Neighborhood Deprivation and Severe Maternal Morbidity in the State of California: An Examination of Effect Modification by Race/Ethnicity

Mahasin S. MUJAHID PhD , Elizabeth WALL-WIELER PhD , Ms. Elleni M. HAILU MPH , Rachel L. BERKOWITZ DrPH , Ms. Xing GAO MPH , Ms. Colleen M. MORRIS , Barbara ABRAMS DrPH , Audrey LYNDON PhD , Suzan L. CARMICHAEL PhD

PII: S2589-9333(23)00058-7
DOI: https://doi.org/10.1016/j.ajogmf.2023.100916
Reference: AJOGMF 100916

To appear in: *American Journal of Obstetrics & Gynecology MFM*

Received date: 2 November 2022
Revised date: 16 February 2023
Accepted date: 28 February 2023

Please cite this article as: Mahasin S. MUJAHID PhD , Elizabeth WALL-WIELER PhD , Ms. Elleni M. HAILU MPH , Rachel L. BERKOWITZ DrPH , Ms. Xing GAO MPH , Ms. Colleen M. MORRIS , Barbara ABRAMS DrPH , Audrey LYNDON PhD , Suzan L. CARMICHAEL PhD , Neighborhood Deprivation and Severe Maternal Morbidity in the State of California: An Examination of Effect Modification by Race/Ethnicity, *American Journal of Obstetrics & Gynecology MFM* (2023), doi: https://doi.org/10.1016/j.ajogmf.2023.100916

Neighborhood Deprivation and Racial/Ethnic Differences in Severe Maternal Morbidity in the State of California

Mahasin S. MUJAHID, PhD; Division of Epidemiology, School of Public Health, University of California Berkeley

Elizabeth WALL-WIELER, PhD; Department of Pediatrics, Division of Neonatal & Developmental Medicine, Stanford University[1]

Ms. Elleni M. HAILU, MPH; Division of Epidemiology, School of Public Health, University of California Berkeley

Rachel L. BERKOWITZ, DrPH; Division of Health Policy and Management, School of Public Health, University of California Berkeley

Ms. Xing GAO, MPH; Division of Epidemiology, School of Public Health, University of California Berkeley

Ms. Colleen M. MORRIS; Division of Epidemiology, School of Public Health, University of California Berkeley

Barbara ABRAMS, DrPH; Division of Epidemiology, School of Public Health, University of California Berkeley

Audrey LYNDON, PhD; Rory Meyers College of Nursing, New York University

Suzan L. CARMICHAEL, PhD; Department of Pediatrics, Division of Neonatal & Developmental Medicine and Department of Obstetrics & Gynecology, Division of Maternal-Fetal Medicine, Stanford University

Disclosure statement: The authors report no conflict of interest.

Sources of Financial Support: Financial support was provided by the National Institute of Nursing Research (grant number NR017020). The National Institute of Nursing Research had no other involvement in this research.

Corresponding author:
Mahasin S. Mujahid, PhD, MS, FAHA
2121 Berkeley Way West
Berkeley CA 94720-7360
(510)-643-7155
(510) 643-5056 (Fax)
Email: mmujahid@berkeley.edu

Abstract Word Count: 296
Main Text word Count: 2,833

[1] Present address: Winnipeg, MB, Canada; Department of Community Health Sciences, University of Manitoba

Neighborhood Deprivation and Severe Maternal Morbidity in the State of California: An Examination of Effect Modification by Race/Ethnicity

Condensation: Using state-wide data from California, this paper examined associations between neighborhood socioeconomic characteristics and severe maternal morbidity and whether associations were modified by race/ethnicity.

Short Title: Neighborhood Deprivation and Racial/Ethnic Differences in Severe Maternal Morbidity in CA

AJOG at a Glance:

A. Why was this study conducted? Neighborhood environments may be important drivers of severe maternal morbidity (SMM); however, research is needed to investigate these associations at a more granular census tract level and to examine whether associations are modified by race/ethnicity, given that rates of SMM are highest in racially/ethnically marginalized populations.

B. What are the key findings? Odds of severe maternal morbidity increased with increasing neighborhood deprivation, independent of maternal sociodemographic and pregnancy-related factors and comorbidities.

C. What does this study add to what is already known? This work contributes evidence that neighborhood deprivation influences SMM and suggests census tract level may be a meaningful scale to assess how contextual disadvantages influence pregnancy-related outcomes

Keywords: Health equity; Neighborhood health effects; Neighborhood deprivation index; Racial/ethnic disparities; Social determinants of health

Abstract:

Background: Social determinants of health, including neighborhood context, may be a key driver of severe maternal morbidity and its related racial/ethnic inequities, but investigations remain limited.

Objectives: We examined associations between neighborhood socioeconomic characteristics and severe maternal morbidity and whether associations were modified by race/ethnicity.

Study Design: This study leveraged a California statewide data resource on all hospital births ≥20 weeks (1997-2018). Severe maternal morbidity was defined as having at least one of 21 diagnoses and procedures (for example, blood transfusion, hysterectomy) as outlined by the Centers for Disease Control and Prevention. Neighborhoods were defined as residential census tracts (N=8,022; average of 1,295 births per neighborhood), and neighborhood deprivation index was a summary measures of 8 census indicators (for example, percent poverty, unemployment, public assistance). Mixed-effects logistic regression models (individuals nested within neighborhoods) were used to compare odds of severe maternal morbidity across quartiles (Quartile 1= least deprived; Quartile 4 = most deprived) of neighborhood deprivation index before and after adjustment for maternal sociodemographic and pregnancy-related factors and co-morbidities. We also created cross-product terms to determine if associations were modified by race/ethnicity.

Results: Of 10,384,976 births, the prevalence of severe maternal morbidity was 1.2% (N=120,487). In fully adjusted mixed-effects models, odds of severe maternal morbidity increased with increasing neighborhood deprivation index (Odds Ratios and 95% Confidence Intervals, with Quartile 1 as reference: Quartile 4 =1.23 (1.20-1.26), Quartile 3=1.13 (1.10-1.16), Quartile 2=1.06 (1.03-1.08). Associations were modified by race/ethnicity such that associations (Quartile 4 vs. Quartile 1, 95% C.I.) were strongest among individuals in the “Other” racial/ethnic category (1.39, 1.03-1.86) and weakest among Black individuals (1.07, 0.98-1.16).

Conclusion: These findings suggest that neighborhood deprivation contributes to an increased risk of severe maternal morbidity. Future research should examine which aspects of neighborhood environments matter most across racial/ethnic groups.

Introduction:

Severe maternal morbidity (SMM), a myriad of unexpected and life-threatening complications related to pregnancy and childbirth, has emerged as a major public health concern. Severe maternal morbidity affects 1-2% of pregnant individuals (approximately 60,000 people) each year in the United States and has been on the rise for the past two decades.[1,2] There are significant racial/ethnic inequities in SMM, with Black and American Indian/Alaska Native individuals experiencing two- to threefold higher rates of SMM compared to White individuals.[3-5] Although extensive research has identified a range of individual, clinical, and hospital factors associated with this increased risk, these factors alone are insufficient in explaining persistent racial/ethnic inequities in SMM.[3,4,6,7]

Recently, there has been a call to action for the investigation of the multi-level social determinants of SMM.[8-11] A systematic review identified 83 studies from 1999-2018 that examined social factors related to maternal morbidity and mortality and found that 94% of studies focused on individual-level social factors (e.g., maternal education, insurance status).[12] However, neighborhood environments, including their socioeconomic conditions, physical characteristics, and social contexts, may also be important drivers of SMM and SMM inequities. We know that there is substantial geographic variation in SMM and that this variation is more than just a function of the racial/ethnic composition of the region.[13,14] Instead, features of neighborhood environments may impact SMM through several pathways. First, neighborhood environments may influence the risk of pre-existing conditions. Studies have shown that individuals residing in adverse neighborhood environments have higher obesity, diabetes, and other cardio-metabolic risk factors associated with SMM.[15-17] Second, neighborhood environments may be associated with multiple aspects of pregnancy health, including maternal diet, physical activity, and gestational weight gain.[18-21] Third, neighborhood environments may affect direct physiologic processes tied to chronic stress and accelerated aging.[22,23] Finally, neighborhood environments may be related to access to and quality of health care.[24-26]

Investigations of neighborhood factors in relation to SMM are in their infancy. The few existing studies have examined place-based socioeconomic status measures at various scales: county, ZIP code, and New York City community district .[3,27-29] Findings to date have mostly been null, with only one study documenting an association between ZIP code-level median household income and SMM, independent of individual-level confounders.[3] A major limitation of these studies is the use of large geographic boundaries that introduce a great deal of within-area heterogeneity and mask important geographic differences in risk.[30] Thus, more research is needed to examine these associations using more granular units such as census tracts or block groups.

To begin to address these gaps in the literature, we examined associations between neighborhood socioeconomic characteristics, measured at the census tract level, and SMM in the state of California. Given that rates of SMM are highest in racially/ethnically marginalized populations, understanding whether adverse neighborhood environments differentially impact SMM in these groups may inform efforts to address to address disparities in these groups. Thus, we also examined whether associations are modified by race/ethnicity. We hypothesized that birthing people residing in more socioeconomically disadvantaged neighborhoods would have higher risk of SMM and that these associations would vary substantially by race/ethnicity, with associations being more pronounced among racially/ethnically marginalized individuals.

Materials and Methods:

Study Population

Data for this study are from all live hospital births in California from 1997-2018, obtained from the California Department of Health Care Access and Information (HCAI), formerly the Office of Statewide Health Planning and Development (OSHPD), which has linked hospital discharge records with birth certificates (N= 10,971,609). We excluded births from our analyses based on the following criteria: missing

gestational age or gestational age <20 weeks or >45 weeks (N= 307,644); unable to be linked to a census tract (N= 100,568); and missing maternal race/ethnicity, parity, and non-1st birth for non-singleton delivery (N= 178,421). The final analytic sample consisted of 10,384,976 births (Figure 1). The protocol for this study was approved by the State of California Committee for the Protection of Human Subjects and the Institutional Review Boards of Stanford University and University of California, Berkeley.

Study Outcome

We assessed SMM during birth hospitalization using the United States Centers for Disease Control and Prevention SMM Index, which is validated for use with administrative and population surveillance data.[2,31] The SMM index contains 21 indicators related to life-threatening diagnoses and procedures (e.g., heart failure, temporary tracheostomy, transfusion). These indicators were obtained from hospital discharge records using the International Classification of Disease Clinical Modification 9th and 10th Revision (ICD-9-CM and ICD 10th-CM) and diagnostic and procedure codes (Supplementary Table 1). Individuals whose hospital discharge records contained one or more of these 21 indicators were categorized as having SMM.

In sensitivity analyses, we excluded individuals with blood transfusion as their only SMM indicator because they might not all represent true cases of SMM, given that information on the number of units of blood transfusion was not available.[31,32]

Standardized Neighborhood Deprivation Index

Neighborhoods were defined as census tracts. Based on prior work, we constructed a neighborhood deprivation index (NDI) to investigate the association between neighborhood socioeconomic context and SMM. We consider NDI to be a proxy for a broad range of specific features of neighborhood environments, which may provide general insights into the potential impacts of neighborhood environments on SMM. The index, originally developed by Messer et al.[33] and widely utilized in the maternal and infant health literature,[34] combined eight census tract variables: % adults in

management and professional occupations, % crowded households, % households in poverty, % female-headed households with dependents, % households on public assistance, % households earning <$30,000, % adults with less than a high school diploma, and % adults unemployed.[33] This index was then standardized with a mean of 0 and a standard deviation of 1, with higher NDI scores indicating more deprivation and lower values indicating less deprivation. For births between 1997-2004, these variables were extracted from data from the 2000 Census. For births between 2005-2010, NDI variables were characterized using American Community Survey (ACS) 2005-2010 5-year estimates. Similarly, births between 2011-2015 were linked to 2011-2015 ACS estimates, and births between 2016-2017 were linked to ACS 2015-2019 estimates. In our analyses, we categorized this continuous score into quartiles for the 1997-2004 and 2005-2018 births separately (Quartile 1=low deprivation-Quartile 4=high deprivation). Across the state of California there were 8,022 neighborhoods, with an average of 1295 births per neighborhood. Census tract 2000 boundary was normalized to 2010 using the Longitudinal Tract Data Base.[35,36]

Race/Ethnicity

Maternal race/ethnicity was determined from birth certificates and categorized as: Non-Hispanic White (hereafter, White); Non-Hispanic Black (hereafter, Black); Hispanic; Asian/Pacific Islander (Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Native Hawaiian, Guamanian or Chamorro, Samoan, other Asian, or other Pacific Islander; hereafter, Asian/PI); and Other race/ethnicity. Due to small sample sizes, we combined birthing people who were identified as American Indian/Alaska Native (N=44,199, or 0.4%) with Other and Mixed-Race group (N=6,807, or 0.1%) to create an "Other" race/ethnicity category.

Covariates

Based on prior literature, we examined an extensive list of maternal and clinical factors as confounders, using data from birth certificates and hospital discharge records. Maternal demographic and pregnancy-related characteristics assessed included: Maternal education (high school or less, some college, completed college); primary method used for childbirth payment (Medi-Cal, private insurance, other/unknown); maternal age at childbirth (<20, 20-34, ≥35 years); plurality (singleton, multiple); and parity (any versus no prior live births). Clinical comorbidities score (continuous) was estimated from 26 comorbidities with ICD-CM codes, which were assigned weighted values based on their ability to predict SMM.[37]

Statistical Analyses

All statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC). In descriptive analyses, we compared the distribution of study covariates by NDI and SMM and report proportions, means, and standard deviations. To determine whether NDI was associated with SMM, we used a series of mixed-effects logistic regression models with individuals nested within neighborhoods. As SMM is a rare outcome, we report odds ratios as suitable approximations of relative risk.[38] The unadjusted model included only NDI (Model 1) and additional models sequentially included maternal sociodemographic characteristics, pregnancy-related factors, and clinical comorbidities (Model 2), and maternal race/ethnicity (Model 3). To examine whether associations between NDI and SMM were modified by race/ethnicity, we created a cross-product term, and interactions with $p<0.05$ were considered statistically significant.

Results:

Among 10,384,976 births, 1.2% (120,487) were SMM births, and the mean maternal age was 28.4 (SD=6.26). The distribution of maternal race/ethnicity was 50.8% Hispanic, 29.5% White, 13.5% Asian/PI, 5.8% Black, and 0.5% individuals in the "Other" racial/ethnic category. Table 1 shows the distribution of maternal characteristics overall and by quartiles of neighborhood disadvantage. Compared to the overall population, individuals living in the highest quartile of NDI (i.e., most deprived) were more likely to identify

as Black (8.1% vs. 5.8% overall) and Hispanic (75.7% vs. 50.8% overall), and less likely to be White (9.8% vs. 29.5% overall). Compared to the overall population, there was also a higher representation of individuals with less than a high school education (74.2% vs. 50.9%) and individuals with Medi-Cal (72.1% vs. 46.5%) in the highest quartile of NDI.

Incidence of SMM increased with increasing neighborhood disadvantage: 102.9 per 10,000 in Q1, 109.3 in Q2, 115.4 in Q3, and 127.1 in Q4 (Table 2). In mixed-effects unadjusted models, individuals living in neighborhoods with more disadvantage (i.e., Q2-Q4 compared to Q1) had 5-23% higher odds of SMM, conditional on the random effect for neighborhood (all confidence intervals excluded the null). Associations persisted after adjustment for maternal age, education, insurance type, parity, plurality, and clinical co-morbidities (Table 2, Model 2), and became slightly attenuated after adjustment for maternal race/ethnicity (Table 2, Model 3: OR [95% C.I.] Q2=1.04[1.01-1.06]; Q3=1.07 [1.05-1.10); Q4=1.14 [1.11-1.17)).

A further examination of the interplay between neighborhood disadvantage and race/ethnicity revealed a significant interaction in unadjusted (Figure 2; p<0.0001) and fully adjusted models (Table 3; p<0.001). The association between NDI and SMM among White (OR [95% C.I.] Q2= 1.04 [1.01-1.07]; Q3=1.10 [1.07-1.14]; Q4=1.22 [1.17-1.27]), Hispanic (OR [95% C.I.] Q2=1.08 [1.03-1.13]; Q3=1.10 [1.06-1.14]; Q4=1.17 [1.12-1.22]), and API (OR [95% C.I.] Q2=1.05 [1.01-1.09]; Q3=1.07 [1.02-1.12]; Q4=1.14 [1.08-1.20]) individuals was similar in direction and magnitude, with a clear gradient of increasing SMM with increasing NDI as seen in the total population. Among those in the "Other" racial/ethnic category, individuals living the highest quartile of NDI (OR [95%] 1.39 [1.39-1.86]) had higher risk of SMM compared to those living in the lowest quartile of NDI. However, there were no statistically significant associations between NDI and SMM among Black individuals.

In sensitivity analyses, associations between NDI and SMM were comparable for non-transfusion SMM in the overall models, although results had less precision as demonstrated by the wider confidence intervals (Supplemental Table 2) . Race/ethnicity-stratified models showed that the associations between

some levels of NDI and non-transfusion SMM were attenuated for some groups, specifically Hispanic, Asian, and Other racial groups.

Comment:

Principal Findings:

Our analysis of the relationship between neighborhood disadvantage and SMM in a statewide sample of 10.4 million births in California from 1997-2018 found that SMM risk was highest among birthing people who lived in the most deprived areas and that as neighborhood deprivation increased, the odds of SMM increased, independent of maternal sociodemographic characteristics, pregnancy-related factors, and comorbidities. This pattern was observed for all racial/ethnic groups, with the strongest association among individuals in the "Other" racial/ethnic category; however, associations were not statistically significant for Black individuals.

Results:

Our results contribute evidence that neighborhood deprivation, measured at the census-tract level, influences SMM. Other studies have characterized contextual socioeconomic status at broader geographic scales, including county-level socioeconomic status indicators, ZIP code-level household income quartile, and community district-level poverty.[13,27-29] County-level socioeconomic characteristics were not associated with SMM in a study of New York State births,[3,27] while ZIP code-level income, which defined neighborhoods at a comparatively finer scale than county-level, was inversely associated with rates of SMM in a multi-state study.[3,27] Community district-level poverty in New York City, a scale that fell between county and ZIP code, was not statistically significantly associated with SMM overall but modified SMM risk such that residence in a high poverty neighborhood significantly increased the SMM risk difference between Black and White birthing people, as well as between Hispanic and White birthing people, compared to this difference in wealthier districts.[28] Lastly, we found that the associations between NDI and SMM persisted after adjusting for individual-level socioeconomic factors and pregnancy-related clinical

factors, suggesting that other mechanisms, such as quality of care during delivery or exposure to discrimination, may be operating to influence SMM risks.

We also found that the association between neighborhood deprivation and SMM was modified by race/ethnicity. Among White, Hispanic, and Asian/PI individuals and those in the "Other" racial/ethnic category, living in neighborhoods with a higher NDI was associated with higher odds of SMM. It is rare to have sufficient sample size in neighborhood health effects research to explore these cross-level interactions, and our findings that associations are strong among Hispanic, Asian/PI, and especially "Other" (predominately Native American) individuals contributes to a limited literature on multi-level predictors of reproductive outcomes among these groups.

However, we also found that there was no statistically significant association between NDI and SMM among Black individuals. Although this was counter to our *a priori* hypotheses, it is not unprecedented. Evidence regarding the relationship between neighborhood characteristics and reproductive outcomes among Black individuals is mixed.[39,40] One study that examined preterm birth (PTB) outcomes found that White and Black individuals in the same geographic areas had a different relationship between NDI and PTB: while living in a more deprived neighborhood significantly increased the risk of PTB for White individuals in seven out of eight geographies, significantly increased risk of PTB was only seen for Black individuals in two out of eight geographies and at a lower magnitude than observed for White individuals.[41] In another study, significant relationships were found between specific characteristics of neighborhood deprivation (e.g., physical incivilities, walkability) and low birthweight and preterm birth for White but not Black individuals.[42] It is possible that for Black individuals, factors not measured in this study but known to impact chronic stress and reproductive outcomes (e.g., experiences of racism, social support) modify the relationship between NDI and SMM.[34,43-46] For example, Black individuals living in high NDI neighborhoods with high concentrations of chronic stressors may benefit from strong social support networks that mitigate the negative impacts of living in a deprived neighborhood.[47] Black individuals living in lower NDI neighborhoods may be more likely to experience racial discrimination and social exclusion, nullifying the protective effect that a less deprived neighborhood may provide for other racial groups.[48]

Future research is needed to understand the pathways through which neighborhoods may differentially impact the risk of SMM across different groups of Black individuals.

Clinical Implications:

Our findings underscore the need to move beyond pregnancy-related factors and clinical comorbidities and consider a broader range of social determinants of health (e.g., neighborhood context) to fully understand and address the etiology of SMM and SMM disparities. The collection and inclusion of information on patients' neighborhood context in electronic health records and hospital discharge data would be a critical step in this direction.

Research Implications:

As our findings suggest that the scale at which neighborhood context is measured may matter, future research should examine associations at more granular levels to uncover geographic differences in risk that may be masked at the county or ZIP code level. To facilitate this research aim, clinical databases should leverage patient address data to allow for geocoding at the neighborhood level.

As there are persistent racial/ethnic inequities in SMM, future research is needed to expand the measurement of both harmful and protective neighborhood-level factors that may be more salient for racially/ethnically marginalized populations and to examine their impact on SMM.

Strengths and Limitations:

To our knowledge, this is the first study to examine the relationship between NDI and SMM using state-wide data in California and a more granular geographic definition of neighborhood at the census tract level, a more comprehensive characterization of neighborhood disadvantage, and a larger sample size than most prior studies. The large population of Asian/PI and Hispanic individuals in our data set provides an important opportunity for us to examine associations by race/ethnicity that may not be possible using other data sets with smaller sample sizes of these groups.

Several limitations warrant comment. First, though we used a validated measure of SMM, there may be misclassification of our outcome. Potential sources of misclassification include the under-reporting

of rare SMM conditions (e.g., eclampsia and other cardiac and renal conditions) in hospital discharge data and the classification of SMM for individuals who received a blood transfusion for non-severe complications.[31,49] In sensitivity analyses, we found comparable associations between neighborhood disadvantage and SMM, mitigating concern regarding the latter source of bias. Second, our use of census tracts as proxies for neighborhoods may be limiting, in that although census tracts are designed to be more socioeconomically homogenous than larger census-defined boundaries, they may not reflect boundaries that are meaningful to residents or the underlying boundaries of spatial inequities. A related concern is the absence of direct measurement of specific features of neighborhood environments and the use of neighborhood deprivation as a crude proxy for features such as high crime and other place-based stressors that may matter for SMM. Future studies should examine specific features that may be more amenable to change. Finally, although we controlled for an extensive list of covariates, we cannot rule out the possibility of residual confounding due to the unavailability of data on individual-level measures (e.g., household income).

Conclusions:

Leveraging one of the largest statewide databases, we found that neighborhood disadvantage was associated with SMM at the census tract level, which improves upon existing studies. Furthermore, NDI influenced SMM risk among white, API, Hispanic, and Other racial groups. This work provides support for the critical impact of social determinants of health, operating at multiple levels, on maternal health inequities.

Acknowledgements: The authors would like to thank Peiyi Kan for statistical support.

References

1. Callaghan WM, Creanga AA, Kuklina EV. Severe maternal morbidity among delivery and postpartum hospitalizations in the United States. Obstet Gynecol 2012;120:1029-36.
2. CDC. Severe Maternal Morbidity in the United States: Centers for Disease Control and Prevention; 2017.
3. Creanga AA, Bateman BT, Kuklina EV, Callaghan WM. Racial and ethnic disparities in severe maternal morbidity: a multistate analysis, 2008-2010. Am J Obstet Gynecol 2014;210:435 e1-8.
4. Leonard SA, Main EK, Scott KA, Profit J, Carmichael SL. Racial and ethnic disparities in severe maternal morbidity prevalence and trends. Ann Epidemiol 2019;33:30-6.
5. Admon LK, Winkelman TN, Zivin K, Terplan M, Mhyre JM, Dalton VK. Racial and ethnic disparities in the incidence of severe maternal morbidity in the United States, 2012–2015. Obstetrics & Gynecology 2018;132:1158-66.
6. Holdt Somer SJ, Sinkey RG, Bryant AS. Epidemiology of racial/ethnic disparities in severe maternal morbidity and mortality. Semin Perinatol 2017;41:258-65.
7. Gray KE, Wallace ER, Nelson KR, Reed SD, Schiff MA. Population-based study of risk factors for severe maternal morbidity. Paediatr Perinat Epidemiol 2012;26:506-14.
8. Creanga AA, Berg CJ, Ko JY, et al. Maternal mortality and morbidity in the United States: where are we now? J Womens Health (Larchmt) 2014;23:3-9.
9. Gynecologists ACoOa. ACOG Committee Opinion No. 586: Health disparities in rural women. Obstet Gynecol 2014;123:384-8.
10. Carroll AE. Why Is US Maternal Mortality Rising? Jama 2017;318:321.
11. Greenberg MB, Gandhi M, Davidson C, Carter EB. Society for Maternal-Fetal Medicine Consult Series #62: Best practices in equitable care delivery; Addressing systemic racism and other social determinants of health as causes of obstetrical disparities. American Journal of Obstetrics & Gynecology 2022;227:B44-B59.
12. Wang E, Glazer KB, Howell EA, Janevic TM. Social Determinants of Pregnancy-Related Mortality and Morbidity in the United States: A Systematic Review. Obstetrics & Gynecology 2020;135:896-915.
13. Callaghan WM. Geographic variation of reproductive health indicators and outcomes in the United States: place matters. American journal of obstetrics and gynecology 2014;211:278-84.
14. Kramer M, Hogue C. Place Matters: Variation in the Black/White Very Preterm Birth Rate across U.S. Metropolitan Areas, 2002 2004. Public Health Reports 2008;123:576 - 85.
15. Diez AR, Mujahid MS, Hirsch JA, Moore K, Moore LV. The impact of neighborhoods on CV risk. Global heart 2016;11:353-63.
16. Feng J, Glass TA, Curriero FC, Stewart WF, Schwartz BS. The built environment and obesity: a systematic review of the epidemiologic evidence. Health & place 2010;16:175-90.
17. Black JL, Macinko J. Neighborhoods and obesity. Nutrition reviews 2008;66:2-20.
18. Mendez DD, Doebler DA, Kim KH, Amutah NN, Fabio A, Bodnar LM. Neighborhood socioeconomic disadvantage and gestational weight gain and loss. Maternal and child health journal 2014;18:1095-103.
19. Headen I, Mujahid M, Deardorff J, Rehkopf DH, Abrams B. Associations between cumulative neighborhood deprivation, long-term mobility trajectories, and gestational weight gain. Health & place 2018;52:101-9.
20. Headen I, Laraia B, Coleman-Phox K, Vieten C, Adler N, Epel E. Neighborhood typology and cardiometabolic pregnancy outcomes in the maternal adiposity metabolism and stress study. Obesity 2019;27:166-73.
21. Laraia B, Messer L, Evenson K, Kaufman JS. Neighborhood factors associated with physical activity and adequacy of weight gain during pregnancy. Journal of Urban Health 2007;84:793-806.
22. Needham BL, Carroll JE, Roux AVD, Fitzpatrick AL, Moore K, Seeman TE. Neighborhood characteristics and leukocyte telomere length: the Multi-Ethnic Study of Atherosclerosis. Health & place 2014;28:167-72.
23. Ribeiro AI, Amaro J, Lisi C, Fraga S. Neighborhood socioeconomic deprivation and allostatic load: A scoping review. International journal of environmental research and public health 2018;15:1092.
24. Hussein M, Diez Roux AV, Field RI. Neighborhood Socioeconomic Status and Primary Health Care: Usual Points of Access and Temporal Trends in a Major US Urban Area. J Urban Health 2016;93:1027-45.
25. Janevic T, Zeitlin J, Egorova N, Hebert PL, Balbierz A, Howell EA. Neighborhood Racial And Economic Polarization, Hospital Of Delivery, And Severe Maternal Morbidity. Health Aff (Millwood) 2020;39:768-76.
26. Howell EA, Zeitlin J. Improving hospital quality to reduce disparities in severe maternal morbidity and mortality. Semin Perinatol 2017;41:266-72.
27. Guglielminotti J, Landau R, Wong CA, Li G. Patient-, Hospital-, and Neighborhood-Level Factors Associated with Severe Maternal Morbidity During Childbirth: A Cross-Sectional Study in New York State 2013-2014. Matern Child Health J 2018.

28. Howland RE, Angley M, Won SH, et al. Determinants of severe maternal morbidity and its racial/ethnic disparities in New York City, 2008–2012. Maternal and Child Health Journal 2019;23:346-55.
29. Reid LD, Creanga AA. Severe maternal morbidity and related hospital quality measures in Maryland. J Perinatol 2018;38:997-1008.
30. Krieger N, Waterman P, Chen JT, Soobader M-J, Subramanian SV, Carson R. Zip code caveat: bias due to spatiotemporal mismatches between zip codes and US census-defined geographic areas--the Public Health Disparities Geocoding Project. Am J Public Health 2002;92:1100-2.
31. Main EK, Abreo A, McNulty J, et al. Measuring severe maternal morbidity: validation of potential measures. Am J Obstet Gynecol 2016;214:643 e1- e10.
32. Callaghan WM, Kuklina EV, Berg CJ. Trends in postpartum hemorrhage: United States, 1994-2006. Am J Obstet Gynecol 2010;202:353.e1-6.
33. Messer LC, Laraia BA, Kaufman JS, et al. The development of a standardized neighborhood deprivation index. J Urban Health 2006;83:1041-62.
34. Culhane JF, Elo IT. Neighborhood context and reproductive health. Am J Obstet Gynecol 2005;192:S22-9.
35. Logan JR, Xu Z, Stults B. Interpolating U.S. Decennial Census Tract Data from as Early as 1970 to 2010: A Longtitudinal Tract Database. Prof Geogr 2014;66:412-20.
36. Logan JR, Stults BJ, Xu Z. Validating Population Estimates for Harmonized Census Tract Data, 2000–2010. Annals of the American Association of Geographers 2016;106:1013-29.
37. Leonard SA, Kennedy CJ, Carmichael SL, Lyell DJ, Main EK. An Expanded Obstetric Comorbidity Scoring System for Predicting Severe Maternal Morbidity. Obstet Gynecol 2020;136:440-9.
38. Davies HTO, Crombie IK, Tavakoli M. When can odds ratios mislead? Bmj 1998;316:989-91.
39. Mutambudzi M, Meyer JD, Reisine S, Warren N. A review of recent literature on materialist and psychosocial models for racial and ethnic disparities in birth outcomes in the US, 2000-2014. Ethn Health 2017;22:311-32.
40. Ncube CN, Enquobahrie DA, Albert SM, Herrick AL, Burke JG. Association of neighborhood context with offspring risk of preterm birth and low birthweight: A systematic review and meta-analysis of population-based studies. Soc Sci Med 2016;153:156-64.
41. O'Campo P, Burke JG, Culhane J, et al. Neighborhood deprivation and preterm birth among non-Hispanic Black and White women in eight geographic areas in the United States. Am J Epidemiol 2008;167:155-63.
42. Vinikoor-Imler LC, Messer LC, Evenson KR, Laraia BA. Neighborhood conditions are associated with maternal health behaviors and pregnancy outcomes. Soc Sci Med 2011;73:1302-11.
43. Chambers BD, Arabia SE, Arega HA, et al. Exposures to structural racism and racial discrimination among pregnant and early post-partum Black women living in Oakland, California. Stress Health 2020;36:213-9.
44. Culhane JF, Goldenberg RL. Racial disparities in preterm birth. Semin Perinatol 2011;35:234-9.
45. Giurgescu C, Engeland CG, Zenk SN, Kavanaugh K. Stress, Inflammation and Preterm Birth in African American Women. Newborn and Infant Nursing Reviews 2013;13:171-7.
46. Nuru-Jeter A, Dominguez TP, Hammond WP, et al. "It's the skin you're in": African-American women talk about their experiences of racism. an exploratory study to develop measures of racism for birth outcome studies. Matern Child Health J 2009;13:29-39.
47. Dove-Medows E, Deriemacker A, Dailey R, et al. Pregnant African American Women's Perceptions of Neighborhood, Racial Discrimination, and Psychological Distress as Influences on Birth Outcomes. MCN The American Journal of Maternal/Child Nursing 2020;45:49-56.
48. Dailey AB, Kasl SV, Holford TR, Lewis TT, Jones BA. Neighborhood- and individual-level socioeconomic variation in perceptions of racial discrimination. Ethn Health 2010;15:145-63.
49. Lydon-Rochelle MT, Holt VL, Cardenas V, et al. The reporting of pre-existing maternal medical conditions and complications of pregnancy on birth certificates and in hospital discharge data. Am J Obstet Gynecol 2005;193:125-34.

Tables and Figures:

Table 1. Distribution of Maternal Characteristics by Neighborhood Deprivation Index Quartiles; California, 1997-2018 (n =10,384,976)

Maternal Characteristics	All; n (%)	Neighborhood Deprivation Quartiles,[a] n (%)			
		Quartile 1 (n = 1,817,201)	Quartile 2 (n = 2,195,976)	Quartile 3 (n = 2,736,997)	Quartile 4 (n = 3,634,802)
Race/Ethnicity					
Non-Hispanic White	3058,811 (29.5)	1,023,796 (56.3)	960,066 (43.7)	719,740 (26.3)	355,209 (9.8)
Non-Hispanic Black	601,503 (5.8)	45,038 (2.5)	96,443 (4.4)	165,455 (6.0)	294,567 (8.1)
Hispanic	5,274,129 (50.8)	296,099 (16.3)	728,772 (33.2)	1,497,326 (54.7)	2,751,932 (75.7)
Asian/Pacific Islander	1,399,527 (13.5)	446,329 (24.6)	398,834 (18.2)	336,792 (12.3)	217,572 (6.0)
Other	51,006 (0.5)	5,939 (0.3)	11,861 (0.5)	17,684 (0.6)	15,522 (0.4)
Age (years)					
< 20	877,768 (8.5)	35,534 (2.0)	113,457 (5.2)	251,075 (9.2)	477,702 (13.1)
20-34	7,638,780 (73.6)	1,199,995 (66.0)	1,629,178 (74.2)	2,082,402 (76.1)	2,727,205 (75.0)
≥ 35	1,868,428 (18.0)	581,672 (32.0)	453,341 (20.6)	403,520 (14.7)	429,895 (11.8)
Education					
<= High school	5,289,687 (50.9)	291,959 (16.1)	770,600 (35.1)	1,530,647 (55.9)	2,696,481 (74.2)
Some College	2,318,074 (22.3)	365,626 (20.1)	599,651 (27.3)	698,359 (25.5)	654,438 (18.0)
College Graduate	2,595,070 (25.0)	1,128,155 (62.1)	787,513 (35.9)	461,471 (16.9)	217,931 (6.0)
Missing/Unknown	182,145 (1.8)	31,461 (1.7)	38,212 (1.7)	46,520 (1.7)	65,952 (1.8)
Payment Type at Delivery					
Medi-Cal	4,824,537 (46.5)	207,100 (11.4)	631,184 (28.7)	1,365,499 (49.9)	2,620,754 (72.1)
Private	5,207,585 (50.1)	1,542,133 (84.9)	1,482,322 (67.5)	1,274,250 (46.6)	908,880 (25.0)
Other/Unknown	352,854 (3.4)	67,968 (3.7)	82,470 (3.8)	97,248 (3.6)	105,168 (2.9)
Multiple Pregnancy					
Yes	156,640 (1.5)	40,929 (2.3)	37,007 (1.7)	36,623 (1.3)	42,081 (1.2)
No	10,228,336 (98.5)	1,776,272 (97.7)	2,158,969 (98.3)	2,700,374 (98.7)	3,592,721 (98.8)
Primiparous					
Yes	4,018,861 (38.7)	814,028 (44.8)	940,253 (42.8)	1,053,505 (38.5)	1,211,075 (33.3)
No	6,366,115 (61.3)	1,003,173 (55.2)	1,255,723 (57.2)	1,683,492 (61.5)	2,423,727 (66.7)
Comorbidities [b]	8.0 (14.7)	7.9 (15.1)	8.1 (14.9)	7.9 (14.6)	7.9 (14.4)

[a] Quartile 1 represents the lowest deprivation neighborhoods and Quartile 4 the highest (worst).

[b] Mean (SD) for continuous comorbidity score

Clinical comorbidities score =weighted average of 26 co-morbidities.

Table 2. SMM Prevalence, Unadjusted and Adjusted Odds Ratios of SMM by Neighborhood Deprivation Index Quartile; California, 1997-2018 (n = 10,384,976)

Neighborhood Deprivation	Deliveries	SMM Cases	SMM Prevalence per 10,000 Deliveries	Unadjusted OR (95% CI), without neighborhood mixed effect	Including Neighborhood Mixed Effect		
					Unadjusted OR (95% CI)	Adjusted OR [a] (95% CI)	Adjusted OR [b] (95% CI)
Q1 – Low Deprivation	1,817,201	18,690	102.9	Reference	Reference	Reference	Reference
Q2	2,195,976	23,997	109.3	1.06 (1.04-1.08)	1.05 (1.04-1.08)	1.06 (1.03-1.08)	1.04 (1.01-1.06)
Q3	2,736,997	31,593	115.4	1.12 (1.10-1.14)	1.12 (1.10-1.14)	1.13 (1.10-1.16)	1.07 (1.05-1.10)
Q4 – High Deprivation	3,634,802	46,207	127.1	1.24 (1.22-1.26)	1.23 (1.20-1.26)	1.23 (1.20-1.26)	1.14 (1.11-1.17)

SMM=Severe Maternal Morbidity

[a] Adjusted for maternal age, education, insurance type, parity, plurality, and comorbidity score

[b] Adjusted for maternal age, education, insurance type, parity, plurality, comorbidity score, and race/ethnicity

Table 3. Prevalence and Adjusted Odds Ratios of SMM by Neighborhood Deprivation Index Quartile and Maternal Race/Ethnicity; California, 1997-2018 (n = 10,384,976)

NDI Quartile and Maternal Race/Ethnicity	Deliveries	SMM Cases	SMM Prevalence per 10,000 Deliveries	Unadjusted OR (95% CI)	Adjusted OR [a] (95% CI)
Model 1: Non-Hispanic White (n = 2,300,151)					
Q1 – Low Deprivation	1,023,796	9,198	90	Reference	Reference
Q2	960,066	8,844	92	1.01 (0.97-1.05)	1.04 (1.01-1.07)
Q3	719,740	7,024	98	1.03 (0.99-1.08)	1.10 (1.07-1.14)
Q4 – High Deprivation	355,209	3,964	112	1.12 (1.06-1.18)	1.22 (1.17-1.27)
Model 2: Non-Hispanic Black (n = 453,856)					
Q1 – Low Deprivation	45,038	776	172	Reference	Reference
Q2	96,443	1,634	169	0.96 (0.85-1.08)	1.00 (0.92-1.10)
Q3	165,455	2,903	175	0.96 (0.86-1.07)	1.03 (0.94-1.12)
Q4 – High Deprivation	294,567	5,457	185	1.01 (0.90-1.12)	1.07 (0.98-1.16)
Model 3: Hispanic (n = 3,970,402)					
Q1 – Low Deprivation	296,099	3,300	111	Reference	Reference
Q2	728,772	8,404	115	0.96 (0.91-1.02)	1.08 (1.03-1.13)
Q3	1,497,326	17,217	115	0.94 (0.89-1.00)	1.10 (1.06-1.14)
Q4 – High Deprivation	2,751,932	33,704	122	0.97 (0.93-1.03)	1.17 (1.12-1.22)
Model 4: Asian/Pacific Islander (n = 967,753)					
Q1 – Low Deprivation	446,329	5,340	120	Reference	Reference
Q2	398,834	4,956	124	1.04 (0.98-1.10)	1.05 (1.01-1.09)
Q3	336,792	4,203	125	1.00 (0.94-1.06)	1.07 (1.02-1.12)
Q4 – High Deprivation	217,572	2,807	129	1.00 (0.93-1.07)	1.14 (1.08-1.20)
Model 5: Other (n = 37,614)					
Q1 – Low Deprivation	5,939	76	128	Reference	Reference
Q2	11,861	159	134	1.03 (0.70-1.52)	1.07 (0.79-1.44)
Q3	17,684	246	139	0.82 (0.56-1.20)	1.12 (0.83-1.50)
Q4 – High Deprivation	15,522	275	177	1.09 (0.75-1.58)	1.39 (1.03-1.86)

SMM=Severe Maternal Morbidity

[a] Adjusted for maternal age, education, insurance type, parity, plurality, and comorbidity score

Figure Legends

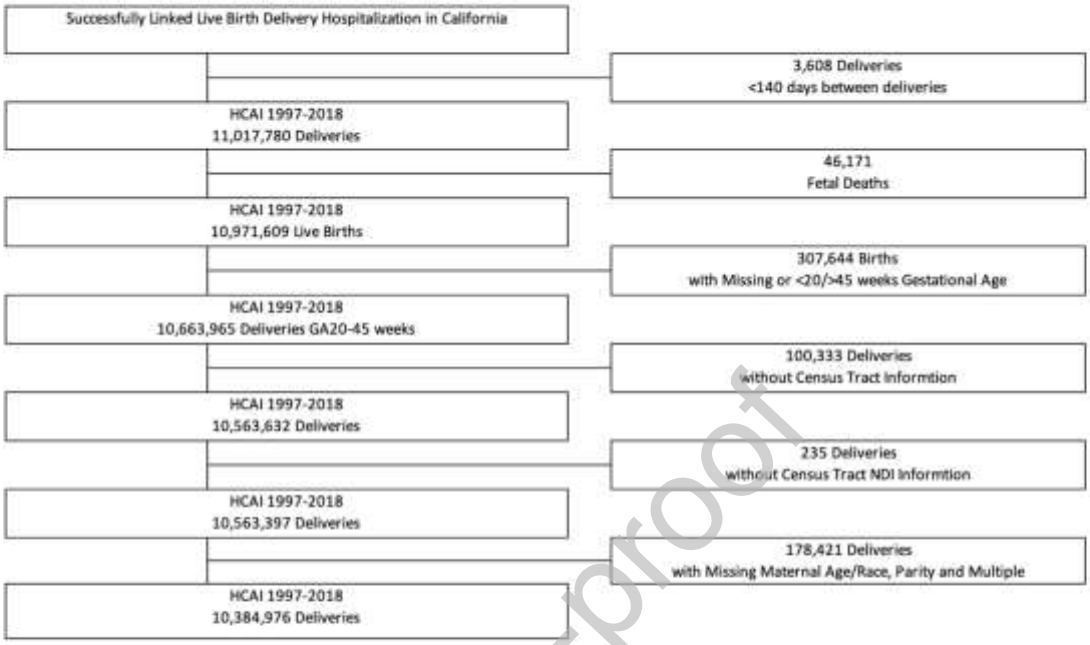

Figure 1. Analytic Sample Selection, California, 1997-2018 (n = 10,384,976

Summary of study exclusion criteria leading to the final analytic sample. After removing samples due to missing or invalid data, the final analytic sample consisted of 10,384,976 births.

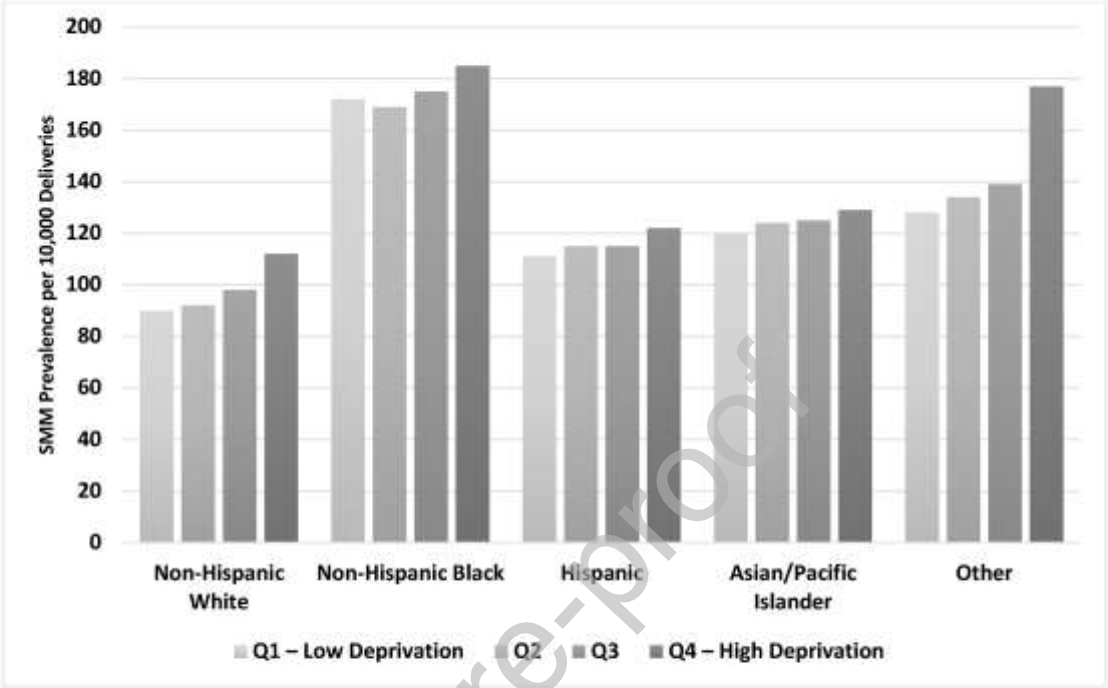

Figure 2. SMM Prevalence per 10,000 Deliveries across Neighborhood Deprivation Index Quartiles by Race/Ethnicity, California, 1997-2018 (n = 10,384,976)

Severe maternal morbidity (SMM) prevalence per 10,000 deliveries across neighborhood deprivation index quartiles by race/ethnicity. “Other” refers to individuals who were identified as American Indian/Alaska Native, Mixed-Race, and Other. Black individuals had the highest prevalence of SMM across all quartiles.