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Risks for Pretem Birth

Hyper-localized measures of air pollution and risk of preterm birth in Oakland and San Jose, California

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Abstract

Background: US preterm-birth rates are 1.6 times higher for Black mothers than for White mothers. Although traffic-related air pollution (TRAP) may increase the risk of preterm birth, evaluating its effect on preterm birth and disparities has been challenging because TRAP is often measured inaccurately. This study sought to estimate the effect of TRAP exposure, measured at the street level, on the prevalence of preterm birth by race/ethnicity.

Methods: We linked birth-registry data with TRAP measured at the street level for singleton births in sampled communities during 2013–2015 in Oakland and San Jose, California. Using logistic regression and marginal standardization, we estimated the effects of exposure to black carbon, nitrogen dioxide and ultrafine particles on preterm birth after confounder adjustment and stratification by race/ethnicity.

Results: There were 8823 singleton births, of which 760 (8.6%) were preterm. Shifting black-carbon exposure from the 10th to the 90th percentile was associated with: 6.8%age point higher risk of preterm birth (95% confidence interval = 0.1 to 13.5) among Black women; 2.1%age point higher risk (95% confidence interval = –1.1 to 5.2) among Latinas; and inconclusive null findings among Asian and White women. For Latinas, there was evidence of a positive association between the other pollutants and risk of preterm birth, although effect sizes were attenuated in models that co-adjusted for other TRAP.

Conclusions: Exposure to TRAP, especially black carbon, may increase the risk of preterm birth for Latina and Black women but not for Asian and White women.

Key words: Air pollution, preterm birth, health disparities

Key Messages

- Across models adjusting for confounders, there were consistently elevated risks of preterm birth associated with black carbon (BC) among Latina and Black women.
- Among Asian and White women, the estimated effects were almost always negative, with confidence intervals crossing the null.
- Interventions to reduce BC that are targeted towards communities with large Black populations and high levels of BC may see the greatest reductions in preterm birth.

Introduction

The prevalence of preterm birth in the USA has increased in recent years and, by 2018, 10% of births were preterm.[1] Black women are 1.6 times more likely than White women to deliver preterm.[1] Socially patterned maternal stress, likely related to discrimination, structural and interpersonal racism, and mediating biologic pathways are implicated in the Black–White disparity in preterm birth.[2–4] In particular, air pollution measured by fine particulate matter and nitrogen dioxide (NO_2) is estimated to explain 5.7% of the Black–White disparity in preterm birth in California.[5]Currie and Walker used a quasi-experimental design to study the effect on preterm birth of reducing traffic-related air pollution (TRAP) under the introduction of 'E-ZPass' electronic toll collection in two states. They estimated reductions in preterm birth of 10.8% among mothers living <2 km from a toll plaza (who would have experienced the greatest reduction in TRAP) relative to mothers living 2–10 km away.[6] Although their design overcomes confounding, it cannot estimate the effects of specific pollutants and pools exposure into broad bins.

Other studies of air pollution and preterm birth suffer from spatial exposure misclassification. For example, they have estimated maternal exposure to TRAP by calculating the distance from home to the nearest road, modelling levels based on measures taken at ambient monitors or using land-use-regression models.[6–10] TRAP levels vary markedly across streets[11,12] so the types of measures used in prior studies are unlikely to accurately characterize individual exposure.

To address this research gap, we conducted a study to evaluate the effect of TRAP on preterm birth using methods that reduce spatial measurement error. We focus on two racially and ethnically diverse cities: Oakland and San Jose, California. In 2015, Oakland was composed of 26% Latino, 16% non-Latino Asian, 25% non-Latino Black, 27% non-Latino White, 1% other racial groups and 4% multiracial.[13] In San Jose, the population consisted of one-third each non-Latino Asians and Latinos, 27% non-Latino Whites, 3% non-Latino Blacks and 3% multiracial.[14] To characterize spatial variation in TRAP exposure, we used data collected by Google Street View cars that measured air quality every 30 m on streets within sampled areas between 2015 and 2018. Chambliss *et al.* found that this technique reproduced the fine-scale variation in concentrations of black carbon (BC) that emerged from dense networks of stationary samples, illustrating its ability to reduce spatial measurement error.[15] These data provide localized annual-average concentration estimates of BC, NO_2 and ultrafine particles (UFP—particles $<0.1\ \mu$m in diameter), thereby improving measurements of the spatial variability of the exposure. These pollutants come from different sources and are associated with different types of vehicles. Large contributing sources to UFP include nucleation, natural-gas combustion and cars/trucks, whereas BC comes from diesel combustion engines, wood heating and wild fires, and NO_2 comes from cars/trucks.[16,17] Further, the relationship between UFP and birth outcomes has been rarely studied, as UFP are not routinely monitored or regulated.[18,19] Because regulators set admissions standards on a pollutant-by-pollutant basis, we studied pollutants individually. This type of analysis can help to inform admission policies. We also aimed to estimate the effects for

UFP, which are not currently monitored, in which case a harmful-effect estimate would support regular monitoring so that the effects of UFP could be studied more broadly.

The objective of this research was to estimate the relationship between maternal TRAP exposure and preterm birth among women living in Oakland and San Jose. This study sought to determine whether the previously measured effects of air pollutants on preterm birth persisted when race/ethnicity was controlled for via stratification and within a population in which TRAP levels vary sizably from block to block, but mothers are otherwise demographically similar.

Methods

Study population and design

We abstracted birth records from the California Department of Public Health for 2013–2015 where the maternal residential address was located within Oakland and San Jose, California at the time of delivery. Using a cross-sectional study design, we linked TRAP measures to birth records by maternal address for women in sampled neighbourhoods. Maternal addresses were encoded by longitude and latitude coordinates, and linked to the closest TRAP measurements from the Google vehicles. To focus on women for whom we could ascertain hyper-localized measures of TRAP, we excluded women living >120 m from the closest TRAP measurements.

Measurement of the exposure to traffic pollutants

Google vehicles repeatedly measured BC, NO_2 and UFP on every street in sampled neighbourhoods. Selected Oakland streets were sampled for a median of 21–71 days (depending on neighbourhood) and San Jose streets were sampled for a median of 9 days. Measures were taken for each 30 m of road during May 2015 to December 2017. An algorithm estimated the median annual-average daytime concentration of each TRAP every 30 m along every sampled road. Full methods for the measurements of NO_2 and BC are described elsewhere.[11] We also incorporate here measurements of UFP count collected by the same vehicles concurrently with the previously reported data. UFP were measured using a condensation particle counter (Model 3788, TSI, Inc., Shoreview MN; minimum diameter 2.5 nm). These instruments were routinely zero-checked and cross-compared among sampling vehicles following similar quality-assurance and quality-control protocols to those described by Apte *et al.*[11]

Measurement of the outcome

Birth certificates provided information on maternal race and ethnicity, age, parity, insurance type, educational attainment and address at birth, as well as infant sex, date of birth and gestational age. Gestational age was based on the best obstetrical estimate.[20] Preterm birth was defined as all births with gestational age <37 completed weeks. Only singleton births were included.

Measurement of socio-economic variables

Because of historical redlining and persistent segregation in the USA,[21] racial and ethnic groups cluster in neighbourhoods, which suggested that exposure to TRAP varies by race/ethnicity according to neighbourhood. Thus, we stratified the analysis by race/ethnicity as a primary mechanism for reducing confounding from variables that are downstream of the systematic and structural factors that race proxies for.[22] To further control for confounding, we adjusted for socio-economic variables. Economic factors directly affect a mother's neighbourhood of residence through the ability to buy or rent houses at varying prices. Maternal education and insurance type were used as measures of SES, and corresponding median family income and percentage living below poverty from each mother's census block group from the 2012–2016 American Community Survey were also used.

Statistical analysis

To assess co-exposure to multiple pollutants, we estimated the Spearman's rank correlation coefficient for the pairwise combinations of pollutants. We used multiple imputation (30 imputed data sets) using chained equations to account for missingness in covariates used for adjustment.[23,24] We stratified the statistical analysis by the following categories: (i) non-Latina Asian and Pacific Islanders, (ii) non-Latina Black, (iii) Latina (all races) and (iv) non-Latina White, and excluded mothers who did not identify with any category. Hereafter, we refer to non-Latina women according to their racial group only (e.g. 'Asian').

Separate logistic models were used to regress the log-odds of preterm birth against each pollutant (BC, NO_2 and UFP). We first ran a crude model, followed by three models that adjusted for additional variables: (i) Socio-economic status (SES) confounders, conception season and city of residence; (ii) strong predictors of preterm birth (maternal age and nulliparity); and (iii) the two other pollutants. Restricted cubic splines were used to model each pollutant and maternal age (with three internal knots at the 10th, 50th and 90th percentiles).[25] Maternal education was coded categorically as (i) no high-school diploma, (ii) high-school diploma to some college and (iii) associates degree or higher. A linear term was used to adjust for median income. Insurance type was coded categorically as (i) private, (ii) Medicaid or other government or (iii) other, and season of conception was coded categorically into four groups (winter: December–February, spring: March–May, summer: June–August, fall: September–November). A summary of the model descriptions is found in Supplementary Table S1, available as Supplementary data at *IJE* online.

To quantify the crude and adjusted effect of TRAP on the risk of preterm birth, we computed risk differences (RDs) using marginal standardization after setting pollutant-exposure levels in the population to a high level (90th percentile of observed exposure across all mothers) and a low level (10th percentile of observed exposure). We computed RDs using marginal standardization and estimated their standard errors using 1000 bootstrap iterations.[26,27] The RD estimates and standard errors were combined across imputations using Rubin's Rules and 95% confidence intervals (CIs) were calculated.[28]

A sensitivity analysis included all women in one model. We ran the same models as described but added indicator variables for race/ethnicity and interaction terms between race/ethnicity and TRAP. To quantify the effect modification of TRAP by race/ethnicity, we used the marginal standardization procedure previously described but also set race/ethnicity so that the RDs estimated for each race/ethnicity could be compared (i.e. a difference in RDs) and a 95% CI for the difference in RDs was estimated. A second sensitivity analysis was conducted to examine whether the estimated effects varied between Oakland and San Jose. For this analysis, we reran the model by combining Asian and White women into one data set and estimated the effect of each pollutant on preterm birth after setting their location to San Jose and then Oakland, and compared the estimates across cities.

Results

There were 16 660 births in Oakland and 38 942 births in San Jose, California between 2013 and 2015 with non-missing latitude and longitude (Supplementary Figure S1, available as Supplementary data at *IJE* online). Ninety-seven per cent of the Black women in the analysis resided in Oakland compared with 58–76% of women of other race/ethnicities (Supplementary Figure S2, available as Supplementary data at *IJE* online). There were 17 663 unique TRAP measures from sampled communities in Oakland and 5440 measures in San Jose. Seventeen per cent of women lived within 120 m of the TRAP measures. Non-singleton pregnancies ($n = 120$) and mothers with unknown race/ethnicities ($n = 592$) were excluded (Supplementary Table S2, available as Supplementary data at *IJE* online). The final sample size was 8823 women, consisting of 1600 Asian, 1910 Black, 4106 Latina of any race and 1207 White mothers, of whom 6689 lived in Oakland and 2537 lived in San Jose. Latinas comprised the largest racial/ethnic group, with more than double the number of Black women, who were the next most populous.

Asian and White women were generally older than Black and Latina women at the time of birth and more likely to be nulliparous and have higher levels of education (Table 1). Black women lived in census block groups with lowest median household incomes (median = $37 455), whereas Latinas lived in block groups with $4795 higher median incomes, and White and Asian women lived in block groups with median incomes $17 221 and $19 489 higher, respectively. The prevalence of preterm birth was highest among Black women (10.8%), followed by Latina women (8.5%), Asian women (7.9%) and White women (6.2%).

Median exposure levels to TRAP were slightly higher for Asian and White women compared with Black and Latina women (Table 1 and Figure 1). Figure 2 shows that areas high in one pollutant are not necessarily high in the others, and that women living a block apart can have very different exposure levels. Spearman's rho was strongest between UFP and NO_2 ($\rho = 0.73$) and more moderate between BC and NO_2 ($\rho = 0.42$) and BC and UFP ($\rho = 0.29$).

BC

Results were similar across crude and adjusted models (Figure 3 and Supplementary Table S3, available as Supplementary data at *IJE* online). We estimated that shifting maternal exposure to BC from 0.14 to 0.70 $\mu g/m^3$ (corresponding to increasing exposure from the 10th to the 90th percentile) would lead to an increased risk of preterm birth of 2.0%age points (95% CI = –1.7 to 5.8) for Latina mothers and 6.6%age points (95% CI = 0.3 to 12.9) for Black mothers. The association was reversed for Asian (RD = –3.3%age points, 95% CI = –9.2 to 2.5) and White (RD = –1.5%age points, 95% CI = –8.8 to 5.7) mothers, though estimates were imprecise.

NO_2

There was little to no anticipated effect of increasing NO_2 exposure from the 10th (6.4 ppb) to the 90th (14.1 ppb)

Table 1 Characteristics of pregnant women delivering live-born neonates between 2013 and 2015 in Oakland and San Jose, California

	Non-Latina Asian		Non-Latina Black		Latina (any race)		Non-Latina White	
	Median (IQR)[a]	Missing, n (%)	Median (IQR)[a]	Missing, n (%)	Median (IQR)[a]	Missing, n (%)	Median (IQR)[a]	Missing, n (%)
Sample size (n)	1600	–	1910	–	4106	–	1207	–
Oakland (n)	932	–	1845	–	3107	–	805	–
San Jose (n)	668	–	65	–	999	–	402	–
Maternal age (years)	32 (28, 35)	–	27 (23, 32)	–	28 (23, 32)	–	31 (28, 35)	–
Nulliparous [n (%)]	829 (51.9)	2 (0.1)	815 (42.8)	4 (0.2)	1322 (32.2)	–	693 (57.4)	–
Maternal education [n (%)]		57 (3.6)		43 (2.3)		78 (1.9)		35 (2.9)
No high-school degree	110 (7.1)		329 (17.6)		1774 (44)		121 (10.3)	
High-school/General Equivalency Diploma (GED)/ some college	583 (37.8)		1211 (64.9)		1838 (45.6)		342 (29.2)	
Associate's degree or higher	850 (55.1)		327 (17.5)		416 (10.3)		709 (60.5)	
Median household income of census block group ($)	56 944 (35 682, 76 288)	29 (1.8)	37 455 (28 051, 51 260)	94 (4.9)	42 250 (33 796, 56 944)	185 (4.5)	54 676 (33 796, 76 042)	30 (2.5)
Percentage below poverty (%)	13 (6, 29)	4 (0.2)	25 (15, 34)	2 (0.1)	21 (13, 32)	1 (0.0)	15 (6, 28)	2 (0.2)
Payment type [n (%)]		12 (0.8)						9 (0.7)
Private insurance	909 (57.2)		529 (28)	24 (1.3)	992 (24.4)	34 (0.8)	781 (65.2)	
Government (e.g. Medicaid)	603 (38)		1299 (68.9)		2993 (73.5)		348 (29)	
Other	76 (4.8)		58 (3.1)		87 (2.1)		69 (5.8)	
Black carbon of nearest measure ($\mu g/m^3$)	0.39 (0.26, 0.61)	1 (0.06)	0.29 (0.21, 0.39)	–	0.29 (0.21, 0.44)	2 (0.05)	0.35 (0.25, 0.47)	–
Ultrafine particle count of nearest measure ($n \times 10/cm^3$)	25.9 (21, 31.4)	–	24.7 (20.4, 29.4)	–	22.5 (19.5, 27.1)	–	25.5 (19.6, 30.5)	–
Nitrogen dioxide, parts per billion	10.7 (8.5, 13.1)	–	8.8 (7.3, 11.2)	–	9.0 (7.6, 11.4)	–	9.9 (8.2, 12.4)	–
Preterm delivery (<37 weeks) [n (%)]	127 (7.9)	–	206 (10.8)	–	351 (8.5)	–	75 (6.2)	–

[a]Interquartile range, unless otherwise specified.

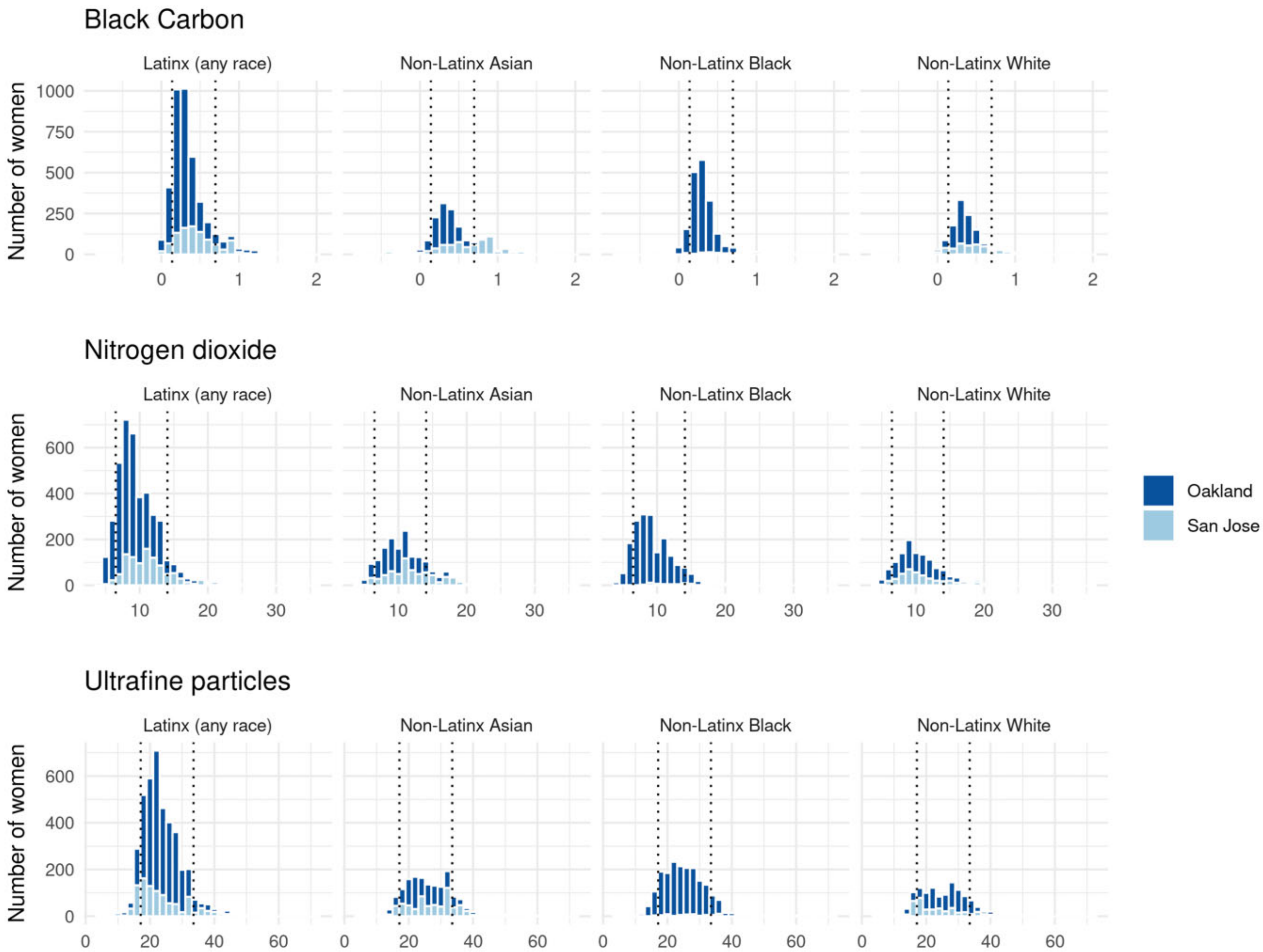

Figure 1 Distribution of pollutants for pregnant women delivering live-born neonates between 2013 and 2015 in Oakland and San Jose, California. Dashed lines correspond to the 10th and 90th percentiles of the distribution across all four races/ethnicities. The distribution of ultrafine particles excludes one outlier that equals 205 from this visual display.

percentile on preterm birth for Asian and Black mothers (Figure 3). For Latina mothers, the fully adjusted model suggested an increase in preterm birth of 1.3%age points (95% CI = –2.5 to 5.0) associated with increasing NO_2 exposure. For White women, full adjustment was associated with the largest estimate of the RD (RD = 4.0%age points; 95% CI = –2.6 to 10.6).

UFP

For Asian, Black and White mothers, increasing the UFP from the 10th percentile to the 90th percentile (a change from 17.1 to 33.5 $n \times 10^3/cm^3$) was associated with an unexpected decreased risk of preterm birth across models (Figure 3). This decrease was largest for Black mothers (RD = –5.4%age points, 95% CI = –10.5 to –0.3) followed by White mothers (RD = –3.7, 95% CI = –8.6 to 1.1). Increasing UFP exposure in Latina mothers was associated with a small increased risk of preterm birth (RD = 1.5, 95% CI = –1.2 to 4.2).

Sensitivity analysis

The first sensitivity analysis found that no statistically significant differences between race/ethnic groups of the effect of TRAP on preterm birth were detected for BC or NO_2 (Supplementary Figure S3, available as Supplementary data at *IJE* online). Black mothers had a significantly reduced estimated effect of UFP on preterm birth compared with Latina mothers. Across pollutants, Asian and White mothers' effects estimates were consistently lower than Latina mothers' estimates.

The second sensitivity analysis found that the effects of NO_2 and UFP on preterm birth were the same in Oakland and San Jose (Supplementary Figure S4, available as

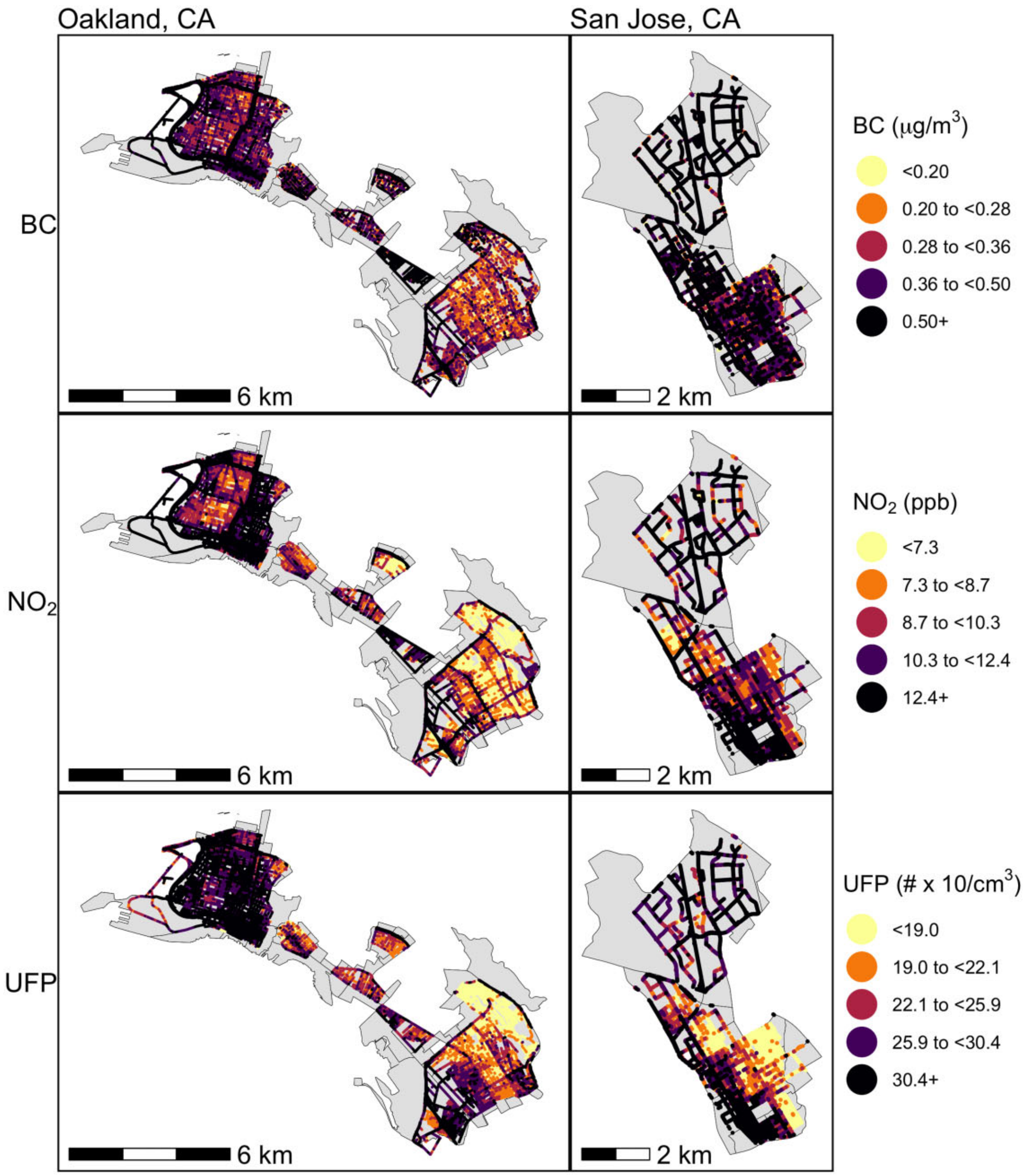

Figure 2 Spatial distribution of black carbon (BC), nitrogen dioxide (NO_2) and ultrafine particles (UFP) in Oakland and San Jose, California (CA)

Supplementary data at *IJE* online). For BC, the effect estimates were positive in Oakland but negative in San Jose, although the CIs were wide and overlapped the null so that no statistically significant interaction was detected.

Discussion

Key findings

We investigated the association between TRAP exposure and risk of preterm delivery among a cohort of diverse individuals in Oakland and San Jose, California from 2013 to 2015. Across models, we estimated consistently elevated risks of preterm birth associated with BC among Latina and Black women. Among Asian and White women, the CIs overlapped the null, although, in almost all models, the effect estimates were negative. For Latinas, increased exposure to NO_2 and UFP was also associated with increased risk of preterm birth, though the effect estimates were attenuated in the models that adjusted for other pollutants. Thus, models not adjusting for other pollutants may have captured a combination of all TRAP given the moderate correlation between BC, NO_2 and UFP in our sample.

The results for Black women were less consistent across pollutants than for Latinas. We did estimate a consistent, albeit large, effect on risk (6.6%age points) for BC

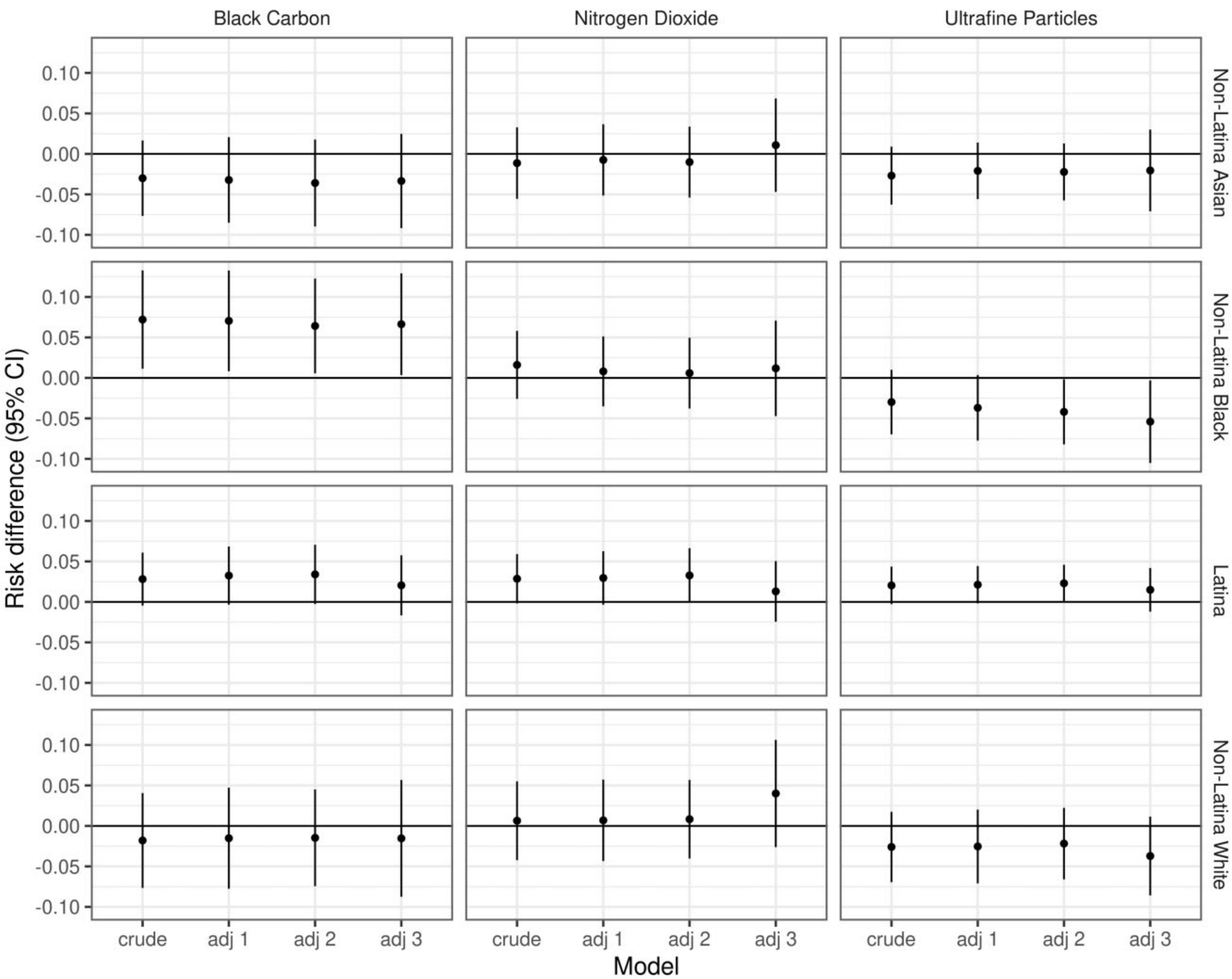

Figure 3 Estimated risk differences and 95% confidence intervals for preterm birth associated with setting exposure to traffic-related air pollutants at high vs low levels for pregnant women in Oakland and San Jose, California, 2013–2015. These risk differences correspond to the estimated change in absolute risk of preterm birth (in percentage points) comparing risk when each pollutant exposure is set to the 90th percentile of its empirical distribution in this cohort vs the 10th percentile of the same distribution. Positive risk differences imply that increasing levels of the pollutant are associated with higher risks of preterm birth and negative differences imply that increasing levels of the pollutant are associated with lower risks of preterm birth. Refer to Supplementary Table S1, available as Supplementary data at *IJE* online, for the description of each model.

exposure. This estimate was likely biased upward, since an increase of this magnitude is implausibly large. Although other studies have shown that racial/ethnic minorities experience both social disadvantage and heightened levels of pollution exposure,[29,30] Black and Latina women in our study had slightly lower levels of TRAP exposure compared with Whites and Asians, but the association between increased TRAP and preterm birth appeared only for Blacks (BC only) and Latinas (BC, NO_2 and UFP).

Results for Asian and White women are hard to interpret. Nearly all associations between the pollutants and preterm birth were negative or null, and our ability to provide more conclusive findings is limited by the smaller number of births in these groups. One possible explanation for the negative associations between TRAP and preterm birth in adjusted models among Asian and White women is that, in our sample, higher SES Asian and White women tend to live on more polluted streets, which could lead to estimates that appear protective due to residual confounding. Previous research shows that the effect of pollutant exposure on preterm birth and other birth outcomes (e.g. low birthweight) is modified by SES.[31–34] If protective factors such as reduced psychosocial stress, improved prenatal care and increased access to nutrition and exercise are more prevalent for Asian and White mothers, then they may buffer/nullify the harmful effects of TRAP.

In California, the average annual concentration of BC is $<0.25\ \mu g/m^3$.[29] Women in this study had an average exposure of $0.37\ \mu g/m^3$, although this measurement may be higher because our measures were directly on roads as opposed to ambient measurements that inform the California average. A recent study found that BC crossed the placenta and that the placental measurement of BC was associated with maternal residential exposure.[35] Thus, BC may affect risk through both maternal systemic inflammation and direct fetal exposure. Three studies that used land-use regression models did not find an association between BC and preterm birth,[7–9] in contrast to our findings. These differences in results may arise because hyperlocal measures capture BC variability that could not be predicted using land-use regression models.

The annual standard for NO_2 is 53 ppb,[36] which is more than five times higher than the median levels in this study. Studies have estimated null or negative associations between NO_2 and preterm birth,[37–39] consistently with our findings for Asians, Blacks and Whites. One study in Shanghai found an increased risk of preterm birth associated with NO_2 exposure, although the levels of NO_2 were much higher than what we observed.[10]

There are currently no air-quality standards for UFP anywhere in the world, and studies of UFP and birth outcomes have been hindered by limited monitoring. Wing *et al.* estimated a positive association between aircraft-origin UFP and preterm birth in California,[18] and Laurent *et al.* also detected a harmful effect using dispersion modelling of road sources.[19] We estimated negative associations between UFP and preterm birth for Blacks and Whites, null associations for Asians and some evidence of positive associations among Latinas. UFP was spatially clustered in these data, so it could be that estimated negative associations are driven by confounders if women living in areas with higher UFP are at otherwise lower risk of preterm birth due to other factors related to residential socio-economic status. Our findings may reflect effect modification by race/ethnicity, residual confounding (e.g. by unmeasured neighbourhood social or environmental factors) and/or chance associations.

Strengths

This study's key strength is that TRAP exposure was measured within 120 m of maternal residence, so that variation in TRAP across women based on local traffic patterns was measured. This is in contrast to the more common method of using monitors to estimate exposure that are often ≤20 km from an individual's residence. The cohort was racially and ethnically diverse, and included Asian, Black, Latina and White women. The analytic method reduced confounding by socio-economic factors, accounted for non-linearity in the effect of each pollutant and adjusted for the presence of multiple pollutants.

Limitations

This study also has limitations. One limitation is that TRAP was assessed during 2015–2017, whereas births occurred during 2013–2015. We assumed that these exposure measurements serve as valid proxies for exposures occurring in 2013–2015. Because exposure estimates were spatially refined but annually averaged, we were unable to assess specific exposure windows. Levels of BC and NO_2 vary seasonally, with highest levels in winter months and lowest levels in spring and summer. UFP does not have a strong seasonal pattern. Previous studies find that the effects of TRAP may vary by trimester, with several pollutants showing more harmful effects in the third trimester vs earlier trimesters, though measures over the entire pregnancy also detect harm.[40] Because of the cross-sectional nature of our exposure data, we were unable to incorporate either of these aspects into analyses. This likely attenuates the effect, as the assigned annual exposure is too high for some women and too low for others. Exposure measurement may also be less accurate for women spending more time away from their residences or if the TRAP measured during regular business hours do not reflect TRAP measures at other times. Measurement inaccuracy may vary by type of roadway (e.g. local street, freeway) because of differences in traffic patterns and resulting TRAP throughout the day. Another limitation is that preterm birth was based on the obstetrical estimate of gestational age, which may underestimate preterm birth especially for non-White and non-Latina individuals.[41] Lastly, because TRAP has been associated with reduced fertility and miscarriage,[42,43] this may induce selection bias. For example, if TRAP's only harms on birth were through increased miscarriage and reduced fertility, live births to women living in more polluted areas may have a lower risk of preterm birth if the fetuses affected were those who would have otherwise been born preterm.[44]

Conclusions

We found the greatest support for a harmful effect of TRAP on preterm birth among Black (BC) and Latina (BC, NO_2, UFP) mothers living in the Bay Area of California. Interventions targeted towards communities with large Black populations and high levels of BC may see the greatest reductions in preterm birth.

Supplementary data

Supplementary data are available at *IJE* online.

Ethics approval

Study protocols were approved by the institutional review boards at Columbia University (AAAS6309), the University of California, Berkeley (#2013–10-5,693) and the California Department of Public Health (#13–05-z).

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Data availability

The outcome data underlying this article were provided by the California Department of Public Health (CDPH). Data requests must be submitted to CDPH for access to the birth-certificate data. The TRAP-exposure data can be requested from the data provider using a Google form: https://docs.google.com/forms/d/e/1FAIpQLSf_4GIkK1tmVMFRSxz42KgvOM3Z3NGeOFFje_FS8FBbz1vTig/viewform.

Conflict of interest

None declared.

References

1. Martin JA, Hamilton BE, Osterman MJK, Driscoll AK. Births: Final Data for 2018. *National Vital Statistics Reports. Report No.: vol 68, no 13*. Hyattsville, MD: National Center for Health Statistics, 2019.
2. Kramer MR, Hogue CR. What causes racial disparities in very preterm birth? A biosocial perspective. *Epidemiol Rev* 2009;**31**:84–98.
3. Olson DM, Severson EM, Verstraeten BSE, Ng JWY, McCreary JK, Metz GAS. Allostatic load and preterm birth. *Int J Mol Sci* 2015;**16**:29856–74.
4. Eichelberger KY, Alson JG, Doll KM. Should race be used as a variable in research on preterm birth? *AMA J Ethics* 2018;**20**:296–302.
5. Benmarhnia T, Huang J, Basu R, Wu J, Bruckner TA. Decomposition analysis of black-white disparities in birth outcomes: the relative contribution of air pollution and social factors in California. *Environ Health Perspect* 2017;**125**:107003.
6. Currie J, Walker R. Traffic congestion and infant health: evidence from E-Z Pass. *Am Econ J Appl Econ* 2011;**3**:65–90.
7. Brauer M, Lencar C, Tamburic L, Koehoorn M, Demers P, Karr C. A cohort study of traffic-related air pollution impacts on birth outcomes. *Environ Health Perspect* 2008;**116**:680–86.
8. Kingsley SL, Eliot MN, Glazer K, *et al.* Maternal ambient air pollution, preterm birth and markers of fetal growth in Rhode Island: results of a hospital-based linkage study. *J Epidemiol Community Health* 2017;**71**:1131–36.
9. Gehring U, Wijga AH, Fischer P, *et al.* Traffic-related air pollution, preterm birth and term birth weight in the PIAMA birth cohort study. *Environ Res* 2011;**111**:125–35.
10. Ji X, Meng X, Liu C, *et al.* Nitrogen dioxide air pollution and preterm birth in Shanghai, China. *Environ Res* 2019;**169**:79–85.
11. Apte JS, Messier KP, Gani S, *et al.* High-resolution air pollution mapping with Google street view cars: exploiting Big Data. *Environ Sci Technol* 2017;**51**:6999–7008.
12. Alexeeff SE, Roy A, Shan J, *et al.* High-resolution mapping of traffic related air pollution with Google street view cars and incidence of cardiovascular events within neighborhoods in Oakland, CA. *Environ Health* 2018;**17**:38.
13. American Community Survey. *2015* American Community Survey *5-Year Estimates for Oakland CA, Table DP05*. US Census Bureau, 2020. https://data.census.gov/cedsci/table?q=dp05%20oakland%20city,%20california&tid=ACSDP5Y2015.DP05&hidePreview=false. (18 May 2020, date last accessed).
14. American Community Survey. *2015* American Community Survey *5-Year Estimates for San Jose CA, Table DP05*. US Census Bureau, 2020. https://data.census.gov/cedsci/table?q=dp05%20san%20jose%20city,%20california&tid=ACSDP5Y2015.DP05&hidePreview=false. (18 May 2020, date last accessed).
15. Chambliss SE, Preble CV, Caubel JJ, *et al.* Comparison of mobile and fixed-site black carbon measurements for high-resolution urban pollution mapping. *Environ Sci Technol* 2020;**54**:7848–57.
16. Yu X, Venecek M, Kumar A, *et al.* Regional sources of airborne ultrafine particle number and mass concentrations in California. *Atmospheric Chem Phys* 2019;**19**:14677–702.
17. Janssen N, Gerlofs-Nijland ME, Lanki T *et al. Health Effects of Black Carbon (2012)*. Copenhagen: World Health Organization, Regional Office for Europe, 2012. https://www.euro.who.int/__data/assets/pdf_file/0004/162535/e96541.pdf.
18. Wing SE, Larson TV, Hudda N, Boonyarattaphan S, Fruin S, Ritz B. Preterm birth among infants exposed to in utero ultrafine particles from aircraft emissions. *Environ Health Perspect* 2020;**128**:47002.
19. Laurent O, Hu J, Li L, *et al.* A statewide nested case-control study of preterm birth and air pollution by source and composition: California, 2001-2008. *Environ Health Perspect* 2016;**124**:1479–86.
20. *Guide to Completing the Facility Worksheets for the Certificate of Live Birth and Report of Fetal Death (2003 Revision)*. Hyattsville, MD: Department of Health and Human Services, Centers for Disease Control and Prevention, 2003. https://www.cdc.gov/nchs/data/dvs/GuidetoCompleteFacilityWks.pdf. (13 April 2020, date last accessed).
21. Aaronson D, Hartley DA, Mazumder B. The effects of the 1930s Holc 'redlining' maps. *Report No.: FRB of Chicago Working Paper No. WP-2017–12*. 2020. https://ssrn.com/abstract=3038733. (2 May 2021, date last accessed).

22. Bailey ZD, Feldman JM, Bassett MT. How structural racism works—racist policies as a root cause of U.S. racial health inequities. *N Engl J Med* 2021;**384**:768–73.
23. Azur MJ, Stuart EA, Frangakis C, Leaf PJ. Multiple imputation by chained equations: what is it and how does it work? *Int J Methods Psychiatr Res* 2011;**20**:40–49.
24. van Buuren S, Groothuis-Oudshoorn K. Mice: Multivariate Imputation by Chained Equations in R. *J Stat Softw* 2011;**45**:1–67.
25. Harrell FE. Restricted cubic splines. In: *Regression Modeling Strategies*. New York: Springer, 2001, pp. 20–23.
26. Muller CJ, MacLehose RF. Estimating predicted probabilities from logistic regression: different methods correspond to different target populations. *Int J Epidemiol* 2014;**43**:962–70.
27. Rice JA. Estimating variability of location estimates by the bootstrap. In: *Mathematical Statistics and Data Analysis*, 3rd edn. Belmont, CA: Thomson Higher Education, 2007, pp. 399–401.
28. Rubin DB. *Multiple Imputation for Nonresponse in Surveys*. New York: Wiley, 1987.
29. Morello-Frosch R, Shenassa ED. The environmental 'riskscape' and social inequality: implications for explaining maternal and child health disparities. *Environ Health Perspect* 2006;**114**: 1150–53.
30. Krieger N, Waterman PD, Gryparis A, Coull BA. Black carbon exposure, socioeconomic and racial/ethnic spatial polarization, and the Index of Concentration at the Extremes (ICE). *Health Place*. 2015;**34**:215–28.
31. Padula AM, Mortimer KM, Tager IB, *et al.* Traffic-related air pollution and risk of preterm birth in the San Joaquin Valley of California. *Ann Epidemiol*. 2014;**24**:888–95.e4.
32. Gray SC, Edwards SE, Schultz BD, Miranda ML. Assessing the impact of race, social factors and air pollution on birth outcomes: a population-based study. *Environ Health* 2014;**13**:4.
33. Yi O, Kim H, Ha E. Does area level socioeconomic status modify the effects of PM(10) on preterm delivery? *Environ Res*. 2010; **110**:55–61.
34. Ponce NA, Hoggatt KJ, Wilhelm M, Ritz B. Preterm birth: the interaction of traffic-related air pollution with economic hardship in Los Angeles neighborhoods. *Am J Epidemiol* 2005;**162**: 140–48.
35. Bové H, Bongaerts E, Slenders E, *et al.* Ambient black carbon particles reach the fetal side of human placenta. *Nat Commun* 2019;**10**:3866.
36. NAAQS Table [Internet]. *United States Environmental Protection Agency.* 2020. https://www.epa.gov/criteria-air-pollutants/naaqs-table. (20 May 2020, date last accessed).
37. Barba-Vasseur M, Bernard N, Pujol S, *et al.* Does low to moderate environmental exposure to noise and air pollution influence preterm delivery in medium-sized cities? *Int J Epidemiol* 2017; **46**:2017–27.
38. Smith RB, Beevers SD, Gulliver J, *et al.* Impacts of air pollution and noise on risk of preterm birth and stillbirth in London. *Environ Int* 2020;**134**:105290.
39. Johnson S, Bobb JF, Ito K, *et al.* Ambient fine particulate matter, nitrogen dioxide, and preterm birth in New York City. *Environ Health Perspect* 2016;**124**:1283–90.
40. Stieb DM, Chen L, Eshoul M, Judek S. Ambient air pollution, birth weight and preterm birth: a systematic review and meta-analysis. *Environ Res* 2012;**117**:100–11.
41. Frutos V, González-Comadrán M, Solà I, Jacquemin B, Carreras R, Checa Vizcaíno MA. Impact of air pollution on fertility: a systematic review. *Gynecol Endocrinol* 2015;**31**:7–13.
42. Conforti A, Mascia M, Cioffi G, *et al.* Air pollution and female fertility: a systematic review of literature. *Reprod Biol Endocrinol* 2018;**16**:117.
43. Kioumourtzoglou M-A, Raz R, Wilson A, *et al.* Traffic-related air pollution and pregnancy loss. *Epidemiology* 2019;**30**:4–10.
44. Goin DE., Casey JA, Kioumourtzoglou M-A, Cushing LJ, Morello-Frosch R. Environmental hazards, social inequality, and fetal loss: implications of live-birth bias for estimation of disparities in birth outcomes. *Environ Epidemiol* 2021;**5**: e131.