and census tracts, with the characteristics of their respective non-host units. Not taken into account are the varying sizes of the host units. As a result, for very large host units, people living at considerable distances from the hazard who may not be exposed to significant risks from the hazard are counted among the 'affected population'. Also not taken into account are the precise locations of the hazardous sites within the host unit and the distance of these sites to adjacent or nearby units. Therefore, the method does not consider whether the hazard inside the host unit is near the center, off-center, or near a boundary. If near a boundary, the hazard may impact not just the host unit alone, but the adjacent and other nearby units as well. If there is a disproportionate concentration of poor people and people of color near the hazardous site, then these disproportionate concentrations may also exist in the nearby units (which are nevertheless counted as part of the comparison or 'control population') as well as in the host unit proper.

In their analysis and critique of the unit-hazard coincidence method, Mohai and Saha (2006, 2007) found that, in relation to commercial hazardous waste treatment, storage, and disposal facilities (TSDFs), TSDFs' host census tracts vary greatly in size from 0.07 to 7521 square miles, and the TSDFs are indeed often located near their host unit boundaries. They found that almost three quarters (71%) of the nation's TSDFs are within 0.50 mile of the boundaries of their respective host census tracts, while almost half (49%) are

within 0.25 mile. Furthermore, they found that the demographic characteristics of non-host tracts near hazardous waste TSDFs are more similar to those of the host tracts proper than to those of non-host tracts farther away. Thus, contrasting the demographic characteristics of the host tracts proper with the characteristics of all non-host tracts, including the nearby tracts, leads to an underestimation of the extent of the disparities between the populations living near the hazard compared to those farther away, and can even result in an inability to detect such disparities.

These findings led Mohai and Saha (2006, 2007) and others (Chakraborty *et al* 2011) to call for replacing the unit-hazard coincidence method with distance-based methods in proximity-based environmental justice analyses. Distance-based methods control for differences in the size of geographic units employed and take into account the exact location of the hazardous sites inside the host units and their distances to nearby units. The demographic characteristics of the nearby units within specified distances of the hazard are then combined with the demographic characteristics of the host unit proper rather than combined with those of non-host units farther away (beyond the specified distance). Combining the host units proper with nearby units within the specified distances uncovers the actual extent of the demographic disparities between host neighborhoods of relatively consistent size and shape and non-host areas whereas the unit-hazard coincidence method does not.

Two frequently employed distance-based methods include the 50% areal containment method (Anderton *et al* 1994, Davidson and Anderton 2000, Mohai and Saha 2006) and areal apportionment method (Glickman 1994, Chakraborty and Armstrong 1997, Hamilton and Viscusi 1999). In applying the 50% areal containment method, the boundary of the host neighborhood of an environmental hazard is determined by combining all the geographic units where at least 50% of the area of the unit is captured by a radius of fixed distance from the hazard. The populations within the captured units are then combined and their demographics contrasted with those of the units not captured. In applying the areal apportionment method, the boundary of the host neighborhood is a perfect circle within a fixed distance from the hazard. The population within this circle is determined by combining the populations of all the units intersected by the circle. However, each unit's contribution is weighted by the proportion of its area captured by the circle. For example, if 25% of the unit's area is captured by the circle, then 25% of the unit's population is allocated to the unit's population inside the circle. The demographics of the combined weighted populations of units intersected by the circle are then contrasted with the demographics of the population beyond the circle. Mohai and Saha (2006, 2007) found that applying distance-based methods such as these uncovers far greater racial and socioeconomic disparities around

hazardous waste TSDFs than when the unit-hazard coincidence method is applied.

Whether the conflicting findings of existing longitudinal environmental justice studies are the result of these studies (a) employing differing geographic scopes, (b) differing methods (unit-hazard coincidence versus distance-based), or (c) both is difficult to sort out. This is because the only three longitudinal environmental justice studies (Oakes *et al* 1996, Been and Gupta 1997, Hunter *et al* 2003) that are national-level also employed the unit-hazard coincidence method, while the only three longitudinal environmental justice studies that employ distance-based methods are also sub-national (Pastor *et al* 2001, Saha and Mohai 2005, Hipp and Lakon 2010). The three sub-national studies employing distance-based methods have found statistically significant evidence to support the disparate siting hypothesis and some, albeit less, support for the post-siting demographic change hypothesis. In contrast, the three national-level studies employing the unit-hazard coincidence method found little support for either disparate siting or post-siting demographic change hypotheses. Is the lack of evidence for these two hypotheses from existing national-level studies because of their different geographic scope from the sub-national studies? Or is it because of their reliance on the unit-hazard coincidence method? To sort this out, national-level studies that also employ distance-based methods are needed. However, to our knowledge, no such national-level analyses have been conducted to date.

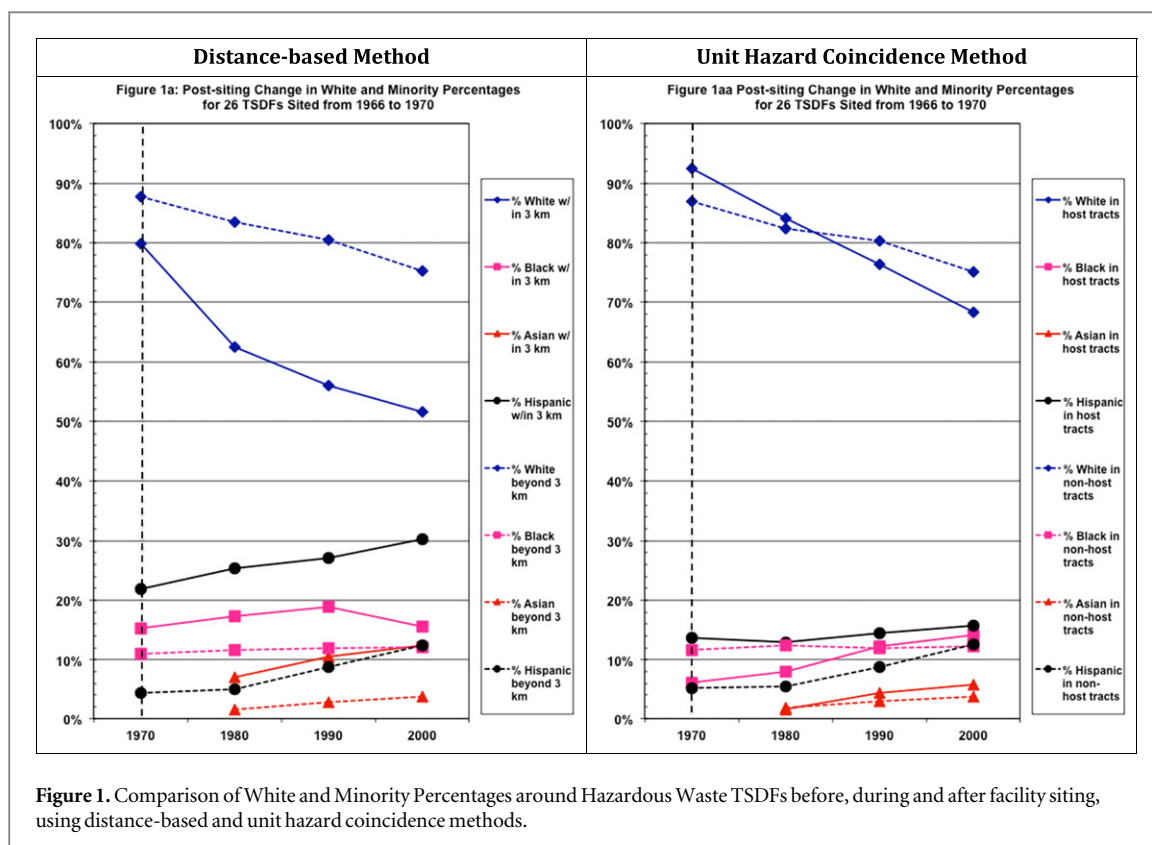
A principal objective of our study therefore is to conduct the first national-level longitudinal environmental justice analysis employing distance-based methods in order to determine whether the application of such methods helps resolve the conflicting findings of earlier studies and provides clearer evidence of the role that the processes of disparate siting and post-siting demographic change play in accounting for present-day disparities. Given Mohai and Saha's (2006, 2007) finding that employing the unit-hazard coincidence method in a cross-sectional study leads to significant underestimation of present-day racial and socioeconomic disparities in the distribution of hazardous waste TSDFs, we hypothesize that the contrasting findings from earlier longitudinal environmental justice studies are principally the result of their employing the unit-hazard coincidence method compared to distance-based methods. Our national-level longitudinal study allows us to determine if findings of disparities at the time of siting and disproportionate post-siting demographic change differ depending on the method employed and whether the findings using distance-based methods contrast with those of the prior national-level studies and are more similar to those of the sub-national studies employing distance-based methods. A second objective of our study is to test several important hypotheses about the economic, socio-political, and discriminatory factors thought to drive

disparate-siting and post-siting demographic change processes. These factors are reviewed in our companion article (Mohai and Saha 2015).

Data and methods

A total of 413 TSDFs were identified as legally permitted and operating in 1999 and mapped using GIS and information from various public and private databases. The operating status, location and dates of facility siting were determined or verified by contacting facility owners and state and federal regulatory agencies (see Mohai and Saha supplement for additional details). We found information about the start dates of many of the facilities sited before 1966 to be unreliable (e.g., due to lack of legal definitions of hazardous waste and difficulties of determining start dates for facilities that changed operations or ownership). For our analysis, we thus narrowed the universe to 319 TSDFs that were sited during the 30-year period from 1966 to 1995. To assess patterns of disparate siting for these TSDFs, we used the areal apportionment method (see discussion above and Mohai and Saha 2006, 2007, 2015) to examine the demographic characteristics of the 3 km radius circular host neighborhoods at or near the time of siting for six cohorts of facilities sited in various 5-year time periods⁴. We then compared the demographic characteristics of TSDF host neighborhoods from the decennial Census closest to the siting dates of the cohorts of facilities to demographics of non-host areas beyond 3 km of the TSDFs. Thus, to assess whether the cohort of TSDFs sited between 1966 and 1970 ($N = 26$) were sited where disproportionate numbers of people of color and low-income people live, 1970 Census data were used. The 1970 Census data similarly were used to assess TSDFs sited between 1971 and 1975 ($N = 55$), 1980 data were used to assess TSDFs sited between 1976 and 1980 ($N = 88$) and between 1981 and 1985 ($N = 68$), and 1990 data were used to assess TSDFs sited between 1986 and 1990 ($N = 58$) and between 1991 and 1995 ($N = 24$). To assess patterns of post-siting demographic change, a number of race/ethnicity and socioeconomic variables were used to examine the demographic characteristics of the neighborhoods for each of the cohorts of facilities at each subsequent Census year up to 2000. We also examined the demographic characteristics of the host neighborhood of the various cohorts of facilities in all prior Census years (beginning with the 1970 Census) to assess demographic changes *before* siting (see Mohai and Saha supplement for additional details). We also replicated our analyses using the unit-hazard coincidence approach to see if outcomes differed.

⁴ The 3 km distance is within the range of distances used in prior studies and within which health, economic and other quality of life impacts have been found to exist (Mohai and Saha 2007).



Multivariate statistical analyses were used to assess the relative importance of racial and socioeconomic characteristics of nearby census tracts in predicting the siting of new hazardous waste TSDFs for each of the Census years, 1970, 1980, and 1990. Nearby tracts were identified as those tracts within 3.0 km of the TSDFs using the 50% areal containment method. The census variables used in the statistical analyses included: mean property values; percent of persons 25 years old and over with a four-year college degree; percent employed in executive, managerial or professional occupations; percent employed in precision production, transportation or labor occupations; percent African American or black; percent Asian/Pacific Islander; and percent Latino or Hispanic (see Mohai and Saha supplement for a description of the construction of these variables). These variables have been used in many prior quantitative environmental justice analyses. Although these census variables are often correlated with each other, and thus risk creating multi-collinearity problems in multivariate statistical analyses, we examined the variance inflation factors (VIF) in selecting variables to include in our regression equations such that the VIFs were within acceptable limits of less than 10 in all cases (Hair *et al* 1995).

Results

We first examined the existence and extent of racial disparities around TSDF locations at or near the time of facility siting. Figure 1 displays the results of

comparing the percentages of each racial and ethnic group within and beyond the TSDF host areas at or near each period of siting. When the areal apportionment distance-based method is applied, these comparisons reveal a clear pattern of racially disparate siting at each time period. For example, using the 1970 Census, figure 1(a) reveals that at or near the time of siting the percentage of whites in neighborhoods within 3.0 km of facilities sited between 1966 and 1970 was lower than the percentage of whites in neighborhoods beyond 3.0 km. At the same time, the percentage of African Americans in neighborhoods within 3.0 km of a TSDF was greater than the percentage beyond 3.0 km. The same is true of Hispanics, and in this case the disparities appear to be even greater than they are for blacks. When we examine changes in demographic disparities around the TSDFs after siting with areal apportionment (i.e., in 1980, 1990, and 2000 in figure 1(a)), they appear to widen for whites, Hispanics, and Asians and Pacific Islanders (although not for blacks), indicating that the present-day disparities around facilities sited between 1966 and 1970 are a function of both disparate siting at the time of siting and post-siting demographic changes.

The unit-hazard coincidence method produces very different results (figure 1(aa)). Racial and ethnic disparities at the time of siting are much reduced, and in some cases reversed. For example, at the time of siting (near 1970) a somewhat larger percentage of whites are found in the host tracts than non-host tracts, while a slightly larger percentage of blacks are found in the

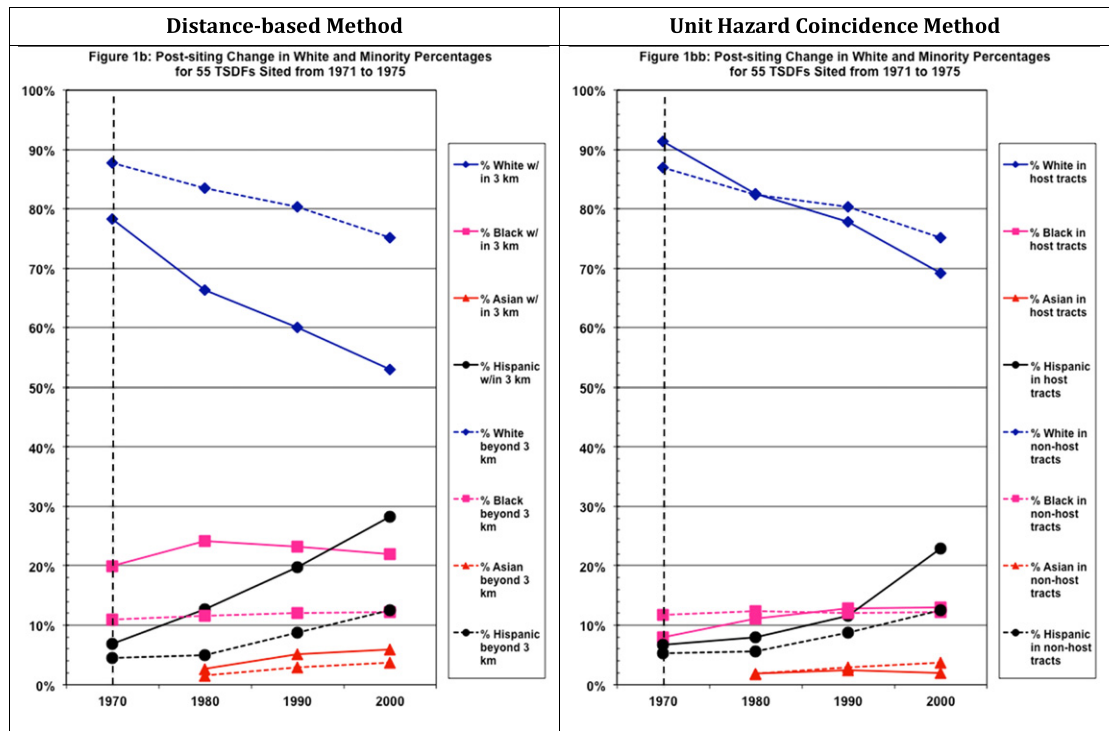


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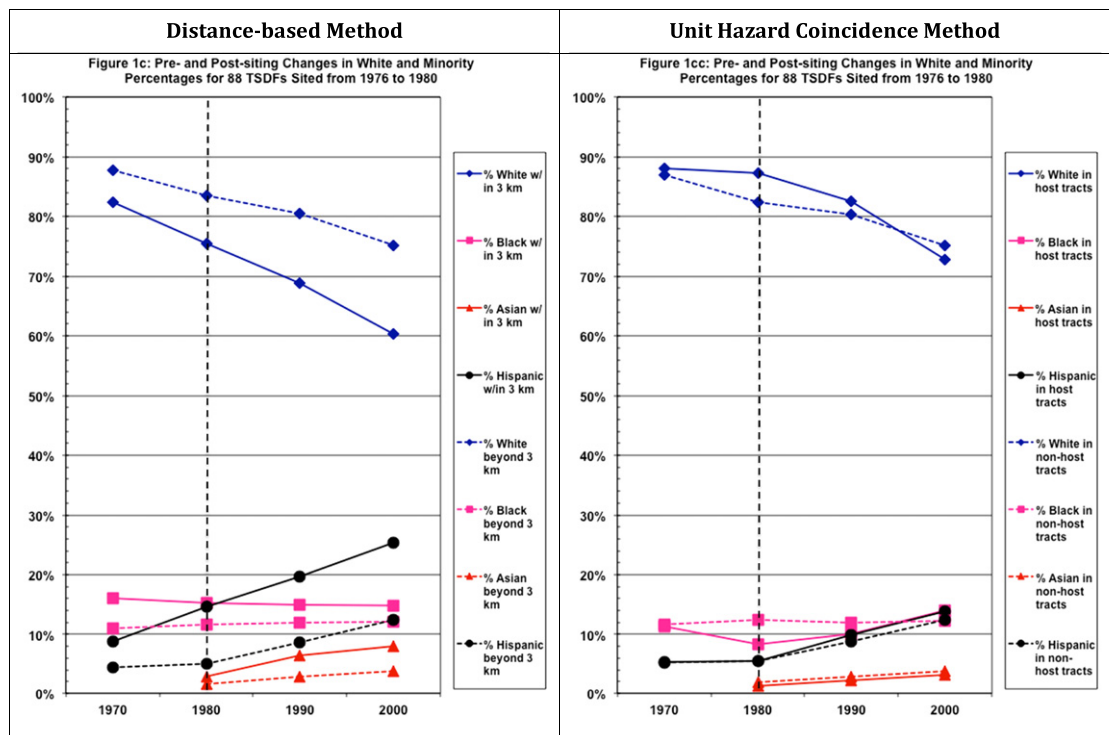


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non-host tracts than host tracts. Furthermore, changes in demographic disparities over time are also much smaller (figure 1(aa)) and reveal no clear pattern. Sometimes the disparities widen slightly (Asians and

Pacific Islanders), sometimes shrink (Hispanics), and sometimes reverse direction (whites and blacks).

When we examine the demographic characteristics around facilities sited between 1971 and 1975, similar

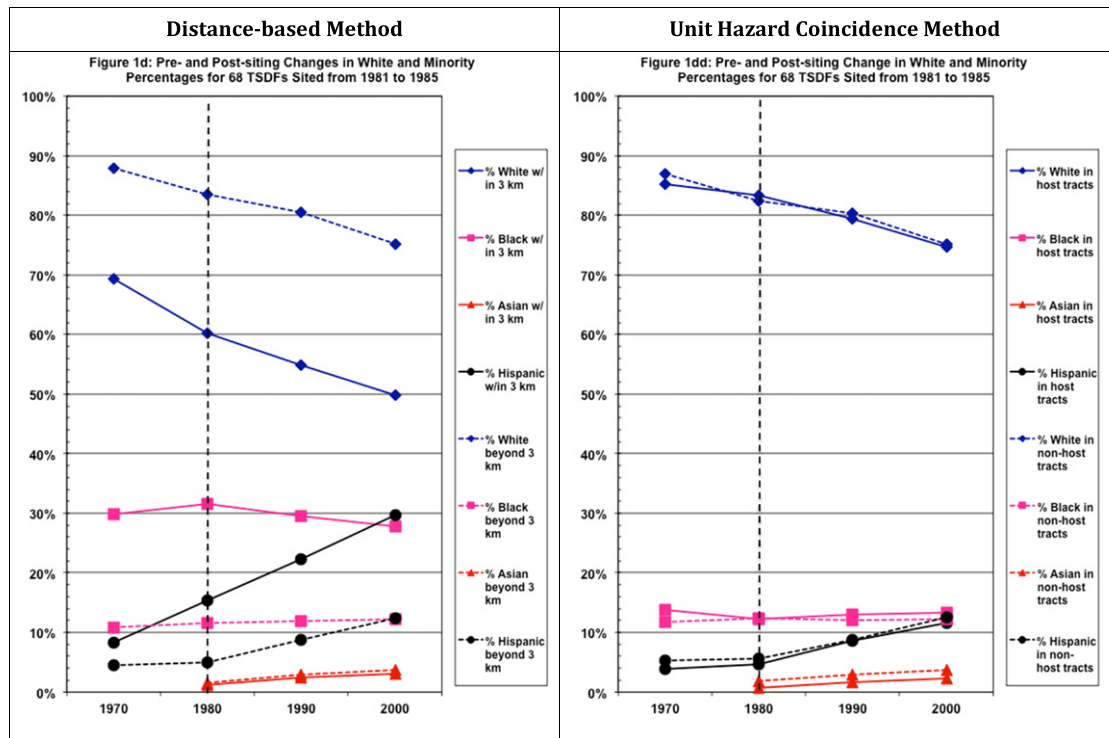


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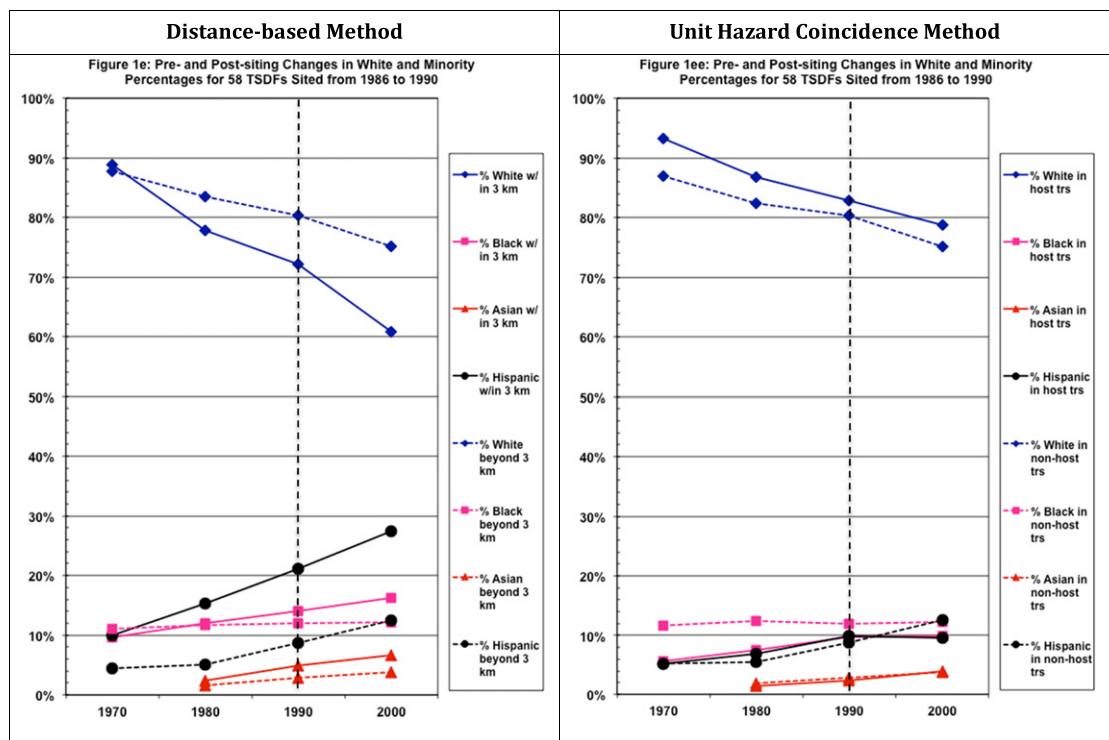
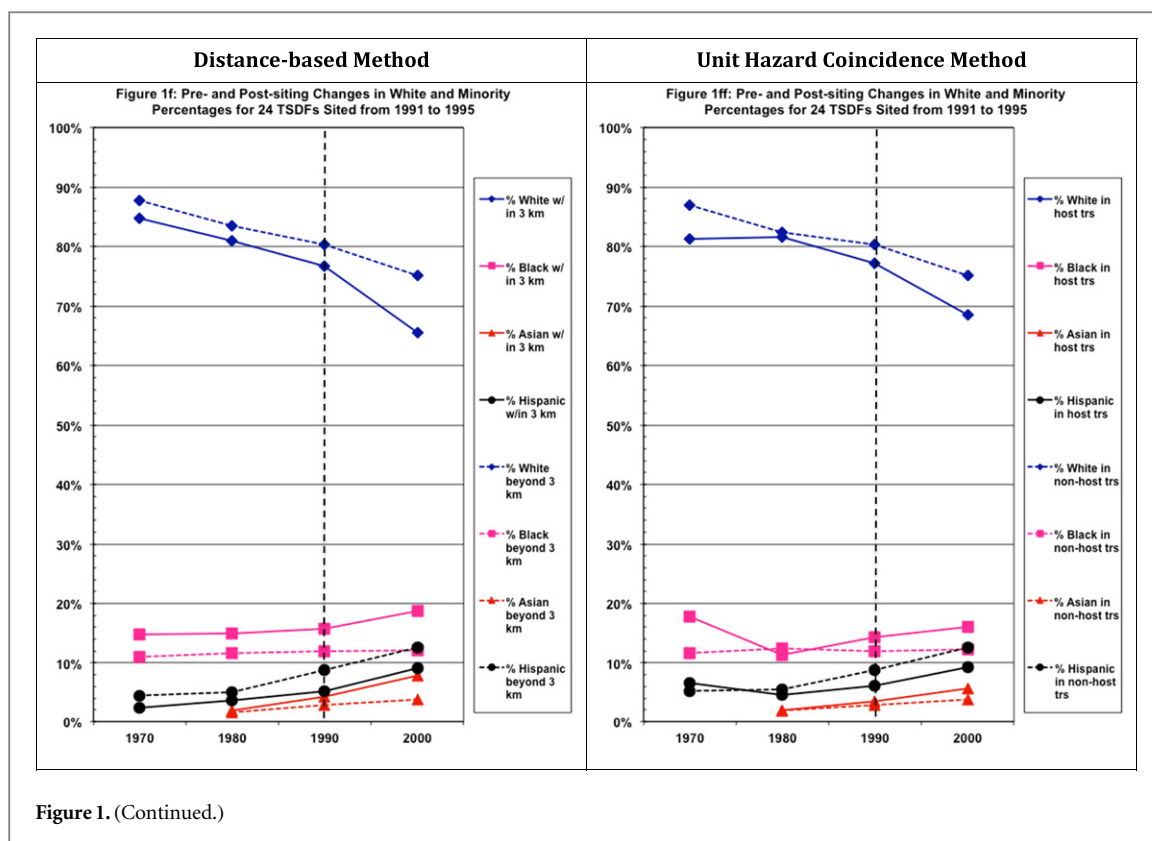


Figure 1. (Continued.)

patterns are found, as shown in figures 1(b) and (bb). As before, racial disparities at the time of siting are found to be greater when applying areal apportionment (figure 1(b)), although this time the disparities are greater for blacks than they are for Hispanics. In

addition, disparities after siting widen over time for whites, Hispanics, and Asian and Pacific Islanders, but not for blacks. When the unit-hazard coincidence approach is applied, the demographic disparities at the time of siting are much smaller (even reverse in



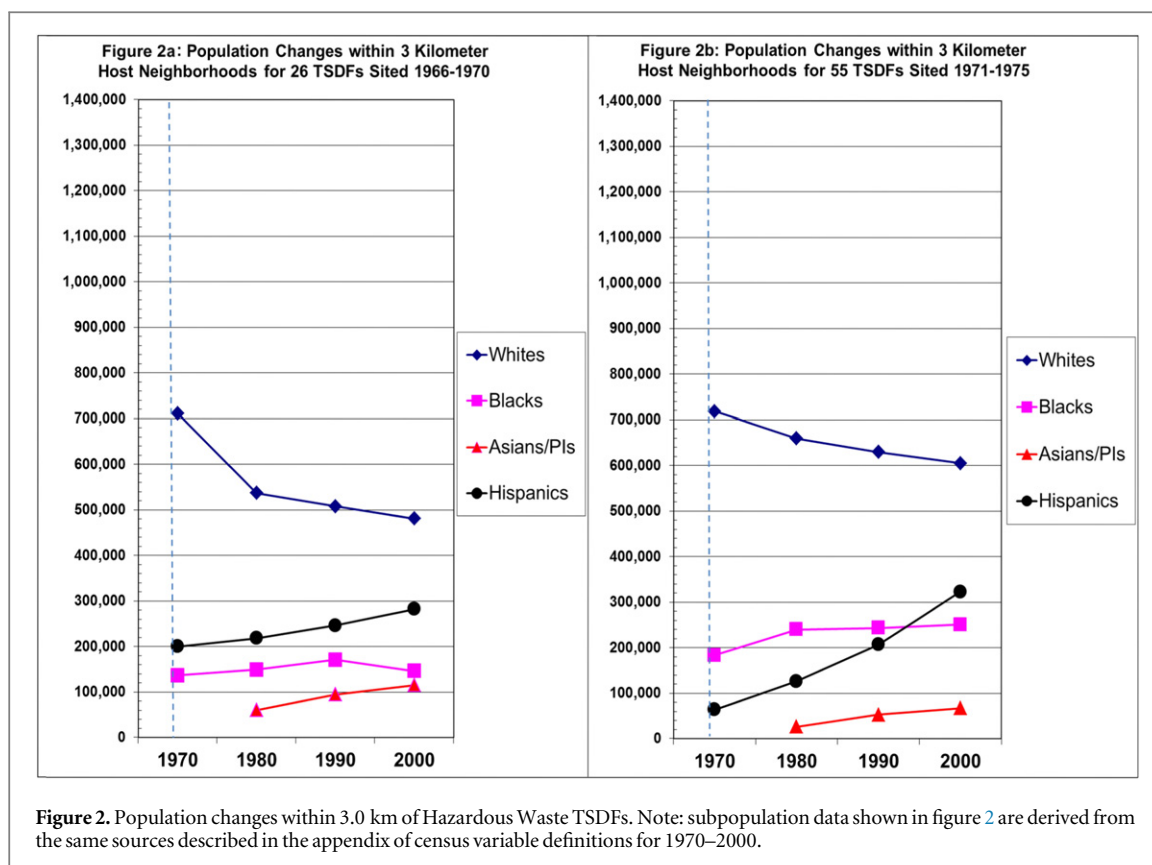
direction for blacks) and changes in demographic disparities over time are also much smaller (figure 1(bb)).

When we examine racial disparities at or near the time of facility siting using areal apportionment and the 1980 Census (figures 1(c) and (d)), we can see that the patterns of disparities are very similar to those found for facilities sited at or near 1970 (figures 1(a) and (b)). Racial disparities around TSDFs sited at or near 1980 are found for every racial and ethnic group, including for Asians and Pacific Islanders (differences appear small due to their relatively small numbers but we examine these differences again in our statistical analyses). Although disparities in the black percentages appear to decrease somewhat after siting, disparities in the white, Hispanic, and Asian and Pacific Islander percentages widen. Together these results suggest, as they did for facilities sited around 1970 (figures 1(a) and (b)), that when the areal apportionment method is applied to facilities sited around 1980 (figures 1(c) and (d)) present-day racial disparities are largely the result of both a pattern of disparate siting at the time of siting and demographic changes after siting. Such patterns are not found when the unit-hazard coincidence method is applied. Disparities at the time of siting are found to be virtually non-existent for facilities sited around 1980, as are demographic changes after siting (figures 1(cc) and (dd)).

Although it may be tempting to deduce from the above results using areal apportionment that the presence of the TSDFs in some way ‘causes’ the demographic changes that widen the racial disparities around these TSDFs after siting, closer examination of

figures 1(c) and (d) suggests an alternate interpretation. We see that for whites and Hispanics, the percentages around the TSDF locations had already begun to change before the siting and these are in the same trajectory as after siting. Thus, rather than the TSDFs causing the demographic changes that amplify the disparities around the TSDFs, it appears that TSDFs may be sited in locations that are both disproportionately nonwhite at the time of siting and are already undergoing demographic changes. In other words, contrary to the post-siting demographic change hypothesis, and consistent with Pastor *et al* (2001) findings for the Los Angeles area (see also Mohai and Saha 2015), the demographic changes appear to ‘attract’ the facilities rather than the facilities attract minorities. An exception to this pattern is for blacks. However as noted earlier, disparities in the black percentages around TSDFs sited at or near 1980 remain relatively stable before and after siting, although they decrease slightly after siting.

We next turn our attention to the facilities sited between 1986 and 1990 and between 1991 and 1995, and examine racial disparities at or near the time of siting using the areal apportionment distance-based method and the 1990 Census. As can be seen in figures 1(e) and (f), the patterns around these facilities appear very similar to those found earlier. For every racial and ethnic group, disparities exist in the percentages within and beyond 3.0 km of these facilities at or near the time of siting. For both cohorts of TSDFs, the disparities also widen after siting. And as with the facilities sited at or near 1980, the demographic changes



appear to have begun well before the siting. In fact, they appear to have commenced at least as far back as 1970. As in the case of the facilities sited at or near 1980, these results suggest that the demographic changes appear to be attracting the facilities rather than the facilities attracting minorities or repelling whites.

Applying the unit-hazard coincidence method to the facilities sited around 1990 produces results similar to those found when the unit-hazard coincidence method was applied to the facilities sited around 1970 and 1980. Demographic disparities at the time of siting are small as are changes in the demographic disparities after siting (figures 1(ee) and (ff)). The weak evidence for both disparate siting and post-siting demographic change at each of the decades (1970, 1980, and 1990) using the unit-hazard coincidence method is consistent with the similarly weak evidence of the earlier national-level longitudinal studies using this method (Oakes *et al* 1996, Been and Gupta 1997, Hunter *et al* 2003). Instead, the robust evidence that we obtained using areal apportionment is similar to that of the earlier sub-national longitudinal studies using distance-based methods, such as Pastor *et al* (2001), Saha and Mohai (2005), and Hipp and Lakon (2010).

Summarizing the results in figures 1(a)–(f) using distance-based methods, one sees a clear historical pattern of racially disparate siting of hazardous waste TSDFs at the time of siting. And although we also witness post-siting demographic changes that tend to widen the racial disparities around the TSDFs, a surprising finding is that the demographic changes

appear to have already begun before siting. These results suggest that demographic changes in places which eventually receive a TSDF tend to ‘attract’ TSDFs rather than the other way around. We also found similar patterns when we examined changes in poverty rates, mean incomes, and property values around the TSDF locations (see Mohai and Saha supplement, figures 3–5).

However, the percentage changes alone do not tell us what groups actually move into or away from the sites. For example, if the white percentages around hazardous waste TSDFs are decreasing while minority percentages are increasing, these changes could be the result of a number of possibilities: (a) whites may be moving out while minorities are simultaneously moving in; (b) there is no net movement of the white population away from TSDF sites but their percentage is decreasing simply because minorities are moving in; (c) there is no net movement of minorities to TSDF sites but their percentage is increasing because whites are moving out; (d) both whites and minorities are moving away from TSDF locations but whites are moving out at a faster rate (possibly due to higher incomes and fewer residential mobility constraints imposed on them by discrimination in the housing market).

Thus, to better understand what accounts for the decreasing white percentages and increasing minority percentages around TSDF locations using areal apportionment, we examined actual subpopulation changes within 3.0 km of these sites for each racial and ethnic

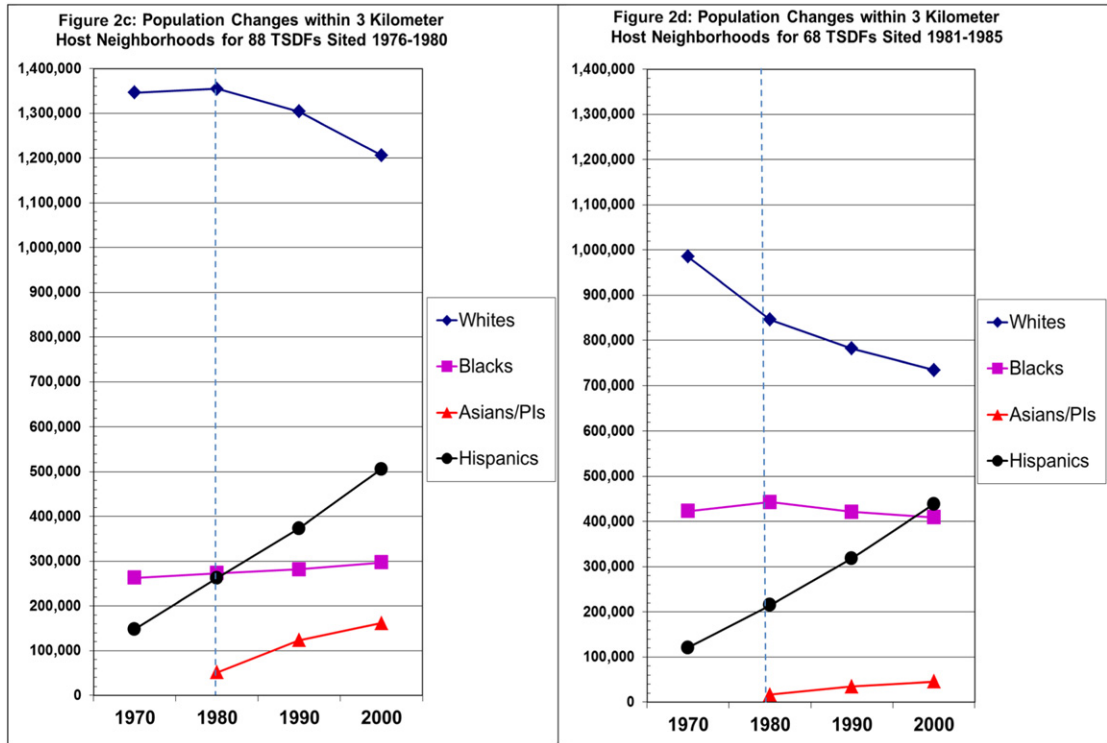


Figure 2. (Continued.)

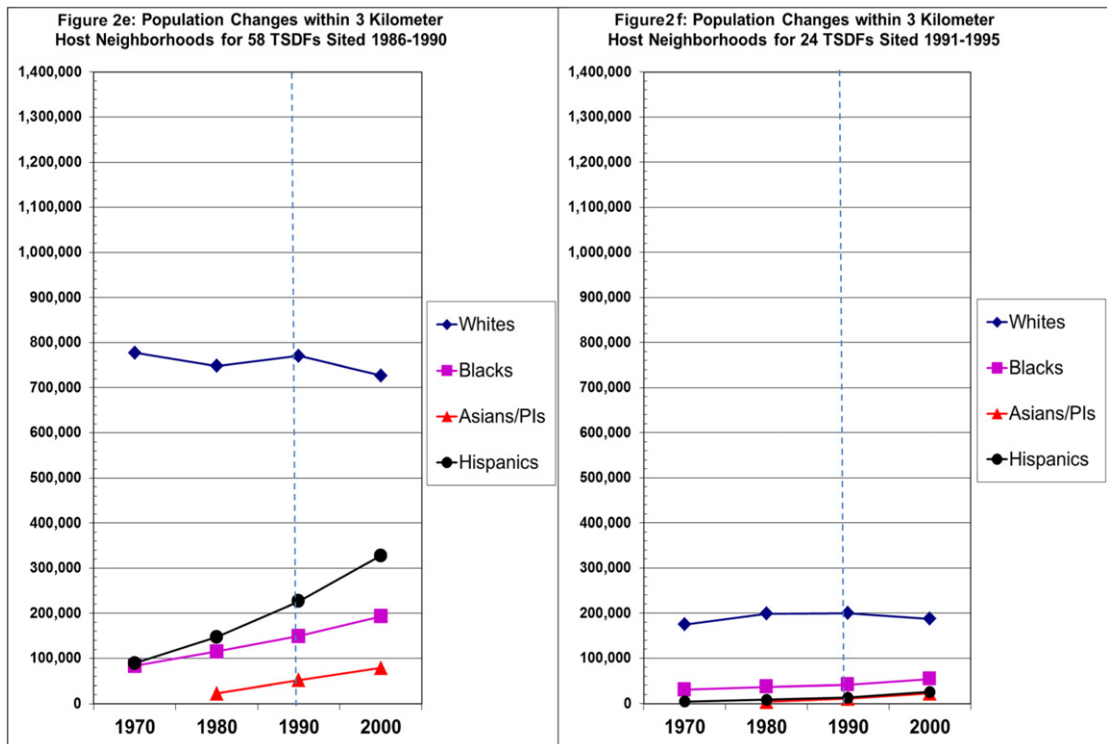


Figure 2. (Continued.)

group between 1970 and 2000. These results are displayed in figures 2(a)–(f). Regarding the TSDFs sited between 1966 and 1970 (figure 2(a)), it is clear that whites have moved out and minorities have moved in since 1970 (we do not include in the figure subpopulation totals for areas beyond 3.0 km because of their very large size)⁵. A similar pattern is found around facilities sited between 1971 and 1975. However, for TSDFs sited between 1966 and 1970 and between 1971 and 1975, the numbers of blacks that moved in around these sites was slight compared to the numbers of Hispanics and Asians and Pacific Islanders moving in.

We found very similar patterns in examining in- and out-migration around TSDFs sited between 1976 and 1980 and between 1981 and 1985. Whites moved out while Hispanics and Asians and Pacific Islanders moved into the areas around the sites. At the same time, there was only a very slight change in the numbers of blacks around these sites. As we saw earlier when examining the percentage changes, the in- and out-migrations appear to have occurred in advance of facility siting, suggesting once more that the facilities themselves may not be the ‘cause’ of these migrations. Although the rate of out-migration by whites appears to have increased after 1980 around TSDFs sited between 1976 and 1980, this rate slowed around the facilities sited between 1981 and 1985, and population changes around these facilities for blacks shifted from slightly increasing to slightly decreasing before and after 1980.

The above patterns are largely the same for TSDFs sited between 1986 and 1990 and between 1991 and 1995, although the numbers of people affected by TSDFs and the rates of subpopulation changes were considerably less for the facilities sited in the latter period. This could be due to the much smaller number of TSDFs sited in this period (24 facilities) than in prior periods and the much smaller span of time passing from facility siting to the 2000 Census (less than 10 years) as compared to the facilities sited earlier. Nevertheless, we see that around facilities sited between 1986 and 1990, there was a decrease in the number of whites after siting, while there was a large increase in the numbers of each of the other racial and ethnic groups, including this time also blacks. However, as we have

seen before, the subpopulation changes appear to have occurred well before the facilities are sited.

In sum, the above analyses demonstrate that: (a) TSDFs sited between 1966 and 1995 were placed in locations that were disproportionately nonwhite and poor (see Mohai and Saha supplement regarding socioeconomic status) at the time of siting; (b) although disparities around TSDFs widened after siting, the demographic changes were already occurring at TSDF locations before siting; (c) the widening demographic disparities were largely the result of whites moving out of TSDF neighborhoods and Hispanics and Asians/Pacific Islanders moving in (again, before and after siting); and (d) there is little evidence of net movement of blacks either into or away from such locations. These results are consistent with the ‘path of least resistance’ (sociopolitical) explanation of racially and socioeconomically disparate siting. This sociopolitical explanation posits that the siting of LULUs tends to occur in communities that, relative to other communities, may lack political clout and resources needed to effectively oppose new facility siting proposals (see Mohai and Saha 2015, for a more detailed description of this explanation). Communities that are disproportionately people of color, poor, and experience demographic change are particularly vulnerable to loss of social capital and political clout (Elliot and Frickel 2013).

Because the most argued for alternative explanations of disparate siting have been the market dynamics and racial discrimination explanations (see Mohai and Saha 2015)⁶, we wanted to see whether the racial disparities found at or near the time of facility siting (figure 1) were independent or largely the result of people of color coincidentally living in areas where land values are low. We thus used distance-based methods (this time the 50% areal containment method) and logistic regression analyses to determine (a) whether the race variables were statistically significant predictors of facility locations at the time of siting (Models 1 in table 1) and (b) whether they remained so after controlling for mean property values and other socioeconomic variables (Models 2). In the regression, the dependent variable took a value of ‘1’ if 50% or more of a census tract lay within 3.0 km of a TSDF location at the time of siting and a value ‘0’ if

⁵ Natural population changes, i.e., births and deaths, may have had some effect on the observed post-siting subpopulation changes, but we did not fully assess the size of such changes. We used tract-level demographic data from the US Census Bureau. However, National Center for Health Statistics is the primary source for births and deaths, but neither it nor the Census Bureau compiled such data at the tract level. Overall, black birth rates were about one-third greater than those of whites in 1980, 1990, and 2000, while death rates for blacks were comparable to those of whites. Hispanic birth and death rates were not reported for 1980 and 1990, but in 2000 Hispanic birth rates were nearly double of those of non-Hispanic whites and death rates were about one-quarter lower than those of whites. Hispanic birth and death rates together account for natural population growth of about 15 persons per 1000 in excess of the natural growth rate of non-Hispanic whites.

⁶ The market dynamics explanation argues that the disproportionate siting of hazardous facilities in people of color communities is the result of industries’ desire to minimize the costs of doing business. Since facilities such as TSDFs require land, which can incur a significant expense, industries attempt to locate in areas where land values are low. These areas tend to be where poor people and people of color also live. Racial discrimination explanations have raised questions about whether people of color communities are targeted for society’s undesirable land uses because such communities represent the path of least resistance due to a lack of political clout and whether institutionalized forms of racism involving past discriminatory decisions regarding housing, industrial zoning, provision of services, and others, continue to perpetuate disadvantages for people of color communities (see Mohai and Saha 2015, for further discussion about these explanations).

Table 1. Comparison of logistic regression results applying the 50% areal containment distance-based method and unit hazard coincidence method.

Variables	50% areal containment method		Unit hazard coincidence method	
	Model 1	Model 2	Model 1	Model 2
<i>TSDFs sited 1966–1970 1970 census</i>				
% Black	0.775 ^b	−1.380 ^b	−1.099	0.055
% Hispanic	3.796 ^c	1.098 ^a	2.582 ^c	1.363
%Asian/Pacific islander				
Mean property value (\$1000 s)		0.025		0.059
% with college degree		−4.064		−10.819
% in prof./mana. occupations		−9.976 ^c		10.693
% in prec. prod./labor occupations		−0.835		9.124 ^b
Constant	−5.600 ^c	−3.589 ^c	−7.494 ^c	−13.519 ^c
−2 log likelihood	2480.24	1235.84	359.74	286.50
Model X^2	202.147 ^c	93.71 ^c	7.921 ^a	14.603 ^a
<i>TSDFs sited 1971–1975 1970 census</i>				
% Black	1.121 ^c	−0.525 ^a	−0.350	−0.339
% Hispanic	1.034 ^a	0.260	1.869 ^a	1.548 ^a
%Asian/Pacific islander				
Mean property value (\$1000 s)		0.010		−0.043
% with college degree		−1.448		−8.445
% in prof./mana. occupations		−5.225 ^a		5.593
% in prec. prod./labor occupations		3.090 ^c		3.087
Constant	−5.348 ^c	−5.481 ^c	−6.866 ^c	−7.584 ^c
−2 log likelihood	2531.99	2170.99	615.614	529.46
Model X^2	28.82 ^c	160.52 ^c	5.015	22.822 ^c

Table 1. (Continued.)

Variables	50% areal containment method		Unit hazard coincidence method	
	Model 1	Model 2	Model 1	Model 2
<i>TSDFs sited 1976–1980 1980 census</i>				
% Black	1.029 ^c	0.785 ^c	−0.619	−0.787
% Hispanic	2.114 ^c	1.846 ^c	1.223 ^a	−0.107
% Asian/Pacific islander	1.984 ^c	3.017 ^c	−6.167	−0.630
Mean property value (\$1000 s)		−0.004		0.0001
% with college degree		−1.733		−2.116
% in prof./mana. occupations		2.314		−0.249
% in prec. prod./labor occupations		2.418 ^c		3.413 ^a
Constant	−5.099 ^c	−5.905 ^c	−6.344 ^c	−7.220 ^c
−2 log likelihood	4778.23	4489.18	1132.91	1066.97
Model X^2	114.29 ^c	153.14 ^c	6.986	28.24 ^c
<i>TSDFs sited 1981–1985 1980 census</i>				
% Black	2.240 ^c	1.901 ^c	0.064	−0.091
% Hispanic	2.373 ^c	2.004 ^c	0.833	−0.399
% Asian/Pacific islander	−2.526	1.867	−40.171 ^b	−21.075
Mean property value (\$1000 s)		−0.022 ^c		0.005
% with college degree		2.389		−4.149
% in prof./mana. occupations		−0.769		−0.746
% in precision production/labor occupations		3.041 ^c		2.663
Constant	−5.571 ^c	−5.843 ^c	−6.365 ^c	−6.963 ^c
−2 log likelihood	3969.99	3587.14	929.42	879.77
Model X^2	266.13 ^c	376.72 ^c	15.301 ^b	33.430 ^c

Table 1. (Continued.)

Variables	50% areal containment method		Unit hazard coincidence method	
	Model 1	Model 2	Model 1	Model 2
<i>TSDFs sited 1986–1990 1990 census</i>				
% Black	0.636 ^b	0.292	−0.637	−0.857
% Hispanic	1.749 ^c	1.667 ^c	0.025	−0.105
%Asian/Pacific islander	2.468 ^c	3.554 ^c	−1.831	0.403
Mean property value (\$1000 s)		−0.004 ^c		−0.004
% with college degree		0.366		0.963
% in prof./mana. occupations		−2.924 ^a		−2.104
% in prec. prod./labor occupations		−1.661 ^a		0.399
Constant	−5.815 ^c	−4.327 ^c	−6.824 ^c	−6.332 ^c
-2 log likelihood	3268.64	3165.68	919.384	911.359
Model X^2	57.05 ^c	98.39 ^c	1.580	7.980
<i>TSDFs sited 1991–1995 1990 census</i>				
% Black	0.292	−0.261	−0.248	−0.942
% Hispanic	−3.991 ^a	−3.295	−0.160	−0.414
%Asian/Pacific islander	2.383 ^a	3.721 ^b	1.439	3.472
Mean property value (\$1000 s)		−0.009 ^a		−0.008
% with college degree		1.014		−0.574
% in prof./mana. occupations		−4.278 ^a		−4.312
% in prec. prod./labor occupations		−4.074 ^a		−1.725
Constant	−6.884 ^c	−4.211 ^c	−7.821 ^c	−5.539 ^c
-2 log likelihood	883.98	862.07	422.99	411.90
Model X^2	9.16 ^a	29.50 ^c	0.472	10.886

Note: values in table represent logistic regression coefficients.

^a $p < 0.05$.

^b $p < 0.01$.

^c $p < 0.001$.

most of the tract lay beyond that distance. We conducted the analyses for each of the TSDF siting periods discussed above.

When we examine the results for TSDFs sited between 1966 and 1970, we find that both the percent black and the percent Hispanic are statistically significant predictors of facility siting in Model 1 using the 1970 Census. When mean property values, percent with college degrees, percent in professional/managerial occupations, and percent in precision production/labor occupations are entered into the equation (Model 2), percent Hispanic remains a statistically significant predictor of facility location in the expected direction. However, the sign for percent black becomes negative indicating it now predicts facility location in the unexpected direction. When comparing these results with the graphical analysis in figure 1(a), the regression results may not be all that surprising given that the disparity in the Hispanic percentage was found to be much greater than the disparity in black percentage at the time of siting for these facilities. Note, however, that the mean property values of the census tract are not significant in Model 2, which tends to contradict the market dynamics explanation of environmental disparities. At the same time, the percent employed in professional/managerial occupations in the tracts is a statistically significant predictor of facility location and in the expected direction (i.e., tracts with a high percentage employed in such occupations are less likely to be near a TSDF), which lends support to the path of least resistance (sociopolitical) explanation.

When facilities sited between 1971 and 1975 are examined, both percent black and percent Hispanic are statistically significant predictors of facility locations in Model 1. However, this time neither percent black nor percent Hispanic are statistically significant predictors of facility locations in the expected direction, when mean property values and the other control variables are entered (Model 2). As before, mean property values are not a significant predictor of facility locations, contradicting the market dynamic explanations of environmental disparities. At the same time, both percent in professional/managerial occupations and percent in precision production/labor occupations are statistically significant predictors in the expected direction.

Similar patterns in the results were obtained when we conducted logistic regression analyses of the facilities sited between 1976 and 1980 using the 1980 Census, although this time the racial and ethnic variables tended to be much stronger predictors of facility locations. All three are statistically significant predictors of facility siting in the expected direction in Model 1. When mean property values and the socioeconomic variables are entered into the equation in Model 2, all three race/ethnicity variables remain statistically significant in the expected direction. However, as earlier, the mean property value variable is not a

statistically significant predictor of facility siting, again contradicting the market dynamics explanation, while the percent employed in precision production/labor occupations is statistically significant. Similar patterns are found for facilities sited between 1981 and 1985, with a couple of exceptions. Although the percent black and percent Hispanic are statistically significant predictors of facility location in Models 1 and 2, the percent Asian and Pacific Islanders is not significant in either model. Also contrasting earlier results, the mean property value variable is a statistically significant predictor of facility location in Model 2 and in the expected direction, i.e., tracts with lower property values are more likely to receive a TSDF directly or nearby.

When TSDFs sited between 1986 and 1990 are examined using the 1990 Census, patterns very similar to those above are again found. In Model 1, all three race variables are statistically significant predictors of facility location in the expected direction. In Model 2, percent Hispanic and percent Asian and Pacific Islander remain statistically significant after applying controls. As with the facilities sited between 1981 and 1985, the mean property variable is a statistically significant predictor of facility siting between 1986 and 1990 while percent with a college degree is not. However, this time percent employed in professional/managerial occupations is a statistically significant predictor of TSDF siting, and in the expected direction (with tracts with higher percentages in those occupations less likely to have a facility sited nearby). Although percent employed in precision production/labor occupations is also statistically significant, it is no longer so in the expected direction.

Finally, when we examine the results for facilities sited between 1991 and 1995 the outcomes for the race variables appear to be more mixed than previously. Whereas percent black and percent Hispanic tended to be robust predictors of facility siting in the earlier time periods, they are no longer so for these facilities. Percent black is not statistically significant in either Models 1 or 2, and percent Hispanic predicts facility location only in the unexpected direction. However, percent Asian and Pacific Islander is a statistically significant predictor of facility siting before and after controls, suggesting increasing vulnerability of that group and decreasing vulnerability of blacks and Hispanics to TSDF siting in that time period. As with the facilities sited between 1986 and 1990, the mean property values variable and the occupation variables are statistically significant predictors of facility siting.

In sum, although mean property values are statistically significant predictors of TSDF siting for facilities sited between 1981 and 1995, they are not statistically significant predictors of TSDF siting for facilities sited between 1966 and 1980. At the same time, the race variables remain statistically significant predictors of TSDF siting throughout all the siting periods in spite of controlling for mean property values and other socioeconomic characteristics of the census tracts

within 3 km of the TSDFs. Thus, although there is some limited evidence that property values are related to facility siting, the racial disparities observed around facility sites are independent of them and other socioeconomic characteristics for the entire 30-year period we examined.

Finally, we provide logistic regression results using the unit-hazard coincidence method (table 1) in order to compare the outcomes with those using the 50% areal containment method. Confirming what we found earlier, outcomes generally are much weaker using the unit-hazard coincidence method than when distance-based methods are applied. When all variables are entered into the models (Model 2), in only one instance does a race/ethnicity variable remain statistically significant; specifically the percent Hispanic remains a statistically significant predictor of facility siting for facilities sited between 1971 and 1975. And in only two cases is the percent employed in precision production/labor occupations a statistically significant predictor of facility siting: those sited between 1966 and 1970 and those sited between 1976 and 1980. No other variables are statistically significant predictors of facility siting when all variables are entered in the regression models using the unit-hazard coincidence method.

Conclusions

A considerable number of quantitative analyses have been conducted in the past several decades that demonstrate the existence of racial and socioeconomic disparities in the distribution of environmental hazards of a wide variety. The vast majority of these have been cross-sectional, snapshot studies employing data on the hazardous facilities and population characteristics at only one point in time. Although some limited hypotheses can be tested with cross-sectional data, fully understanding how present-day disparities come about requires longitudinal analyses that examine the demographic characteristics of sites at the time of facility siting and track demographic changes after siting. Relatively few such studies exist, mainly because of the difficulty of obtaining adequate information about start dates for facilities, shifting census tract and zip code boundaries over time, and uncertainties regarding the most appropriate methodologies to employ.

The number of longitudinal environmental justice analyses has not only been limited, but those that exist have often led to contradictory findings. We have argued in this paper and elsewhere (Mohai and Saha 2015) that much of the uncertainty of these findings has likely resulted from the application of unit-hazard coincidence methodology in earlier studies. Mohai and Saha (2006, 2007) demonstrated that its application leads to an underestimation of the degree of racial and socioeconomic disparities around hazardous sites

while distance-based methods lead to more reliable results. Their findings led us to consider whether, in a longitudinal analysis, the use of the unit-hazard coincidence method would yield similar results, i.e., underestimate or fail to detect racial and socioeconomic disparities. We also sought to determine whether the application of distance-based methods would lead to clearer and more definitive results about the two processes thought to account for present-day racial and socioeconomic disparities around hazardous waste TSDFs: (1) disparate siting, and (2) post-siting demographic change. To our knowledge, our study is the first national-level longitudinal study to employ distance-based methods to test hypotheses about these two processes.

When applying the unit hazard coincidence method, we found virtually no evidence of either disparate siting or post-siting demographic change. These results are similar to prior national longitudinal analyses that have employed the unit-hazard coincidence method. In contrast, we found clear support for the disparate siting hypothesis when distance-based methods were applied. We also found racial and socioeconomic disparities around hazardous waste facility sites to widen over time. However, contrary to the expectations of the post-siting demographic change hypothesis, we found little evidence to suggest that the siting of hazardous waste TSDFs are the cause of white move-out and minority move-in. Instead, by examining both actual population changes and percentage changes before and after TSDF siting, we found the opposite to be true. Hazardous waste TSDFs were sited where white move-out and minority move-in were already occurring, and had been occurring for a decade or two prior to siting for some cohorts of TSDFs. Thus our national-level findings add support to Pastor *et al* (2001) conclusions from their Los Angeles study that demographic changes in an area 'attract' LULUs rather than the other way around (i.e., LULUs 'attract' minorities and the poor).

Pre-siting demographic changes have rarely been examined in longitudinal environmental justice analyses. However, our results and those of Pastor, Sadd, and Hipp highlight the need for future studies to examine such changes in neighborhoods at least one to two decades prior to siting in order to fully understand the dynamics of facility siting. This type of approach is needed to inform understanding of the direction of causality regarding the question of 'Which came first, the facilities or the disproportionate numbers of poor people and minorities?' Such studies are also needed to test explanations of disparate siting and the independent role of racial, sociopolitical and economic factors. The possibility that these factors may overlap and be mutually reinforcing also needs to be explored (Mohai *et al* 2009).

Nevertheless, and again similar to Pastor, Sadd, and Hipp, we found that the racial composition of geographic areas tends to be a stronger independent

predictor of which areas are destined to receive hazardous waste TSDFs than are other socioeconomic characteristics of the areas. When we employed multivariate statistical analyses we found that the race variables remained statistically significant predictors of TSDF siting in the expected direction in nearly all the siting periods in spite of controlling for mean property values and other socioeconomic characteristics. At the same time, mean property values were found to be statistically significant predictors of TSDF siting only between 1981 and 1995, but not between 1966 and 1980. Percent employed in professional/managerial occupations was statistically significant in the expected direction in four of the time periods, while percent employed in precision production/labor occupations was statistically significant in the expected direction in three. Percent with college degrees was not statistically significant in any of the time periods.

That the racial composition of areas tends to be an independent and stronger predictor than socioeconomic characteristics of which areas receive hazardous waste TSDFs provides especially strong support for racial explanations of disparate siting (see Mohai and Saha 2015). Racial disparities at the time of siting can readily occur when people of color live in highly segregated residential areas that can be targeted for new facilities siting and that may also already have other industrial land uses. Such land use patterns—created in part by past racial discrimination in zoning, property law and housing—continue to persist into the present-day (Stretesky and Hogan 1998, Morello-Frosch and Jesdale 2006). Although many blatantly discriminatory practices of the past are now illegal, less overt forms of discrimination exist today that have the effect of concentrating minorities in environmentally undesirable neighborhoods, for example, by discouraging their out-migration and encouraging in-migration (Bullard *et al* 1994, Taylor 2014). In addition, institutionalized forms of discrimination in environmental policy and industry practice limit access to information by and participation of people of color in siting decisions and thereby steer new facility sitings into minority neighborhoods (Stretesky and Hogan 1998, Cole and Foster 2001, Bullard and Wright 2012).

Sociopolitical explanations of disparate siting are also supported. Areas with large numbers of people of color with limited resources and political clout have limited ability to fend off new unwanted facility siting (Cole and Foster 2001). Furthermore, areas undergoing demographic changes are also areas vulnerable to declining social capital, resources, and political clout, as demographic change may represent the weakening of social ties, the loss of community leaders, and weakening of civic organizations (Elliot and Frickel 2013).

Although Saha and Mohai's (2005) longitudinal analysis of hazardous waste facility siting in Michigan tested the disparate siting hypothesis only, their study

nevertheless applied distance-based methods and found similarly strong support for it. Furthermore, they examined changes in the historical context in which facilities were sited since 1950 and found little evidence of racial and socioeconomic disparities in facility siting before 1970. However, they found such siting disparities emerged beginning with the 1970s, strengthened in the 1980s, and declined but persisted after 1990. Although our national-level analysis does not extend back in time as far as theirs, we are struck that the pattern of changes we found over time in the magnitude of disparities at the time of facility siting closely follows theirs. Nationally we found racial and socioeconomic disparities in facility siting in the period around 1970 to be significant. Furthermore, we found the disparities in siting to be even greater in the period around 1980, but smaller again in the period around 1990 (although still significant).

Saha and Mohai have argued that the historical context of siting is an important factor in understanding the patterns of disparate siting over time. Public awareness about many environmental risks had not developed before the environmental movement gained momentum in the 1960s and 1970s. They and others argue that environmental disasters, which received national attention in the late 1960s and throughout the 1970s and 1980s, particularly Love Canal in 1979, sensitized the public to concerns about hazardous wastes and resulted in increasing NIMBYism ('not in my backyard' siting opposition behaviors) around the country. NIMBYism in more affluent, white communities, however, resulted in industry taking the 'path of least resistance,' and targeting communities with fewer resources and political clout as the sites for new hazardous waste facilities and other LULUs. These communities are where the poor and people of color live. As Bullard and Wright (1987) have argued, NIMBY became PIBBY (place in blacks' back yards). The narrowing of siting disparities in the 1990s raises for us the question of whether the gathering momentum of the environmental justice movement has had a tangible impact of reducing the incidence of disparate siting decisions in more recent times. We believe this will be an important line of research for scholars interested in understanding the environmental justice movement and the extent of environmental discrimination.

We have shown that findings from our national longitudinal study using distance-based methods are consistent with those from other similar subnational studies and stand in contrast to studies that have used the unit-hazard coincidence method in proximity-based environmental justice analyses. In answer to 'Which came first?', our findings show that rather than hazardous waste TSDFs 'attracting' people of color, neighborhoods with already disproportionate and growing concentrations of people of color appear to 'attract' new facility siting. The body of distance-based

research suggests that government policies, industry practices and community empowerment measures are needed to ensure fairness in the siting process and to address disparities in risks associated with existing facilities. In addition, more studies that use reliable methods to assess such racial and socioeconomic disparities in the location of other types of environmental hazards could also improve our understanding of the processes and factors that contribute to environmentally unjust conditions in the United States and around the world.

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