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Increased Stillbirth Rates and Exposure to Environmental Risk Factors for Stillbirth in Counties with Higher Social Vulnerability: United States, 2015–2018

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Abstract

Introduction—Exposure to unfavorable environmental conditions during pregnancy, such as extreme heat and air pollution, has been linked to increased risk of stillbirth, defined as fetal mortality at or after 20 weeks' gestation, however no studies have examined its association with social vulnerability. We examined associations between county-level stillbirth rates, environmental risk factors for stillbirth, and social vulnerability in the United States.

Methods—This ecologic study linked county-level data from three nationwide datasets on stillbirths (National Vital Statistics System), environmental conditions (North American Land Data

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Author Contributions JM designed the study, acquired the data, conducted the analysis, and wrote the manuscript. SE independently replicated the analysis and provided input on the methodology and manuscript. CR provided input on the methodology, analysis, and manuscript. MS and YC assisted in the acquisition of the data, served as subject matter experts on the environmental health data, provided input on the methods and manuscript. CD supported the development and refinement of the manuscript and served as a subject matter expert on stillbirth. As senior authors, CC and CB, provided direction and oversight throughout the project life cycle and supported the development and refinement of the manuscript.

Ethical Approval This project received CDC ethical approval and was determined to be Not Research - Public Health Surveillance under 45 CFR 46.102(1)(2).

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Assimilation System and Environmental Protection Agency), and social vulnerability (Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry Social Vulnerability Index). Poisson and negative binomial models were fit to the variables and produced rate ratios to estimate associations among stillbirth rates, environmental risk factors, and social vulnerability.

Results—Social vulnerability was positively associated withn stillbirth rates, annual average number of extreme heat days, and ambient concentration of particulate matter ≤ 2.5 μm in diameter (PM2.5). The average number of days that ozone and PM2.5 each exceeded regulatory standards were not associated with stillbirth rates or social vulnerability. A positive association between average annual PM2.5 concentration and stillbirth rates was detected; no other significant associations between environmental risk factors and stillbirth rates were observed.

Discussion—We found evidence of associations between social vulnerability and stillbirth rates, and between social vulnerability and environmental risk factors for stillbirth at the county level. Further research could inform understanding of how social vulnerability impacts the relationship between environmental exposures and stillbirth risk.

Keywords

Fetal Mortality; Stillbirth; Social Vulnerability; Extreme heat; Air Quality

Introduction

Stillbirth, defined as the death of a fetus at or after 20 weeks' gestation, occurs in approximately 23,000 pregnancies annually in the United States (Pruitt et al., 2020) and has significant psychosocial and economic impacts (Heazell et al., 2016). Emerging evidence suggests certain environmental exposures, including extreme heat (Bekkar et al., 2020; Chersich et al., 2020; Ha et al., 2017; Nyadanu et al., 2024; Rammah et al., 2019; Sexton et al., 2021) and air pollution (Bekkar et al., 2020; Nyadanu et al., 2024; Sarovar et al., 2020; Song et al., 2023), may be associated with stillbirth. These environmental exposures are often more intense in areas with lower socioeconomic status; on average, these areas have higher concentrations of air pollution (Bell & Ebisu, 2012; Hajat et al., 2013) and experience more extreme heat (Lehnert et al., 2020), often resulting from poor community design (Benz & Burney, 2021; Jesdale et al., 2013). People in underrepresented racial and ethnic groups in the United States are more likely to live in these areas as a result of historic and systemic factors (Bell & Ebisu, 2012; Benz & Burney, 2021; Jesdale et al., 2013), and are more likely to experience poor health and pregnancy outcomes from exposures to heat and air pollution (Bekkar et al., 2023; Dzekem et al., 2024; O'Neill, 2005; Spiller et al., 2021).

While overall stillbirth rates are declining (5.7 per 1,000 live US births in 2020) (Gregory et al., 2022), disparities in stillbirth rates have been identified. Stillbirth rates among Black non-Hispanic and Native Hawaiian or Other Pacific Islander people are over twice that of White non-Hispanic and Hispanic people (Gregory et al., 2022; Pruitt et al., 2020; Tanner et al., 2023; Willinger et al., 2009). Stillbirth rates among American Indian or Alaska Native people are also over 60% higher than those of White non-Hispanic and Hispanic people (Gregory et al., 2022). There are likely many contributors to these disparities, including biological risk factors, implicit bias and medical racism, and factors such as access to care and environmental exposures (Pruitt et al., 2020; "Racism and Bias in Maternity Care Settings," 2021; Williams et al., 2018; Willinger et al., 2009).

Analyses examining risk factors for stillbirths generally focus on individual-level factors, such as medical history, demographics, and socioeconomic status. Structural racism impacts socioeconomic status and social vulnerability among people in underrepresented racial and ethnic groups (Bailey et al., 2017; Dean & Thorpe, 2022; Williams et al., 2019), which are associated with poor reproductive health outcomes, including stillbirth. Analyses focusing on race/ethnicity often exclude and obscure different subgroups of the population due to limitations in racial and ethnic categories (Morey et al., 2022; Nguyen et al., 2022; Quint et al., 2021), and have insufficient statistical power because of small population sizes (Gaps and Strategies for Improving American Indian Alaska Native/Native American Data, 2007).

Social vulnerability, as defined by the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry Social Vulnerability Index (CDC/ATSDR SVI)(Flanagan et al., 2018), and other geography-based measures offer inclusivity for populations that may not be otherwise captured using the most commonly deployed racial and ethnic categories. Another advantage of these indices is that they include race/ethnicity and socioeconomic status but also incorporate structural factors that influence health, thus providing a more holistic measure of vulnerability.

Few studies have examined how community characteristics and environmental risk factors might be associated with stillbirth rates in the United States. We aimed to understand the association of county-level social vulnerability with (a) stillbirth rates, and (b) environmental risk factors for stillbirth, and to (c) understand the relationship between stillbirth rates and environmental risk factors for stillbirth.

Methods

This ecologic study linked data from three databases: the National Vital Statistics System (NVSS), the National Environmental Public Health Tracking Network (NEPHTN), and the CDC/ATSDR SVI.

Stillbirth and Live Birth Data

The analysis used records of live births and stillbirths that occurred during 2015—2018 provided by the National Center for Health Statistics through the NVSS. The NVSS offers the most complete dataset on births and deaths in the United States; stillbirths were defined as the spontaneous uterine demise of a fetus during or after the 20th week of gestation as determined by obstetric estimation (Martin et al., 2015). Live birth and stillbirth data from 2015 to 2018 were aggregated by maternal county of residence to obtain county-level frequencies. Live births and stillbirths to persons who were not residents of the United States were excluded from the analysis because of uncertainty about place of residence and environmental exposures during the gestational period. The proportion of live births and stillbirths to non-residents made up 0.25% and 0.20%, respectively. The four-year average county-level stillbirth prevalence was calculated by dividing the total number of stillbirths by the sum of stillbirths and live births and multiplying by 1,000.

Social Vulnerability Index

The 2018 CDC/ATSDR SVI is a measure that uses 15 social variables collected by the US Census Bureau to estimate the vulnerability of a community to natural and human-made disasters, such as disease outbreaks, floods, chemical spills, and more (Flanagan et al., 2011). While this index was created to help public health officials and local planners allocate resources and prepare communities for disasters, more recent analyses have used SVI as an alternative way to estimate risk for poor health outcomes instead of income and education and race/ethnicity, as it is multi-dimensional with many more variables. The present analysis used national county-level social vulnerability, which means that each county was ranked against all other counties in the US. Scores range from 0 (lowest vulnerability) to 1 (highest vulnerability). Analyses used both the overall SVI, which combines all 15 variables, as well as four SVI themes [Socioeconomic Status (persons below poverty, unemployed, and with no high school diploma; per capita income), Household Composition and Disability (persons aged 65 or older and aged 17 or younger; civilians with a disability; single-parent households), Minority Status and Language (minority populations, defined as all persons except White, non-Hispanic; persons who speak English “less than well”), and Housing Type and Transportation (housing structures with 10 or more units; mobile homes; more people than rooms at household level; households with no vehicle available; persons in group quarters)], which are used to estimate different types of vulnerability (Flanagan et al., 2018). SVIs for 2016 and 2018 were averaged to obtain an average index reflective of the study period, overall and for each theme.

Environmental Exposure Data

Environmental data were provided by CDC’s NEPHTN. Extreme heat days were defined as the average number of days per year that the maximum daily heat index reached or exceeded 90°F. Data originated from the North American Land Data Assimilation System (NLDAS-2). To estimate air quality, variables that included data both collected by monitoring stations and modeled using Bayesian space-time downscaling modeling (Fused Air Quality Surface Using Downscaling (FAQSD) Files, 2023) were obtained from the Environmental Protection Agency’s Air Quality System (AQS) via the NEPHTN. AQS data were used to estimate the number of days with the maximum 8-hour average ozone concentration above the National Ambient Air Quality Standard (NAAQS) (Reviewing National Ambient Air Quality Standards (NAAQS): Scientific and Technical Information), which is 0.070 parts per million (ppm). AQS data were also used to estimate the number of days $PM_{2.5}$ exceeded 12.0 micrograms per cubic meter of air ($\mu g/m^3$), the NAAQS value in effect during the study period. Finally, NAAQS data were used to calculate the annual average ambient concentration of $PM_{2.5}$ in $\mu g/m^3$. Four-year averages were calculated using annual data from 2015 to 2018 to estimate the county-level values for each variable.

Statistical Analyses

Univariate analyses were performed to obtain descriptive statistics and quartile ranges for each variable. In our multivariate analyses, the primary dependent variable was stillbirth rates and the primary independent variable was SVI. A bivariate map was generated displaying stillbirth and SVI. Next, the arithmetic mean stillbirth rate and 95% confidence intervals (alpha = 0.05) were obtained for each SVI quartile. Poisson models were fit with a robust standard error to obtain rate ratios for stillbirth rates comparing the highest SVI counties with the lowest SVI counties (reference group) by SVI theme. For SVI (independent variable) and environmental variables (dependent variables) including extreme heat, days above the ozone regulatory standard, and days above the $PM_{2.5}$ regulatory standard, negative binomial models were fit, while for average ambient $PM_{2.5}$ concentration, a normal distribution regression model was fit. Finally, data were stratified by SVI quartile (independent variable) and models were fit for each environmental variable (independent variable) and stillbirth rates (dependent variable), to examine how SVI impacted relationships between the environmental variables and stillbirth. Negative binomial models were fit for each variable with stillbirth as the outcome and using all events (fetal deaths plus births) as the offset variable. Rate ratios were calculated to estimate the change in stillbirth rate resulting from changes in values for each environmental variable. A one-unit change in value for each variable generated during the univariate analysis was used to produce contrast estimates. To account for clustering at the state level, state was defined as a repeated statement in all models. Statistical analyses were conducted using SAS version 9.4 (SAS Institute Inc, Cary, North Carolina) and maps were generated using QGIS version 3.10 (Open Source Geospatial Foundation, Chicago, IL).

Results

Of 3,144 US counties for which live birth data were available, 3,107 (98.8%) counties also had stillbirth, social vulnerability, and environmental exposure data available and were included in the analysis (Fig. 1).

During 2015–2018, there were 92,942 fetal deaths and 15,770,683 births recorded in the US, representing an average of 23,236 fetal deaths and 3,942,671 births per year. The median county-level stillbirth rate during this time was 5.63 per 1,000 fetal deaths and live births (Table 1) [Interquartile range (IQR) = 3.66]. The median SVI was 0.50 (IQR = 0.50). The median number of extreme heat days per year was 56.00 (IQR = 71.25). Ozone concentration exceeded the NAAQS a median number of 0.25 days per year (IQR = 1.00), while the median number of days $PM_{2.5}$ exceeded the NAAQS was 0.0 days per year (IQR = 0.46). Finally, the median annual average ambient concentration of $PM_{2.5}$ was 8.25 $\mu g/m^3$ (IQR = 2.08) (data not shown).

Stillbirth Rates and Social Vulnerability

The mean four-year stillbirth rate increased incrementally by SVI quartile (Fig. 2). In quartile one (SVI = 0.00-0.25), the mean stillbirth rate was 5.18 (95% CI, 4.86–5.49), in quartile two (SVI = 0.26–0.50), the mean stillbirth rate was 5.51 (95% CI, 5.26–5.75), and in quartile three (SVI = 0.5-0.75), the mean stillbirth rate was 5.92 (95% CI, 5.70–6.13). In the highest vulnerability counties (SVI = 0.76-1.0), the mean stillbirth rate was 7.34 (95% CI, 7.03–7.65).

When examined by SVI theme, theme one (socioeconomic status) and theme two (household composition and disability) were most strongly associated with higher stillbirth rates (Table 2). Theme four (housing type and transportation) was also positively associated with higher stillbirth rates, while theme three (minority status and language) did not have any significant association.

Environment and Social Vulnerability

Compared with counties in the lowest SVI quartile, the average annual number of extreme heat days was 1.24 times higher (95% CI, 1.04–1.47) among counties in the second SVI quartile, 1.71 times higher (95% CI, 1.35–2.15) among counties in the third SVI quartile, and 2.35 times higher (95% CI, 1.88–2.94) among counties in the highest SVI quartile (Table 3). There were no statistically significant differences in the annual average number of days above the regulatory standard for ozone or $PM_{2.5}$. The average annual ambient $PM_{2.5}$ concentration was higher with each increasing SVI quartile, with the average $PM_{2.5}$ concentration in the highest vulnerability counties 1.13 μg/m^3 higher than that of the lowest counties (95% CI, 0.63–1.64). Extreme heat days and $PM_{2.5}$ ambient concentration were moderately correlated with a Pearson correlation coefficient of 0.41 ($p < 0.001$) (data not shown).

Stillbirth Rates, Environment, and Social Vulnerability

Among environmental risk factors for stillbirth rates, there was a significant positive association between stillbirth rates and average ambient $PM_{2.5}$ concentration; no other statistically significant associations were found between stillbirth rates and other air pollution or heat variables (Table 4). Further analyses by SVI quartile identified a significant relationship between average ambient $PM_{2.5}$ concentration and stillbirth rates only between counties in SVI quartile three (data not shown).

Discussion

In this nationwide examination of four years of US county-level data including over 15 million births and 90,000 fetal deaths, we observed higher stillbirth rates in areas with higher social vulnerability. The ‘socioeconomic status’ SVI theme was most strongly associated with increased stillbirth rates. The environmental risk factors examined were most prevalent in the highest SVI counties; the mean number of extreme heat days in the highest SVI counties was 2.35 times the number of extreme heat days in the lowest SVI counties, and the average ambient $PM_{2.5}$ concentration in the highest vulnerability counties was 13% higher than in the lowest SVI counties. No associations were found between stillbirth rates and extreme heat days or days above the regulatory standards for ozone or $PM_{2.5}$; a weak association between stillbirth rates and annual average ambient $PM_{2.5}$ concentration was found.

To our knowledge, this study is the first to examine the relationship between county-level SVI and stillbirth rates nationwide. Results from this analysis are similar to those in the United Kingdom, Sweden, and Brazil, which have identified links between higher measures of socioeconomic status or social vulnerability and stillbirth rates (Marques et al., 2021;

Seaton et al., 2012; Silva et al., 2021; Stephansson et al., 2001). A population-based study conducted in the United Kingdom found that stillbirth rates among people who resided in an area with the highest social deprivation (a measure similar to the social vulnerability index that encompasses income, employment, health and disability, education, skills and training, barriers to housing, living environment, and crime) were almost twice the rate of those in areas with the lowest social deprivation (Seaton et al., 2012). Ecological investigations conducted in two regions in Brazil found positive associations between stillbirth rates and social vulnerability (measured by a 9-item index focusing on household income and makeup) at the district (Marques et al., 2021) (similar to census tract in the US) and city levels (Silva et al., 2021). A national matched case-control study that examined individual maternal characteristics in Sweden found that low socioeconomic status (defined by occupation type) increased the risk of stillbirth (Stephansson et al., 2001). Despite differences in settings and in the methodologies used to measure social vulnerability, all studies found that higher social vulnerability was linked with increased stillbirth rates. The consistency of these findings in a diverse set of countries with different healthcare systems and demographic compositions is likely due, in part, to systemic factors driving health disparities among people with lower socioeconomic status or higher social vulnerability.

In the present analysis, SVI theme one, ‘socioeconomic status,’ was most strongly associated with stillbirth rates. The stillbirth rate in the highest ranked counties was almost 50% higher than that of the lowest ranked counties. This aligns with other studies that have found a strong relationship between socioeconomic status and stillbirth and other pregnancy outcomes, including preterm birth (Givens et al., 2021). Theme two, ‘household composition and disability,’ was the next most strongly associated theme, as counties with the highest ranking had a stillbirth rate 1.34 times that of the lowest ranking. The drivers of this relationship are less clear. Theme four, ‘housing type and transportation,’ had a similar relationship, as stillbirth rates in the highest ranked counties for this measure were approximately 1.26 times that of the lowest ranked counties. This might reflect the different levels of exposure to structural risk factors due to differences in housing (e.g., access to air conditioning) and transportation (e.g., walking and use of public transportation compared to private vehicle use). We did not detect an association among stillbirth rates and SVI theme three, ‘minority status and language’.

The areas in which people live and work are important social determinants of health (Office of Disease Prevention and Health Promotion). The association between areas with lower socioeconomic status (Hajat et al., 2013; Mikati et al., 2018) or higher levels of poverty (Colmer et al., 2020) and poor air quality is well documented; there is also evidence suggesting an association between increased exposure to extreme heat and areas with higher levels of poverty (Benz & Burney, 2021). This association has been detected nationally (Benz & Burney, 2021; Hsu et al., 2021) and within metropolitan areas at the census tract level (Benz & Burney, 2021; Dialesandro et al., 2021; Hsu et al., 2021; Huang et al., 2011) across various climate zones (Dialesandro et al., 2021; Hsu et al., 2021; Huang et al., 2011; Renteria et al., 2022) and is not unique to the United States (Chakraborty et al., 2019). Our findings add to the literature on environmental exposures to heat and poor air quality among areas with higher social vulnerability. The lack of association between social vulnerability and the average annual number of days exceeding regulatory standards may be more reflective of the regulatory standards (Independent Particulate Matter Review Panel, 2020) than of risk for exposure, as few counties exceeded regulatory standards for more than one day a year, yet tens of thousands of deaths annually are attributed to $PM_{2.5}$ exposure (Independent Particulate Matter Review Panel, 2020). In the context of climate change, these differences in exposures to environmental risk factors may become more pronounced, which may in turn further widen inequities in associated health outcomes.

Contrary to findings from the present analysis, results from previous studies examining individual-level data have found associations between stillbirth rates and exposures to extreme heat and air pollution (Bekkar et al., 2020). A case-crossover analysis of 709 stillbirths during May–September in Harris County, Texas found that a 10°F increase in temperature in the week preceding delivery was positively associated with a 45% increase in risk for stillbirth (Rammah et al., 2019). Another case-crossover analysis of 987 stillbirths from around the US found that extreme heat and extreme cold were associated with excess stillbirths, and that a 1°C (1.8°F) temperature increase in the week prior to delivery was associated with a 6% increase in risk for stillbirth during May-September (Ha et al., 2017). Similarly, a case-crossover analysis of nearly 500 stillbirths in Utah found 7% increased odds for stillbirth associated with a 1°C (1.8°F) temperature increase in the week prior to delivery (Kanner et al., 2020). Additionally, a meta-analysis examining exposure to heat and negative pregnancy outcomes found that the association was strongest among people in lower socioeconomic groups and at both ends of the age spectrum (Chersich et al., 2020). There is also some evidence linking air pollution and stillbirth occurrence. While a case-crossover study of 821 placental abruptions in western Japan found no association between exposure to increased levels of $PM_{2.5}$ and placental abruption (Michikawa et al., 2017), a case-crossover analysis of over 5,000 stillbirths in California found associations between stillbirth and $PM_{2.5}$ and ozone (Sarovar et al., 2020). The present analysis found an association between stillbirth rates and average annual ambient $PM_{2.5}$ concentration only. The absence of strong associations between the environmental variables and stillbirth rates may be due to the ecological nature of this study and large number of potential confounders, such as county-level healthcare facility density, differences of socioeconomic status within counties, and additional variables that were not accounted for.

The disparities in stillbirth rates and environmental exposures do not occur in a vacuum. Systemic factors rooted in racism have shaped the sociodemographic makeup of many areas and resulted in higher levels of social vulnerability among racial and ethnic minorities (Mitchell, 2018); other practices such as the placement of major roadways and waste disposal sites have resulted in disparate exposures to environmental risk factors for poor health outcomes (Mikati et al., 2018).

The policies and programs [e.g., redlining (Benz & Burney, 2021; Nardone et al., 2021), segregation (Williams et al., 2018)] leading to social vulnerability and disparities in exposures to environmental risk factors play an important role in disparities in various health outcomes, including the development of biological risk factors associated with stillbirth and other unfavorable reproductive health outcomes (Prather C, 2018) (Fig. 3). These biological risk factors are often exacerbated by challenges accessing healthcare and racism experienced in medical settings ("Racism and Bias in Maternity Care Settings," 2021; Saluja & Bryant, 2021). Health equity is unlikely to be achieved without multi-sectoral collaborative efforts to remediate the present conditions caused by past actions.

Methodological Considerations

There are several limitations to this study. First, the ecological nature of the analysis allows for undetected confounding variables. While the social vulnerability index includes many of the typical confounding variables that are adjusted for in statistical analyses (e.g., race/ethnicity, income, and education) other individual-level variables such as health risk behaviors, insurance status, and proximity to medical care, were not accounted for. Using individual-level data that includes individual health status, behavioral, and socioeconomic risk factors and more information about the timing of each stillbirth related to exposures to extreme heat and poor air quality – both indoors and outdoors – could provide more compelling evidence of a relationship between stillbirth and environmental variables. Second, given the variability of income, education, and other factors within counties, census tract-level would have provided additional granularity, however stillbirth data are only available at the county-level. Third, differences in reporting at the county and state levels and underreporting of fetal deaths are longstanding data quality concerns (Gregory et al., 2022). Fourth, we did not examine seasonality of stillbirth rates, which could have potentially shown a more pronounced association between extreme heat and stillbirth, nor did we examine extreme cold temperatures, which may also be associated with increased stillbirth risk (Ha et al., 2017; Kanner et al., 2020). Additionally, as monitoring station data were not always available, more than half of the air quality data were modeled, which may over or underestimate true pollutant concentrations (Fused Air Quality Surface Using Downscaling (FAQSD) Files, 2023). Finally, we did not account for other etiologies of stillbirth or the community-level prevalence of conditions associated with stillbirth, including diabetes, hypertension, birth defects, congenital infections, and more.

Summary and Implications

These findings highlight the opportunity for efforts to prevent adverse pregnancy outcomes to focus on areas with high social vulnerability. They also highlight the increased prevalence of certain environmental exposures in higher vulnerability areas. In the context of global climate change, there is an opportunity to assess and mitigate environmental exposures among the most vulnerable to reduce disparities in associated health outcomes and promote health equity. While the relationship among social vulnerability, environmental risk factors, and stillbirth rates is less clear, further investigation is warranted. Examining the strength of the relationship between environmental risk factors and stillbirth by season can help clarify the role of heat, cold, and air quality on pregnancy outcomes. Additionally, research to elucidate the intersections between race and ethnicity, social vulnerability, environmental risk factors, and stillbirth at the individual level can help inform tailored stillbirth prevention efforts by providing an understanding of the conditions that are most likely to lead to stillbirth. Future studies might also examine the efficacy of different interventions (e.g., improved access to air conditioning, reduction of exposure to air pollution through masks) for reducing unfavorable health outcomes associated with environmental exposures. Harmonized efforts to address the structural, environmental, medical, and biological contributors to stillbirth and stillbirth disparities may aid in lasting change.

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Disclaimer

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Data Availability

Social vulnerability and environmental data are publicly available. Stillbirth and live birth data must be requested through the National Vital Statistics System.

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Significance

We are not aware of any nationwide studies in the United States that have assessed the relationship between stillbirth rates and social vulnerability. Our findings contribute to the understanding of the complex interplay between social vulnerability, environmental exposures, and adverse birth outcomes. The results of our study have important implications for public health interventions and policy decisions aimed at reducing stillbirth rates in communities with higher social vulnerability.

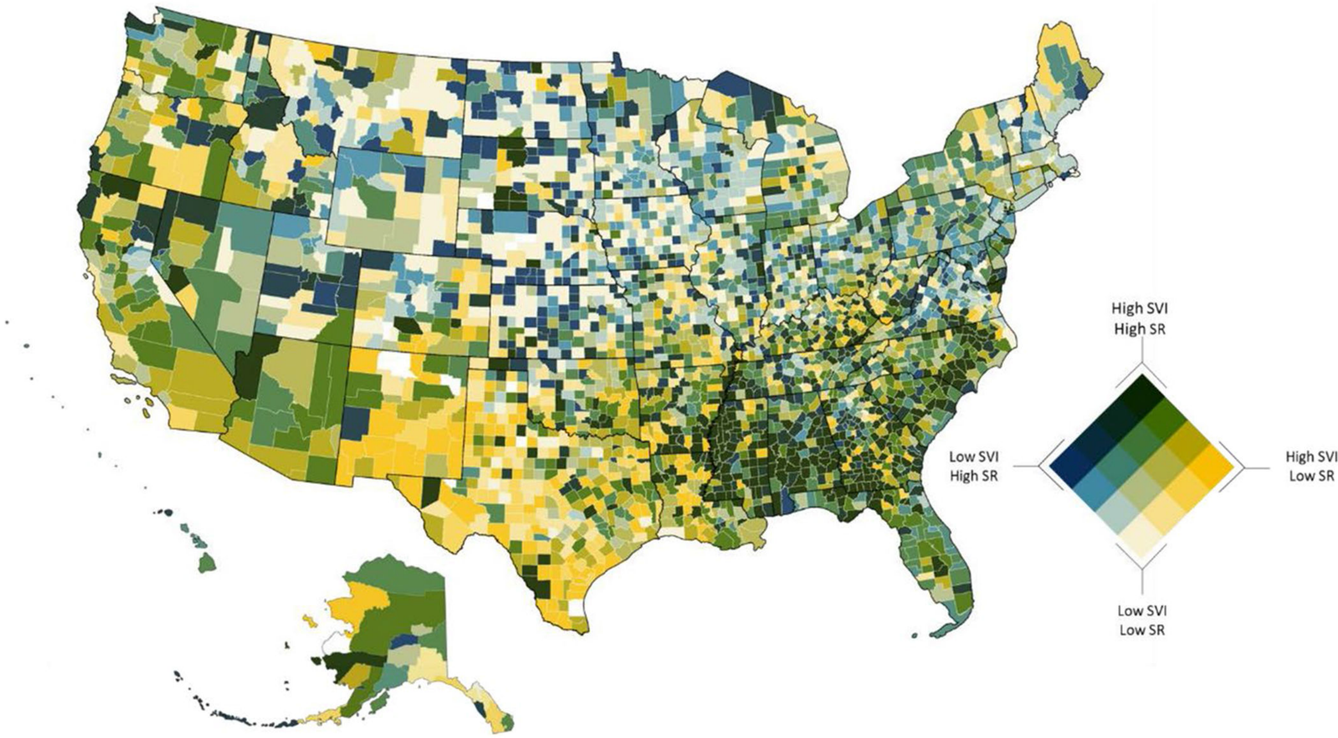

Fig. 1.
County-level stillbirth rates (SR) and Social vulnerability index (SVI), United States, 2015—2018

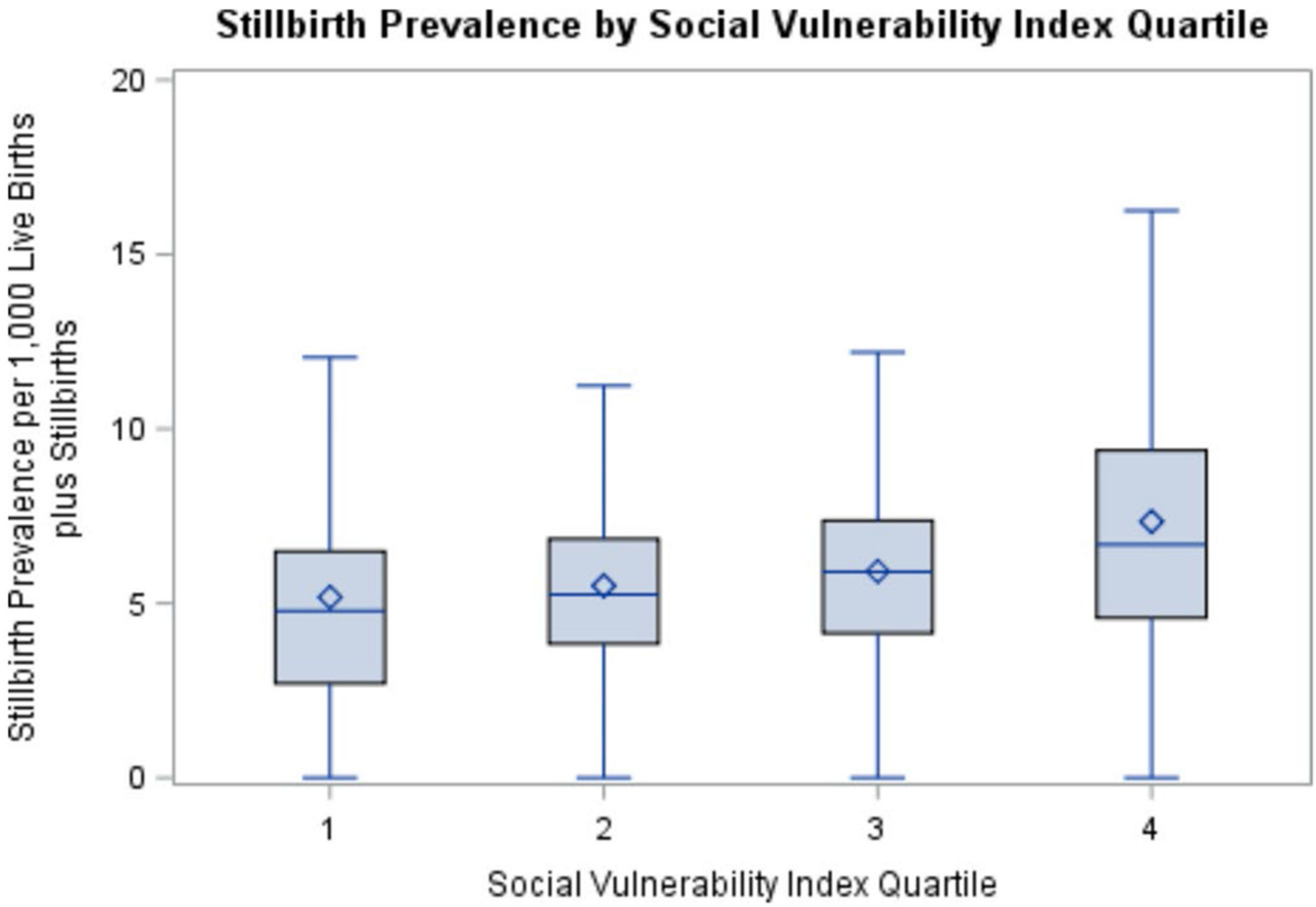

Fig. 2.

Mean county-level stillbirth rate by social vulnerability index quartile, United States, 2015—2018. *Note* This chart depicts the stillbirth prevalence per 1,000 live births plus stillbirths based on SVI quartile. For each SVI quartile, the endpoint of the lower whisker represents the minimum prevalence, the lower edge of the box represents the 25th percentile of prevalence, the diamond-shaped marker represents the mean prevalence, the line inside the box represents the median or 50th percentile of prevalence, the upper edge of the box represents the third 75th percentile of prevalence, and the endpoint of the upper whisker represents the maximum prevalence

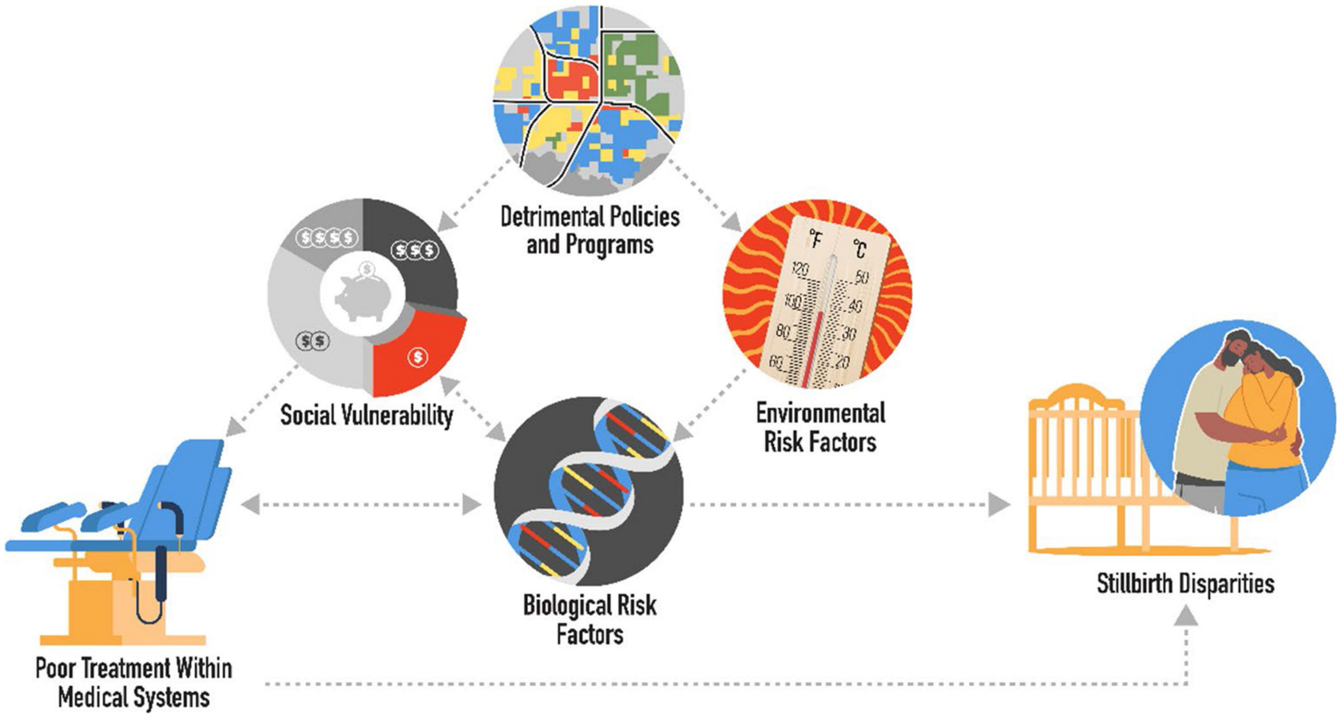

Fig. 3.
Conceptual Framework: Stillbirth disparities, environmental risk factors, and social vulnerability

Table 1

Summary characteristics of counties analyzed (*n* = 3,107), United States, 2015—2018

Variable	Mean	Median	Min	Max	SD
Outcome					
Stillbirth Rate per 1,000 Births (no.)[1]	5.98	5.63	0.00	43.48	3.97
Social Vulnerability					
Social Vulnerability Index	0.50	0.50	0.00	1.00	0.29
Environmental Exposures					
Heat					
Extreme Heat Days (no.)[2]	59.78	56.00	0.00	147.00	41.16
Air Quality					
Days Ozone Exceeded 0.070 ppm(no.)[3]	1.32	0.25	0.00	130.25	5.32
Days $PM_{2.5}$ Exceeded 12.0 $\mu g/m^3$ (no.)[4]	0.68	0.00	0.00	37.69	2.16
Annual Average Ambient $PM_{2.5}$ Concentration ($\mu g/m^3$)[5]	8.05	8.25	3.53	17.80	1.51

[1] Four-year stillbirth rate expressed as the number of fetal deaths per 1,000 live births plus fetal deaths

[2] Average number of days per year during which daily maximum heat index reached or exceeded an absolute threshold of 90 degrees F

[3] Average number of days per year with maximum 8-hour average ozone concentration (measured by monitoring stations and modeled) exceeded the NAAQS

[4] Average number of days per year PM2.5 levels (measured by monitoring stations and modeled) exceeded the NAAQS

[5] Average ambient concentration of PM2.5 in micrograms per cubic meter (measured by monitoring stations and modeled) based on seasonal averages and daily measurement

Table 2

County-level stillbirth rate ratios by social vulnerability index theme (*n* = 3,091)[1]

Variable	Rate Ratio	95% Lower CL	95% Upper CL	*P*-value (2-sided)
Overall Social Vulnerability Index	1.48	1.26	1.74	< 0.001
Theme One – Socioeconomic Status[2]	1.50	1.30	1.72	< 0.001
Theme Two – Household Composition and Disability[3]	1.34	1.14	1.58	< 0.001
Theme Three – Minority Status and Language[4]	1.05	0.85	1.30	0.638
Theme Four – Housing Type and Transportation[5]	1.26	1.10	1.44	0.001

[1] Poisson models were fit with a robust standard error. Some counties (*n* = 16) did not have SVI theme data available

[2] Includes per capita income and proportion of people below poverty, people aged 16 years or older who are unemployed, and people aged 25 years or older with no high school diploma

[3] Includes proportion of people aged 65 years or older, people aged 17 years or younger, civilians with a disability, and households with a single-parent children under age 18 years

[4] Includes proportion of people in racial and ethnic minority groups (all except White non-Hispanic persons), and people aged five years or older who speak English "less than well"

[5] Includes estimates of proportions of housing structures with 10 or more units, mobile homes, homes with crowding (more people than rooms), households with no vehicle available, and persons in group quarters

Table 3

County-level environmental exposure rate ratios/difference by social vulnerability index, United States, 2015—2018

	Rate Ratio	95% Lower CI	95% Upper CI	*P*-value (2-sided)
Annual Average Number of Extreme Heat Days[1]				
SVI Q1	ref	ref	ref	ref
SVI Q2	1.24	1.04	1.47	0.015
SVI Q3	1.71	1.35	2.15	< 0.001
SVI Q4	2.35	1.88	2.94	< 0.001
Days Ozone Exceeded 0.070 ppm (no.) [1]				
SVI Q1	ref	ref	ref	ref
SVI Q2	0.85	0.61	1.19	0.355
SVI Q3	0.98	0.65	1.50	0.935
SVI Q4	1.28	0.40	4.08	0.682
Days $PM_{2.5}$ Exceeded 12.0 μg/m^3 (no.) [1]				
SVI Q1	ref	ref	ref	ref
SVI Q2	1.09	0.75	1.59	0.658
SVI Q3	1.07	0.56	2.04	0.840
SVI Q4	1.32	0.45	3.87	0.611
Annual Average Ambient $PM_{2.5}$ Concentration (μg/m^3)[2]	**Rate Difference**			
SVI Q1	ref	ref	ref	ref
SVI Q2	0.57	0.27	0.88	< 0.001
SVI Q3	0.98	0.59	1.37	< 0.001
SVI Q4	1.13	0.63	1.64	< 0.001

[1] Negative binomial model, exponentiated

[2] Normal distribution model, not exponentiated

Table 4

County-level stillbirth rate ratios by environmental risk factor, United States, 2015—2018

	Rate Ratio	95% Lower CL	95% Upper CL	*P*-value (2-sided)
All SVI Quartiles				
Extreme Heat Days[1]	1.00	1.00	1.00	0.086
Days Ozone Exceeded 0.070 ppm (no.)[2]	1.00	0.99	1.00	0.160
Days $PM_{2.5}$ Exceeded 12.0 μg/m^3 (no.)[3]	0.99	0.98	1.00	0.196
Ambient $PM_{2.5}$ Concentration (μg/m^3)[4]	1.03	1.00	1.06	0.029

[1]Change in fetal mortality rate when average annual extreme heat days increased by 1 day; negative binomial model

[2]Change in fetal mortality rate when average annual days above ozone regulatory standard increased by 1 day; negative binomial model

[3]Change in fetal mortality rate when average annual days above $PM_{2.5}$ regulatory standard increased by 1 day; negative binomial model

[4]Change in fetal mortality rate when average annual ambient concentration of $PM_{2.5}$ increased by 1 μg/m^3; normal distribution model