County-Level Associations Between Pregnancy-Related Mortality Ratios and Contextual Sociospatial Indicators

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OBJECTIVE: To characterize county-level differences in pregnancy-related mortality as a function of sociospatial indicators.

METHODS: We conducted a cross-sectional multilevel analysis of all pregnancy-related deaths and all live births with available ZIP code or county data in the Pregnancy Mortality Surveillance System during 2011–2016 for non-Hispanic Black, Hispanic (all races), and non-Hispanic White women aged 15–44 years. The exposures included 31 conceptually-grounded, county-specific sociospatial indicators that were collected from publicly available data sources and categorized into domains of demographic; general, reproductive, and behavioral health; social capital and support; and socioeconomic contexts. We calculated the absolute difference of county-level pregnancy-related mortality ratios (deaths per 100,000 live births) per 1-unit increase in the median absolute difference between women living in counties with higher compared with lower levels of each sociospatial indicator overall and stratified by race and ethnicity.

RESULTS: Pregnancy-related mortality varied across counties and by race and ethnicity. Many sociospatial indicators were associated with county-specific pregnancy-related mortality ratios independent of maternal age, population size, and Census region. Across domains, the most harmful indicators were percentage of low-birth-weight births (absolute ratio difference [RD] 6.44; 95% CI 5.36–7.51), percentage of unemployed adults (RD 4.98; 95% CI 3.91–6.05), and food insecurity (RD 4.92; 95% CI 4.14–5.70). The most protective indicators were higher median household income (RD −2.76; 95% CI −3.28 to −2.24), percentage of college-educated adults (RD −2.28; 95% CI −2.81 to −1.75), and percentage of owner-occupied households (RD −1.66; 95% CI −2.29 to −1.03). The magnitude of these associations varied by race and ethnicity.

CONCLUSION: This analysis identified sociospatial indicators of pregnancy-related mortality and showed an association between pregnancy-related deaths and place of residence overall and stratified by race and ethnicity. Understanding county-level context associated with pregnancy-related mortality may be an important step towards building public health evidence to inform action to reduce pregnancy-related mortality at local levels.

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The *pregnancy-related mortality ratio* in the United States, defined as the number of pregnancy-related deaths per 100,000 live births, has not improved in more than a decade, and there are significant and persistent disparities.[1] The pregnancy-related mortality ratio among non-Hispanic Black women (Black) is more than two to three times higher

than the pregnancy-related mortality ratio among non-Hispanic White women (White).[2] States with the highest pregnancy-related mortality ratios have approximately three times the ratio of pregnancy-related deaths as states with the lowest pregnancy-related mortality ratios,[2] and residents of rural areas have higher pregnancy-related mortality ratios compared with residents of urban areas.[3]

As with many maternal health outcomes, individual-level factors, such as advanced maternal age,[4] cesarean delivery,[5] obesity, and other chronic health conditions,[6,7] only partially explain disparities in pregnancy-related mortality. Social and contextual determinants of population health, which influence the distribution of these individual proximal factors, should also be considered.[8] "Contextual" determinants are factors related to health and mortality that are external to the individual.[9]

Prior work proposed a conceptual framework for how sociospatial context could shape the geography of opportunity and risk for women across the life course, shaping risk for maternal morbidity and mortality.[2] The current study sought to empirically evaluate sociospatial contextual indicators derived from that conceptual framework as correlates of pregnancy-related mortality. By using pregnancy-related death records with an assigned FIPS (Federal Information Processing System) code from the Centers for Disease Control and Prevention's (CDC) PMSS (Pregnancy Mortality Surveillance System), we characterize county-level differences in pregnancy-related mortality ratio by indicators of demographic; general, reproductive, and behavioral health; social capital and support; and socioeconomic contexts. Because the effect of these indicators may be experienced differently by people of different races and ethnicities, we examined associations for the total population and stratified by race and ethnicity.

METHODS

This cross-sectional, multilevel analysis included all pregnancy-related deaths among Black, Hispanic (all races), and White women aged 15–44 years with available ZIP code or county data in the PMSS during 2011–2016. We use the term "women" but recognize pregnancy-related deaths can occur among transgender or nonbinary persons. Detailed description of PMSS data collection and coding are published elsewhere.[10] Briefly, medically trained epidemiologists review death records of women who died during or within 1 year of pregnancy, matching birth records or fetal death records, and other available information (eg, autopsy records). Deaths are determined to be

pregnancy-related if the death occurred during or within 1 year of pregnancy and from any cause related to or aggravated by the pregnancy or its management.[1] The PMSS receives records from 52 reporting areas (50 states, New York City, and the District of Columbia.)

Residential location, including state, ZIP code, and county, are extracted from available vital records (maternal death record or matching birth or fetal death record) and entered into the PMSS. Because residence ZIP code, regardless of source, was the most complete geographic variable available in PMSS records during 2011–2016 (93% available), it was used to assign a 5-digit, county-specific FIPS code[11] to each death using Centrus Desktop 6.0. When ZIP code was missing for a record, county name was used to assign the FIPS code; the resulting FIPS codes were then compared with the state of residence recorded in the PMSS. If the states did not match or the county was not available, those records were excluded from our analysis.

Birth data from the National Vital Statistics System were used to obtain a count of live births among women aged 15–44 years for each year during 2011–2016, as well as racial and ethnic category, 5-year maternal age group, and FIPS code.

The demographic information on the death certificate, including race and ethnicity, is generally reported by a licensed funeral director, who is legally responsible for the completeness and accuracy of this information. In some situations, a medical examiner, coroner, or facility personnel may provide some of the demographic information on the death certificate. All birth certificate information, including race and ethnicity, reported for the mother are for the woman who gave birth to or delivered the neonate. Maternal race and ethnicity were self-reported. Women whose race and ethnicity were recorded as "non-Hispanic American Indian/Alaskan Native," "non-Hispanic Asian/Pacific Islander," or "unknown," were not included because we were unable to present stratified results for these groups because of inadequate numbers of births across a range of county sociospatial contexts to produce reliable estimates. Results are presented separately for Black, Hispanic, and White populations.

To calculate pregnancy-related mortality ratios for this population, we used PMSS data (numerator) and National Vital Statistics System live birth data (denominator) for 2011–2016. The numerator is a count of pregnancy-related deaths and the denominator is a count of live births for the year the death occurred; in each racial and ethnic category, 5-year maternal age group, and FIPS code.

Table 1. Source and Availability of Each Sociospatial Indicator at the County Level

Domain	Sociospatial Indicator	Source*	Years of Data Available[†]
Demographic context			
	% of total population who are Black	American Community Survey[‡]	2011–2016
	% of total population who are Hispanic	American Community Survey	2011–2016
	% of adults aged 25 y or older without a high school diploma or high school equivalency certificate	American Community Survey	2011–2016
	% of adults aged 25 y or older with a bachelor's degree or higher	American Community Survey	2011–2016
General, reproductive, and behavioral health context			
	No. of MD and DO GPs/100,000 population	HRSA Area Health Resources Files	2011–2016
	No. of MD and DO ob-gyns/100,000 women aged 15–44 y	HRSA Area Health Resources Files	2011–2016
	No. of mental health care professionals/100,000 population	Census County Business Patterns survey	2011–2015
	% of LBW births	RWJF County Health Rankings/CDC County Estimates modeled from BRFSS	2011–2015
	Adolescent pregnancy rate/1,000 women aged 15–19 y	CDC National Center for Health Statistics	2011–2015
	% of women aged younger than 65 y who are uninsured	HRSA Area Health Resources Files	2011–2016
	Prevalence of obesity among adults aged older than 18 y	RWJF County Health Rankings	2011–2012, 2014
	Prevalence of poor or fair self-rated health	RWJF County Health Rankings	2011–2014
	Drug poisoning mortality rate/100,000 persons	CDC National Center for Health Statistics	2011–2016
	No. of retail opioid prescriptions/100 persons	CDC National Center for Health Statistics	2011–2015
Social capital and support context			
	Social capital index	Rupasingha et al (2006)[26]	2011–2012
	% of households headed by single women with children aged younger than 18 y	American Community Survey	2011–2016
	% of households moved in past 12 mo	American Community Survey	2011–2016
	% of households occupied by owners	American Community Survey	2011–2016
	Violent crime rate/100,000 population	ICPSR catalog of Department of Justice Uniform Crime Report data	2011–2014
	% of households with severe housing problems	RWJF County Health Rankings	2014–2015
	% of population who do not speak English or do not speak it well	American Community Survey	2011–2013
Socioeconomic context			
	Neighborhood deprivation index	American Community Survey	2011–2016
	Concentrated affluence	American Community Survey	2011–2016

(*continued*)

Table 1. Source and Availability of Each Sociospatial Indicator at the County Level (*continued*)

Domain	Sociospatial Indicator	Source*	Years of Data Available†
	% of population aged 16 y or older in the labor force and unemployed	American Community Survey	2011–2016
	% of households receiving public assistance income in past 12 mo	American Community Survey	2011–2016
	% of households with more than 1 person/room	American Community Survey	2011–2016
	Median household income	American Community Survey	2011–2016
	% of population below federal poverty line	American Community Survey	2011–2016
	Food insecurity	Feeding America	2011–2016
	Residential racial segregation	American Community Survey	2011–2016
	% of households without a vehicle	American Community Survey	2011–2016

GP, general practitioner; HRSA, Health Resources and Service Administration; ob-gyn, obstetrician–gynecologists; LBW, low-birth-weight; RWJF, Robert Wood Johnson Foundation; CDC, Centers for Disease Control and Prevention; BRFSS, Behavioral Risk Factor Surveillance System; ICSPR, Inter-university Consortium for Political and Social Research.

* Web link to each data source: American Community Survey: https://www.census.gov/programs-surveys/acs; HRSA Area Health Resources Files: https://data.hrsa.gov/topics/health-workforce/ahrf; Census County Business Patterns survey: https://www.census.gov/programs-surveys/cbp.html; RWJF County Health Rankings: https://www.countyhealthrankings.org/; BRFSS: https://www.cdc.gov/brfss/index.html; CDC National Center for Health Statistics: https://www.cdc.gov/nchs/index.htm; ICSPR catalog of Department of Justice Uniform Crime Report data: https://www.icpsr.umich.edu/web/pages/NACJD/guides/ucr.html; Feeding America: https://www.feedingamerica.org/research/map-the-meal-gap/by-county.

† For years with unavailable data, we used data from the closest available year (ie, 2015 data were used for 2016).

‡ All American Community Survey data are derived from 5-year moving window survey results, where the indicated year is the midpoint in the 5-year range.

Thirty-one county-specific, quantitative indicators were collected from publicly available data sources (eg, American Community Survey) and categorized into proxy domains of demographic; general, reproductive, and behavioral health (ie, indicators of health care needs and services); social capital and support; and socioeconomic contexts that could influence the health of women before, during, and within 1 year of pregnancy (Table 1). Indicators were selected to correspond to hypothesized domains described as conceptually relevant to inequities in pregnancy-related mortality[2] and because they were publicly available and measured at the county level. For years in which indicator data were unavailable, data from the closest available year were used (ie, 2015 data were also used for 2016).

For comparability across regression models, sociospatial indicators were robustly scaled by centering at the median value among all counties and standardized to the median of the absolute deviation of counties around the national median. To analyze variations in pregnancy-related mortality ratios as a function of sociospatial indicators, pregnancy-related mortality ratios were linked to sociospatial indicators by FIPS codes.

We used generalized estimating equations to estimate the absolute ratio difference (RD) and robust standard errors in the pregnancy-related mortality ratio for women living in counties with higher compared with lower values of each sociospatial indicator (null value for the RD is 0.00). Year×county×racial and ethnic group×age group strata with 0 births were excluded from models because they had a 0 denominator for calculating the pregnancy-related mortality ratio. In all models, deliveries and maternal deaths were clustered by county to account for potential correlation of pregnancy outcomes of women within the same county. Our preference for the absolute scale as a measure of association is because Black women have a pregnancy-related mortality ratio up to three times greater than Hispanic and White women, and a relative measure of association might mask differences in the absolute burden of pregnancy-related mortality when comparing women across race and ethnicity. The interpretation of modeled RD estimates is the change in pregnancy-related deaths per 100,000 live births for each 1-unit increase in the sociospatial indicator. The 1-unit measure represents an increment equivalent to the median absolute difference among all counties on that indicator; in other words, it represents a standardized and reasonable contrast given the intercounty variation in each indicator.

Table 2. Selected Demographic Characteristics of Pregnancy-Related Deaths, United States, 2011–2016 (N=3,449)

Characteristic	n (%)
Race and ethnicity*	
Black	1,365 (39.6)
Hispanic	567 (16.4)
White	1,517 (44.0)
Age group (y)	
15–19	167 (4.8)
20–24	595 (17.3)
25–29	813 (23.6)
30–34	824 (23.9)
35–39	719 (20.8)
40–44	331 (9.6)
Year	
2011	631 (18.3)
2012	529 (15.3)
2013	592 (17.2)
2014	600 (17.4)
2015	555 (16.1)
2016	542 (15.7)

* Women identified as Black or White were not Hispanic. Hispanic women could be of any race.

As a supplemental comparison, we used Poisson regression with the count of pregnancy-related deaths as the dependent variable and the log of the estimated count of live births in each year×county×racial and ethnic group×age group as the offset to estimate the relative ratio (RR) for the association between a 1-unit change in the scaled value of a sociospatial indicator and the pregnancy-related mortality ratio (null value for the RR is 1.00).

Two models were used for each sociospatial indicator. Model 1 included all three racial and ethnic groups and was adjusted for year of death, maternal age category, the log of the count of women of reproductive age in the county (ie, population size as a proxy for density and urbanicity), and Census region. Model 2 adjusted for the same factors and was stratified by race and ethnicity. These models permitted examination of possible heterogeneity in the associations between sociospatial indicators and the pregnancy-related mortality ratio by race and ethnicity. A test for interaction was used to test for heterogeneous effects of each sociospatial indicator by race and ethnicity on the additive scale.

We describe the magnitude and precision of the relationship between each sociospatial indicator and county-level pregnancy-related mortality ratio, both overall and stratified by race and ethnicity. Data cleaning and merging were performed in SAS 9.4, and models were fit in R. This study did not involve human subjects as defined in 45CFR 46.102(e) and, therefore, was not reviewed by an institutional review board.

RESULTS

There were 4,074 pregnancy-related deaths during 2011–2016 in the United States. Records were excluded if they could not be assigned a FIPS code (n=182), were non-Hispanic American Indian/Alaskan Native or non-Hispanic Asian/Pacific Islander (n=273), were for females younger than 15 years or older than 44 years (n=128) or with unknown race and ethnicity or unknown age (n=13), or were in a year×county×racial and ethnic group×age group stratum with 0 births (n=29). The resulting analytic sample was 3,449 pregnancy-related deaths, representing 85% of all known pregnancy-related deaths and 95% of all known pregnancy-related deaths to women in the age and racial and ethnic groups included in this study in the United States during 2011–2016 (Table 2). The overall pregnancy-related mortality ratio for this population was 15.9 per 100,000 live births. The pregnancy-related mortality ratio per 100,000 live births by race and ethnicity was 39.0 among Black women, 10.4 among Hispanic women, and 11.0 among White women.

Model results are summarized by domains of sociospatial indicators in Table 3, and heterogeneity in measures of association between sociospatial indicators and the pregnancy-related mortality ratio for Black women and White women are plotted by magnitude and direction of association in Figure 1. In model 1, pooling all racial and ethnic groups and adjusting for year of death, age group, county population size, and Census region, the strongest measure of association was for the county-level percentage of low-birth-weight (LBW) births. A 1–standard unit increase in LBW births was associated with 6.44 (95% CI 5.36–7.51) excess deaths per 100,000 live births; for context, the median percent of LBW births across all counties was 7.9% and a 1-standard unit increase in the percent of LBW births was equivalent to a change in county LBW prevalence of 1.78% (See the first two columns of Table 3 for median and median absolute difference values for each sociospatial indicator across all counties). In model 1, an increase in the percentage of college-educated adults and an increase in median household income were the indicators most inversely associated with the pregnancy-related mortality ratio. A 1-standard unit increase in the percentage of college-educated adults was associated with 2.28 (95% CI −2.81 to −1.75) fewer deaths per 100,000 live births and a 1-standard unit increase in median

Table 3. Absolute Ratio Difference* in Pregnancy-Related Deaths Per 100,000 Live Births by Sociospatial Indicators

Domain	Sociospatial Indicator	Median	Median Absolute Difference[†]	Model 1[‡] Pooled RD	Model 1[‡] Pooled 95% CI
Demographic context					
	% of total population who are Black	2.10	2.78	1.12	0.91–1.33
	% of total population who are Hispanic	3.76	3.45	−0.12	−0.30 to 0.06
	% of adults aged 25 y or older without a high school diploma or high school equivalency certificate	13.00	6.33	2.07	1.03–3.12
	% of adults aged 25 y or older with a bachelor's degree or higher	18.40	6.97	−2.28	−2.81 to −1.75
General, reproductive, and behavioral health context					
	No. of MD and DO GPs/100,000 population	31.85	19.26	−0.52	−1.32 to 0.27
	No. of MD and DO ob-gyns/100,000 women aged 15–44 y	20.81	30.85	−0.26	−0.89 to 0.37
	No. of mental health care professionals/100,000 population	11.88	7.71	−1.31	−1.97 to −0.66
	% of LBW births	7.90	1.78	6.44	5.36–7.51
	Adolescent pregnancy rate/1,000 women aged 15–19 y	30.64	16.17	4.71	3.41–6.01
	% of women aged younger than 65 y who are uninsured	13.60	6.23	2.79	1.30–4.28
	Prevalence of obesity among adults aged older than 18 y	30.20	3.56	3.24	2.50–3.98
	Prevalence of poor or fair self-rated health	16.20	5.78	3.67	2.53–4.81
	Drug poisoning mortality rate/100,000 persons	14.32	4.46	0.57	0.05–1.09
	No. of retail opioid prescriptions/100 persons	84.20	41.66	2.41	1.35–3.47
Social capital and support context					
	Social capital index	−0.23	0.89	−0.72	−1.65 to 0.20
	% of households headed by single women with children aged younger than 18 y	22.77	7.97	4.51	3.64–5.39
	% of households moved in past mo months	12.96	3.77	0.39	−0.36 to 1.14
	% of households occupied by owners	72.82	6.79	−1.66	−2.29 to −1.03
	Violent crime rate/100,000 population	181.93	151.26	2.71	2.10–3.32
	% of households with severe housing problems	13.64	3.87	1.41	0.29–2.53
	% of population who do not speak English or do not speak it well	1.69	1.72	−0.12	−0.37 to 0.13
Socioeconomic context					
	Neighborhood deprivation index	0.36	0.12	4.51	3.50–5.52
	Concentrated affluence	0.42	0.31	−0.81	−0.99 to −0.63
	% of population aged 16 y or older in the labor force and unemployed	7.18	3.3	4.98	3.91–6.05
	% of households receiving public assistance income in past 12 mo	2.16	1.15	1.68	1.08–2.28
	% of households with more than 1 person/room	1.89	1.13	0.24	−0.17 to 0.65
	Median household income	46,275.00	10,372	−2.76	−3.28 to −2.24
	% of population below federal poverty line	15.58	6.03	3.92	2.81–5.03
	Food insecurity	14.10	3.56	4.92	4.14–5.70
	Residential racial segregation	4.92	6.49	1.70	1.36–2.03
	% of households without a vehicle	5.81	2.38	0.51	0.19–0.84

RD, ratio difference; GP, general practitioner; ob-gyn, obstetrician–gynecologist; LBW, low-birth-weight.

* The ratio difference measures the difference in the pregnancy-related mortality ratio between women living in counties with a 1-unit increase in each sociospatial indicator compared with women living in counties with the median value of each sociospatial indicator.

[†] The median absolute difference is a robust version of the conventional standard deviation. A 1-unit increase in a sociospatial indicator represents an increment equivalent to the median absolute difference among all counties on that indicator.

[‡] Model 1 is adjusted for year of death, maternal age group, the log of the count of women of reproductive age in the county, and U.S. Census region.

[§] Model 2 includes all covariates in model 1, stratified by race and ethnicity.

[||] P-value refers to test for interaction between each sociospatial indicator and race and ethnic stratum (non-Hispanic Black, Hispanic, and non-Hispanic White race and ethnicities).

Model 2[§]						
Non-Hispanic Black		Hispanic		Non-Hispanic White		
RD	95% CI	RD	95% CI	RD	95% CI	$P^{\parallel}$
0.48	−0.10 to 1.06	0.10	−0.22 to 0.43	0.18	−0.05 to 0.41	.285
0.78	0.02–1.54	0.08	−0.09 to 0.24	0.24	0.03–0.46	.474
8.22	5.00–11.43	0.28	−0.56 to 1.13	2.13	1.23–3.04	<.001
−5.05	−7.01 to −3.08	−0.67	−1.36 to 0.02	−2.20	−2.69 to −1.72	<.001
−1.03	−4.40 to 2.34	−0.02	−1.43 to 1.38	−0.08	−0.81 to 0.65	.255
−0.89	−2.88 to 1.09	−0.62	−1.57 to 0.32	−0.84	−1.41 to −0.26	.133
−5.55	−8.11 to −2.99	0.07	−0.92 to 1.06	−1.42	−2.08 to −0.76	.004
6.21	2.86–9.55	2.64	0.96–4.32	1.96	0.80–3.12	.202
10.75	6.42–15.08	1.80	0.31–3.30	3.83	2.69–4.97	<.001
10.21	6.34–14.07	1.09	−0.16 to 2.34	4.18	3.09–5.26	<.001
4.82	2.03–7.61	0.69	−0.34 to 1.71	1.89	1.13–2.65	.001
10.73	7.11–14.35	0.93	−0.33 to 2.19	3.03	1.95–4.12	<.001
0.00	−1.44 to 1.44	0.55	−0.15 to 1.25	0.65	0.23–1.08	.053
5.47	1.71–9.23	1.36	−0.13 to 2.86	1.87	0.84–2.91	.010
−2.88	−6.34 to 0.57	−0.81	−1.91 to 0.30	−1.88	−2.65 to −1.10	.721
3.70	1.22–6.17	1.38	0.12–2.64	1.56	0.74–2.37	.518
−2.01	−4.80 to 0.79	0.79	−0.25 to 1.84	0.56	−0.09 to 1.21	.147
−2.06	−3.89 to −0.23	−0.60	−1.32 to 0.11	−0.06	−0.58 to 0.46	.008
2.47	0.65–4.30	0.97	0.05–1.88	1.08	0.36–1.80	.611
2.68	−1.34 to 6.71	−0.12	−1.32 to 1.08	0.21	−0.83 to 1.26	.228
1.06	0.04–2.07	−0.08	−0.30 to 0.15	0.05	−0.27 to 0.38	.278
7.02	4.01–10.03	0.94	−0.12 to 2.00	2.75	1.91–3.59	.002
−1.61	−2.20 to −1.02	−0.36	−0.55 to −0.17	−0.57	−0.73 to −0.41	<.001
6.59	3.22–9.96	−0.34	−1.65 to 0.97	2.58	1.54–3.62	.003
1.83	−0.41 to 4.07	−0.02	−0.69 to 0.66	1.03	0.35–1.72	.894
2.44	1.14–3.74	−0.05	−0.37 to 0.26	0.25	−0.13 to 0.64	.030
−4.97	−6.78 to −3.15	−1.01	−1.63 to −0.40	−1.97	−2.44 to −1.50	<.001
6.52	3.65–9.39	0.87	−0.20 to 1.95	2.34	1.51–3.17	.009
5.45	3.06–7.85	1.39	0.34–2.44	2.70	1.96–3.44	.002
1.39	0.37–2.41	0.20	−0.25 to 0.66	0.27	−0.04 to 0.57	.041
0.33	−0.24 to 0.90	0.20	−0.04 to 0.44	−0.05	−0.24 to 0.14	.103

household income was associated with 2.76 (95% CI −3.28 to −2.24) fewer deaths per 100,000 live births.

Aggregate community levels of education had a strong relationship to the pregnancy-related mortality ratio among Black and White women (Table 3). A 1-standard unit increase in the percentage of adults older than age 25 years without a high school diploma or high school equivalency certificate was associated with 8.22 (95% CI 5.00–11.43) excess deaths per 100,000 live births among Black women and 2.13 (95% CI 1.23–3.04) excess deaths per 100,000 live births among White women. An increase in the
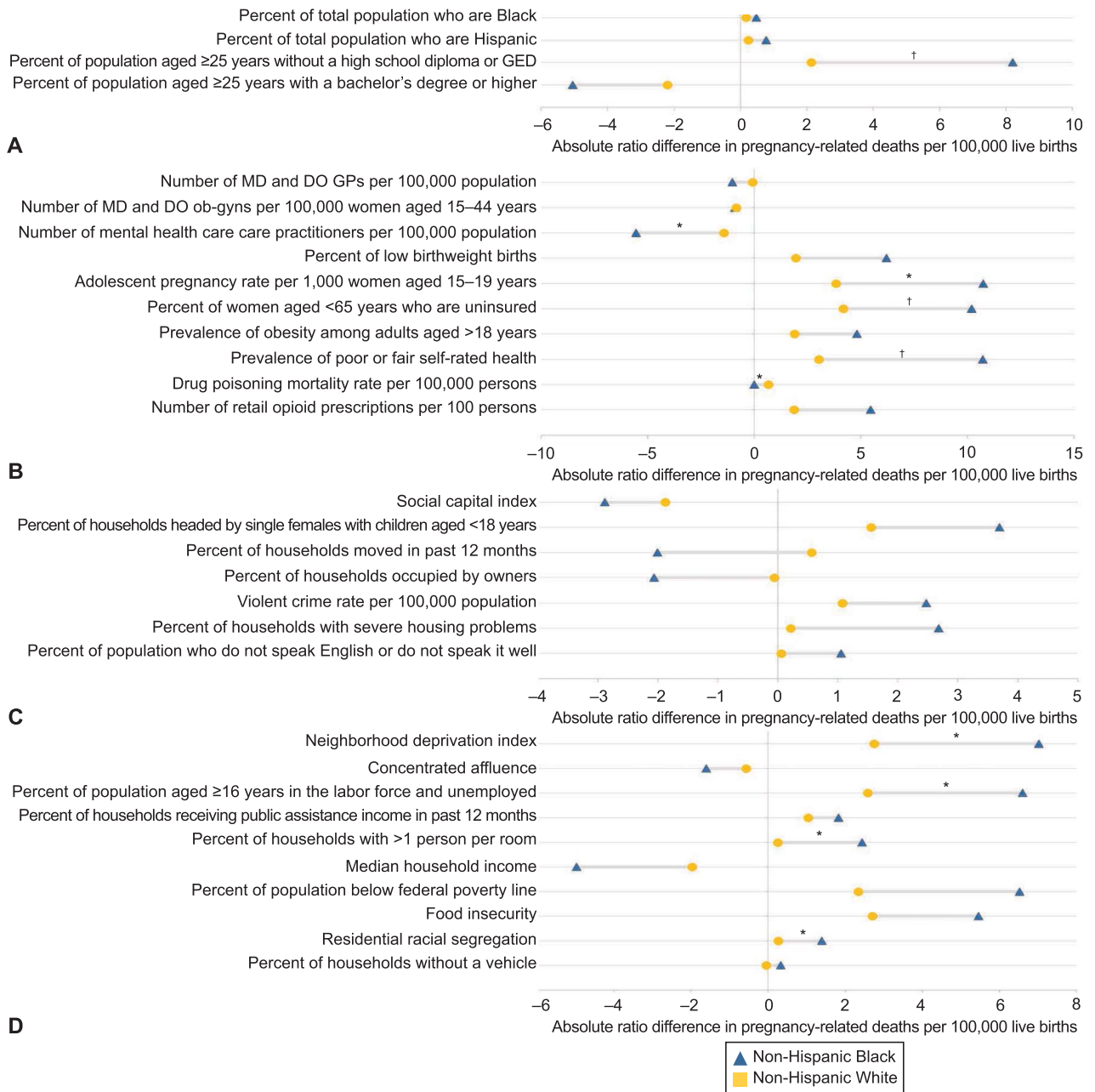
Fig. 1. Heterogeneity in measures of association between sociospatial indicators and pregnancy-related mortality ratios for non-Hispanic Black women and non-Hispanic White women. The pregnancy-related mortality ratio is the number of pregnancy-related deaths per 100,000 live births. Each point represents the ratio difference in the pregnancy-related mortality ratio. The ratio difference estimates the difference in the pregnancy-related mortality ratio between women living in counties that differ by 1 standardized unit (eg, the median absolute difference). *P<.05, †P<.01. P-values refer to the statistical significance of the test for heterogeneous effects of each sociospatial indicator by race and ethnicity (eg, for non-Hispanic Black women and non-Hispanic White women). Domains: demographic (**A**); general, reproductive, and behavioral health (**B**); social capital and support (**C**); socioeconomic (**D**). GED, general education development test; GP, general practitioner.

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percentage of adults older than age 25 years with at least a bachelor's degree was associated with 5.05 (95% CI −7.01 to −3.08) fewer deaths per 100,000 live births among Black women and 2.20 (95% CI −2.69 to −1.72) fewer deaths per 100,000 live births among White women.

Among health care needs and services indicators, the number of mental health care professionals per 100,000 population had a strong inverse relationship with the pregnancy-related mortality ratio. Each standard unit increase in the number of mental health care professionals was associated with 5.55 (95% CI −8.11 to −2.99) fewer deaths per 100,000 live births among Black women and 1.42 (95% CI −2.08 to −0.76) fewer deaths per 100,000 live births among White women (Table 3).

Among Black and White women, the largest magnitudes of association were found in counties with a higher adolescent pregnancy rate, a higher prevalence of poor or fair self-rated health, and a higher percentage of uninsured women (Table 3). Among Hispanic women, the largest magnitude of association was found in counties with an increase in the percentage of LBW births (RD 2.64; 95% CI 0.96–4.32).

For this domain, the strongest positive association was found for the percentage of households with children younger than age 18 years headed by a single woman. An increase in this indicator was associated with 3.70 (95% CI 1.22–6.17) excess deaths per 100,000 live births among Black women, 1.56 (95% CI 0.74–2.37) excess deaths per 100,000 live births among White women, and 1.38 (95% CI 0.12–2.64) excess deaths per 100,000 live births among Hispanic women (Table 3). The violent crime rate was positively associated with the pregnancy-related mortality ratio across racial and ethnic groups, and the association was largest for Black women (RD 2.47; 95% CI 0.65–4.30). Among Black women, the percentage of owner-occupied households had an inverse relationship with the pregnancy-related mortality ratio. An increase in the percentage of owner-occupied households was associated with 2.06 (95% CI −3.89 to −0.23) fewer deaths per 100,000 live births. Among White women, the social capital index had an inverse relationship with the pregnancy-related mortality ratio. An increase in the social capital index was associated with 1.88 (95% CI −2.65 to −1.10) fewer deaths per 100,000 live births.

Among Black and White women, the strongest positive associations were found between the neighborhood deprivation index and the percentage of people unemployed. The largest magnitude of association was for an increase in the neighborhood deprivation index, with 7.02 (95% CI 4.01–10.03) excess deaths per 100,000 live births among Black women and 2.75 (95% CI 1.91–3.59) excess deaths per 100,000 live births among White women, for each standard unit change in county deprivation index. The strongest positive association for Hispanic women was for the relationship between food insecurity and the pregnancy-related mortality ratio (RD 1.39; 95% CI 0.34–2.44). The greatest inverse association was found for an increase in the median household income, with 4.97 (95% CI −6.78 to −3.15) fewer deaths per 100,000 live births among Black women, 1.97 (95% CI −2.44 to −1.50) fewer deaths per 100,000 live births among White women, and 1.01 (95% CI −1.63 to −0.40) fewer deaths per 100,000 live births among Hispanic women.

Results from the supplemental comparison estimating the RR for the association between a 1-unit change in the scaled value of a sociospatial indicator and the pregnancy-related mortality ratio are presented in Appendix 1, available online at http://links.lww.com/AOG/C673. The direction (positive vs negative association), estimate precision, and significance were largely consistent between the RD and RR analyses.

DISCUSSION

Place of residence has long been believed to shape lived experiences and influence health outcomes, and sociospatial indicators are known to differ in importance within and across counties.[12] This study examines the association of a wide array of county-level contextual indicators, including indicators of demographic; general, reproductive, and behavioral health; social capital and support; and socioeconomic contexts, with pregnancy-related mortality.[13] We found that sociospatial indicators are associated with county-specific pregnancy-related mortality ratios independent of population size, maternal age, and Census region, and the magnitude of these associations varies by indicator and by race and ethnicity. These ecologic associations do not test causal relationships but do generate hypotheses about the relative importance of social and contextual indicators in understanding county-level variation in pregnancy-related mortality.

Our results were consistent with past studies that found an association between increased rates of maternal mortality and the following factors: lower incomes at the neighborhood[14] and county level,[15] income inequality,[16] higher population prevalence of obesity,[17] higher proportion of births to African American women,[17,18] and higher percentage of women who have not completed high school.[17] Although these studies sought to understand the social and geographic context as forces influencing risk for maternal death, they were limited by validity of case ascertainment,[16–18] or they were limited to a single city[14] or state.[15]

Using national data, we found higher pregnancy-related mortality ratios in counties with an above average amount of most of the selected sociospatial indicators, particularly population indicators of women's general and reproductive health (eg, obesity prevalence, adolescent pregnancy rate, LBW). However, increases in some indicators resulted in a reduction in the pregnancy-related mortality ratio. For example, counties with a higher percentage of college-educated adults and a higher median household income had fewer pregnancy-related deaths than counties with an average amount of these indicators. Although the number of general practitioners or obstetricians–gynecologists per capita was only modestly associated with the pregnancy-related mortality ratio, the number of mental health care professionals had a strong protective association with the pregnancy-related mortality ratio.

We also found variation in the magnitude of association between sociospatial indicators and the pregnancy-related mortality ratio when stratified by racial and ethnic groups. This finding is unsurprising given the potent role of systemic discrimination, such as racial residential segregation, on life opportunities.[19] This sociospatial stratification includes potential indicators of structural racism, meaning differences in magnitude by race and ethnicity, particularly for Black women, may represent unmeasured factors related to the social construct of race, such as weathering from ongoing exposure to social, economic, and political disadvantage.[20,21] Accordingly, within a county, women's exposures and access to resources vary by race and ethnicity. For example, we found higher county-level prevalence of food insecurity was associated with a higher absolute risk of mortality across all race and ethnicities, but the absolute difference was nearly twice as large for Black women as for White and Hispanic women.

Pregnancy-related mortality is a multi-faceted issue and there are still many gaps in the literature as to why these deaths occur. Exploring differences in associations between the pregnancy-related mortality ratio and sociospatial indicators by region and exploring additional indicators of racial disparity may provide additional insight into the implications of contextual indicators on pregnancy-related mortality.

The findings in this report are subject to limitations. Vital records have the potential for misclassifications, such as inaccuracies in the coding of place of residence, pregnancy status and race and ethnicity. Pregnancy Mortality Surveillance System reviewers use additional information, such as matching birth records, whenever possible to improve the accuracy of data. Further, although it is possible that misclassifications could have occurred regarding pregnancy-relatedness, a validation study of PMSS data compared with data from the Louisiana Maternal Mortality Review Committee found identical pregnancy-related mortality ratios in Louisiana between the two data systems (Kieltyka L. Validity of pregnancy-related death classification by the CDC Pregnancy Mortality Surveillance System compared with the Louisiana Maternal Mortality Review Committee. In: 2021 CityMatCH Leadership and MCH Epidemiology Conference; 2021 December 9-10; virtual. Presentation nr 1,299 [abstract].). Also, we could not determine pregnancy-relatedness for injury deaths (eg, drug overdoses, suicides, homicides), or cancer-related deaths. These types of deaths are often not included in the pregnancy-related mortality ratio because of limited information about death circumstances. Finally, owing to the rigorous process of case adjudication used in preparing data for the PMSS, the most recent geocoded data available for this report at the time of publication are from 2011 to 2016; however, we do not anticipate the relationships between sociospatial indicators and pregnancy-related mortality to be time-varying.

One strength of this study is that the PMSS is currently the most robust national surveillance system that provides data on pregnancy-related deaths in the United States. Much of the current literature relies on vital statistics data from the National Center for Health Statistics for the identification of maternal deaths, which has known limitations[22–25] to case ascertainment and is prone to misclassification, whereas the PMSS relies on cooperative data sharing between states and the CDC that expands identification and records, combined with systematic review by clinically trained epidemiologists to adjudicate cases, resulting in a more reliable case definition. Further, we were able to include a large sample size representing 95% of pregnancy-related deaths from 2011 to 2016 in the target study population, with an assigned FIPS code and linked to county-level indicators, which fills a critical gap in our understanding of disparities in the pregnancy-related mortality ratio.

This multilevel analysis identified sociospatial indicators associated with the pregnancy-related mortality ratio and demonstrated the relationship between the pregnancy-related mortality ratio and place of residence overall and by race and ethnicity. Results suggest contextual attributes of place of residence may be important in understanding population variation in the pregnancy-related mortality ratio. Although

findings from this study are neither causal nor immediately actionable, they do generate new hypotheses and if replicated and firmly established in future research, they may help stakeholders develop population-level public health interventions and allocate resources where they are needed most. Further, our race-specific results suggest reducing pregnancy-related mortality will potentially require eliminating systems of structural racism that drive the distributions of sociospatial indicators.

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