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Research article

Disparities in exposure to concentrated animal feeding operations (CAFOs) and risk of adverse birth outcomes in Pennsylvania, USA

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ABSTRACT

Background: Previous studies have linked exposure to concentrated animal feeding operations (CAFOs) with various health outcomes. However, relatively few studies evaluated the impacts of CAFOs on adverse birth outcomes, despite significant public health concerns regarding maternal and child health.
Objectives: This cross-sectional study investigated the risk of adverse birth outcomes associated with CAFOs exposure and evaluated disparities in exposure to CAFOs and associated health outcomes.
Methods: We obtained individual-level birth records from 2003 to 2020 from the Pennsylvania Department of Health. We considered two adverse birth outcomes: (1) preterm birth (PTB); and (2) low birth weight (LBW). Exposure was considered as a binary indicator (presence or absence of CAFO) and as categories based on level of exposure. Logistic regression was applied to estimate the association between CAFOs exposure and adverse birth outcomes. Models were adjusted for infant's sex, maternal demographics (age, race/ethnicity, education), prenatal BMI, prenatal care, smoking status, marital status, plurality, WIC status, and urban/rural indicator. We examined both disparities in exposure and in health response.
Results: Presence of CAFOs was associated with higher risk of PTB, with an increasing trend with higher levels of CAFOs exposure. Compared to the no CAFO exposure group, the odds ratios for PTB were 1.022 (95 % confidence interval 1.003, 1.043), 1.066 (1.034, 1.100), 1.069 (1.042, 1.097) for low, medium, and high CAFOs exposure groups, respectively. Some maternal characteristics were associated with a higher CAFO-related risk of PTB. Similar associations were observed for LBW for some characteristics such as mother's race/ethnicity, education, WIC status, and urbanicity, although some findings were not statistically significant.
Conclusions: Our findings suggest that presence of CAFOs increases risk of preterm birth. Our results indicate that some maternal characteristics may be associated with higher risk of CAFO-related PTB or LBW. This study can inform future research on disparities in CAFO exposure and associated health burden.

1. Introduction

The growth of concentrated animal feeding operations (CAFOs) has caused significant negative impacts on the environment and

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human health. CAFOs in Pennsylvania are defined as all federally defined CAFOs as well as all animal operations with over 1000 animal equivalent units (AEUs) and concentrated animal operations (CAOs) with greater than 300 AEUs [1]. Environmental detriments from CAFOs may affect human health and quality of life through multiple pathways such as harmful airborne emissions, poor soil and water quality, odors emitted from large amount of animal waste and wastewater, and negative impacts on the local ecosystems. Previous epidemiological studies have reported that hazardous emissions from CAFOs may be associated with several adverse health outcomes such as respiratory disease, allergies, aggravation of lung function, inflammation of eyes, nose, and throat, increased mortality, and cancer risk [2–5].

Exposure to CAFOs may be a significant risk factor for human health for farm workers and surrounding populations including for maternal and fetal health. Although some studies examined the association between maternal exposure to CAFOs and adverse birth outcomes including preterm birth (PTB), low birth weight (LBW) and infant mortality, most studies investigating CAFOs exposure and health association focused on respiratory-related health outcomes [6,7]. A study conducted in Virginia, US reported that proximity of maternal residence to poultry CAFOs during pregnancy was associated with reduced gestation and birth weight [8]. Another study found higher rates of infant mortality, hospital admissions and emergency department (ED) visits for LBW infants in ZIP codes with hog CAFOs than ZIP codes without hog CAFOs in North Carolina (NC), US [9]. However, still relatively few studies evaluated the impacts of CAFOs exposure on adverse birth outcomes, despite the critical public health concerns of maternal and child health.

Pennsylvania (PA) is the 8th state for milk production in the US, although the state also has various types of animal agriculture such as chickens, turkeys, hogs, sheep, and goats [10]. Dairy farming is a major agricultural industry in Pennsylvania. More than half of the Pennsylvania's operations are located near the Chesapeake Bay, and excess nutrients such as nitrogen and phosphorous from animal manure generated by these facilities are significant contributors of poor water quality and health [11]. Studies in other regions have investigated whether exposure to CAFOs is disproportionately distributed by subpopulation characteristics [12–14]. For example, higher levels of CAFO exposure were observed in communities with higher percentage of Black/African-American populations and low-income populations in NC [9,15]. However, to the best of our knowledge no previous study has investigated the impacts of CAFOs on adverse health outcomes considering disparities in exposure and health associations in PA.

In this study, we examined if maternal residential exposure to CAFOs is associated with adverse birth outcomes including preterm birth and low birth weight in Pennsylvania. We also investigated both disparities in exposure to CAFOs and the association between CAFOs and risk of adverse birth outcomes using individual-level maternal characteristics.

2. Methods

2.1. Data

Individual-level birth records for PA from 2003 to 2020 were obtained from the PA Department of Health. Birth records included maternal and birth characteristics including geocoded residential location (latitude, longitude); mother's age, race/ethnicity, smoking before or during pregnancy, prenatal care, prenatal body mass index (BMI), and marital status; plurality; sex of child; gestational age; and birth weight. We also considered two indicators of socio-economic status: 1) mother's education level, and 2) enrollment in the Special Supplemental Program for Women, Infants, and Children (WIC), which is a nutritional program for low-income persons. We considered two adverse birth outcomes: (1) PTB, defined as the birth of an infant prior to 37 weeks' gestation; and (2) LBW, defined as the birth less than 2,500 g. We excluded births with incomplete data (e.g., birthweight, gestational age, maternal characteristics) (1.6 %) and assigned ZIP code centroid to participants with no geocode information (8.1 %). This study was approved by the Yale University Institutional Review Board (IRB protocol ID: 2000034337) and a waiver of informed consent was granted by the IRB.

To assess CAFOs exposure, we used data on permitted animal facilities from the PA Department of Environmental Protection. This dataset includes information on the operation such as geographic location (i.e., address, ZIP code, county), facility type (e.g., CAFO), facility status (e.g., active), effective date, expiration date, and other ancillary information (e.g., facility name). We geocoded the address of each facility using US Census Geocoder (https://geocoding.geo.census.gov/) as the database has address-level geographic location. For facilities with no exact match, we assigned coordinates of the ZIP code centroid (8.5 %).

To evaluate disparities in exposure to CAFOs and health association, we used maternal characteristics including race/ethnicity (non-Hispanic White, non-Hispanic Black, other), age (<18, 18–35, >35 years), education level (12th grade or less/no diploma, high school graduate or General Education Diploma (GED) completed, some college credit but not a degree, associate/bachelor's degree, master's/doctorate or professional degree, unknown), smoking status before and during pregnancy (yes, no, unknown), WIC status (yes, no, unknown), and urbanicity (urban/rural classification based on population density from US Census Bureau).

2.2. Exposure assessment

To assign exposure to CAFOs for each participant, we calculated the number of CAFOs within 5 km from each participant's residential location. We chose a 5 km buffer based on previous literature review [3,5,8], and conducted sensitivity analysis with alternate buffer sizes (2 km, 10 km). We considered exposure as a binary indicator for the presence or absence of CAFOs and as categories based on level of exposure. Specifically, we assigned CAFOs exposure for each participant based on presence of one or more CAFO within 5 km buffer as the binary indicator (yes/no) and categorized each participant into one of 4 groups based on the number of CAFOs within 5 km from each maternal residence (no exposure, low, medium, and high exposure divided by tertiles) to consider level of exposure. Exposure levels were defined as unexposed (number of CAFOs = 0), low (number of CAFOs = 1), medium (number of CAFOs = 2), and high (number of CAFOs >2) exposure.

2.3. Statistical analysis

We applied multiple logistic regression to estimate the association between exposure to CAFOs and adverse birth outcomes (i.e., preterm birth, low birth weight). Models estimated the odds ratios (ORs) and 95 % confidence intervals (CIs) for each exposure group (i.e., presence of CAFOs, low, medium, and high exposure group) compared to no CAFO exposure group. Models were adjusted for infant's sex, mother's age, mother's race/ethnicity, mother's education, prenatal BMI, prenatal care, smoking status, marital status, plurality, WIC status, and urban/rural indicator. Each birth outcome and characteristic were analyzed separately. We conducted stratified analyses by maternal characteristics and urbanicity and used the Breslow-Day test for homogeneity of odds ratios to evaluate whether the effect of CAFO exposure on preterm birth or low birth weight differs across each characteristic's strata. As a sensitivity analysis, we conducted analysis using different buffer sizes to confirm the robustness of our findings.

In this study, we investigated both disparities in exposure to CAFOs and health associations. We compared the distribution of population characteristics (e.g., racial disparity, socioeconomic disparity) and associated health burden by CAFO exposure level. We considered both disparities in exposure (i.e., whether some subpopulations have higher exposure to CAFOs) and in health response (i.e., whether some subpopulations have a higher health response to CAFO exposure).

We used SAS version 9.4 (SAS Institute, Cary, NC, USA) and ArcGIS Pro 10.6.1 (ESRI, Redlands, CA) for all statistical analyses and mapping.

3. Results

Fig. 1 shows the spatial distribution of CAFOs in PA. There was a total of 461 CAFOs. Most CAFOs were clustered in southeastern part of the state, although some CAFOs were located in middle and northern PA as well.

Table 1 provided descriptive characteristics of the study population by CAFOs exposure level. Of the 2,455,220 births, 9.6 % were preterm births and 8.1 % were low birth weight. Patterns of adverse birth outcomes by CAFO exposure group were slightly different, with lower rates in both outcomes for CAFO exposure group compared to the unexposed group (unexposed vs. CAFO exposure: 9.7 % vs. 8.9 % for PTB, 8.3 % vs. 7.0 % for LBW). The study population had more males than females (51.2 % vs. 48.8 %). Most infants had mothers who were aged 18–35 years (85.8 %), non-Hispanic White (69.1 %), had a high school or higher education (85.7 %), did not smoke before or during pregnancy (79 %), received prenatal care (92.4 %), were married (59.7 %), did not receive WIC (61.7 %), and lived in urban areas (76.4 %). The distribution of most birth and maternal characteristics by CAFOs exposure group were roughly similar except for some characteristics (e.g., mother's race/ethnicity, mother's education). The percentage of non-Hispanic White mothers was higher in the CAFO exposure group than the no CAFO exposure group (83.9 % vs 67.0 %). There were higher percentages of mothers with low education and living in rural areas in the CAFOs exposure group than the no CAFO exposure group.

CAFOs exposure group was based on the presence of CAFOs within a 5 km buffer around residence (CAFO exposure group: one or more CAFOs within a 5 km buffer around residence).

Table 2 shows odds ratios for adverse birth outcomes associated with CAFO exposure. We estimated risks of adverse birth outcomes

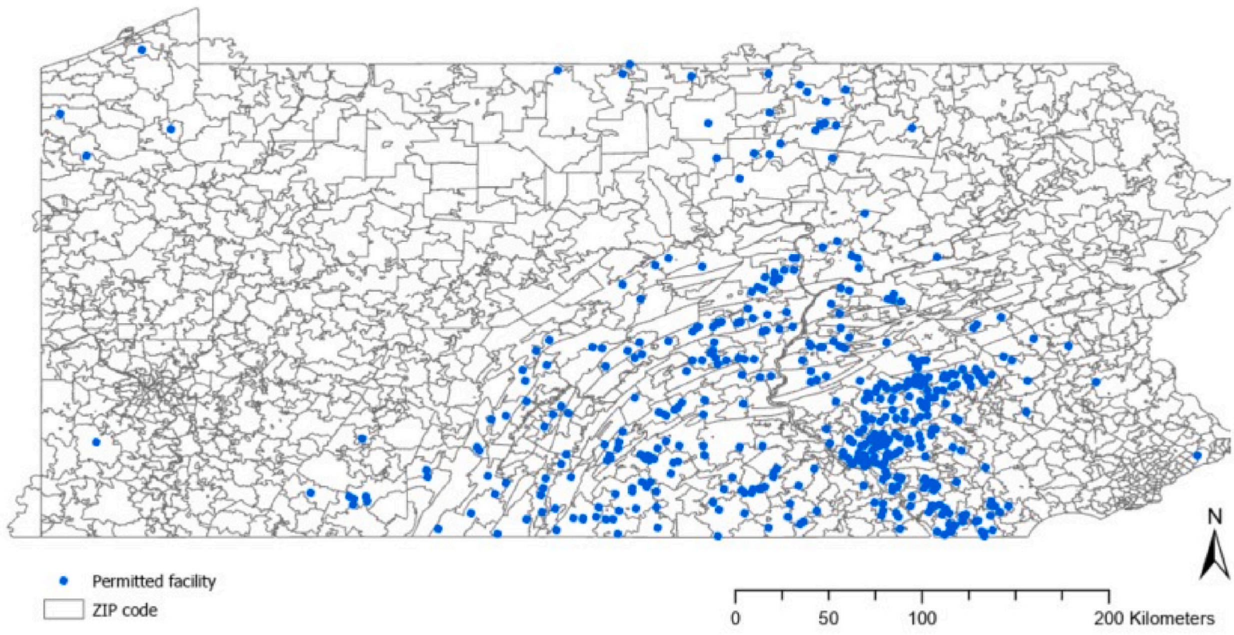

Fig. 1. Location of CAFOs in PA.

Table 1
Characteristics of the study population by CAFOs exposure.

Characteristic	Total (N = 2,455,220)	CAFO exposure	
		No CAFO (N = 2,149,233)	CAFO (N = 305,987)
Birth Characteristics			
Sex of child (# of births (%))			
Male	1,257,149 (51.2)	1,100,018 (51.2)	157,131 (51.4)
Female	1,198,055 (48.8)	1,049,199 (48.8)	148,856 (48.7)
Unknown	16 (0.0)	16 (0.0)	–
Gestational age (weeks) (mean ± SD)	38.6 ± 2.1	38.6 ± 2.1	38.7 ± 2.0
Birth weight (kg) (mean ± SD)	3.3 ± 0.6	3.3 ± 0.6	3.3 ± 0.6
Preterm birth [<37weeks] (%)	235,228 (9.6)	207,866 (9.7)	27,362 (8.9)
Low birth weight [<2,500 g] (%)	199,672 (8.1)	178,274 (8.3)	21,398 (7.0)
Maternal characteristics			
Age (# of births (%))			
<18 years	53,296 (2.2)	48,071 (2.2)	5225 (1.7)
18–35	2,107,207 (85.8)	1,837,938 (85.5)	269,269 (88.0)
>35	294,717 (12.0)	263,224 (12.3)	31,493 (10.3)
Race/Ethnicity (# of births (%))			
Non-Hispanic White	1,697,515 (69.1)	1,440,657 (67.0)	256,858 (83.9)
Non-Hispanic Black	343,840 (14.0)	333,806 (15.5)	10,034 (3.3)
Other	413,865 (16.9)	374,770 (17.4)	39,095 (12.8)
Education			
8th grade or less	82,538 (3.4)	58,330 (2.7)	24,208 (7.9)
9th-12th, no diploma	268,619 (10.9)	230,331 (10.7)	38,288 (12.5)
High school graduate or GED completed	638,433 (26.0)	551,657 (25.7)	86,776 (28.4)
Some college credit, but no degree	431,980 (17.6)	382,402 (17.8)	49,578 (16.2)
Associate degree	208,958 (8.5)	181,554 (8.5)	27,404 (9.0)
Bachelor's degree	498,692 (20.3)	446,066 (20.8)	52,626 (17.2)
Master's degree	242,154 (9.9)	220,954 (10.3)	21,200 (6.9)
Doctorate or professional degree	66,139 (2.7)	61,575 (2.9)	4564 (1.5)
Unknown	17,707 (0.7)	16,364 (0.8)	1343 (0.4)
Smoking before or during pregnancy			
No	1,940,270 (79.0)	1,695,018 (78.9)	245,252 (80.2)
Yes	476,643 (19.4)	418,665 (19.5)	57,978 (19.0)
Unknown	38,307 (1.6)	35,550 (1.7)	2757 (0.9)
Prenatal care			
No	32,876 (1.3)	31,082 (1.5)	1794 (0.6)
Yes	2,268,973 (92.4)	1,977,393 (92.0)	291,580 (95.3)
Unknown	153,371 (6.3)	140,758 (6.6)	12,613 (4.1)
Prenatal BMI	26.2 ± 6.5	26.2 ± 6.5	26.3 ± 6.5
Marital status (# of births (%))			
Married	1,464,986 (59.7)	1,256,162 (58.5)	208,824 (68.3)
Unmarried	986,495 (40.2)	889,657 (41.4)	96,838 (31.7)
Unknown	3739 (0.2)	3414 (0.2)	325 (0.1)
Plurality (# of births (%))			
1	2,369,793 (96.5)	2,073,366 (96.5)	296,427 (96.9)
2	82,316 (3.4)	73,127 (3.4)	9189 (3.0)
3+	3111 (0.1)	2740 (0.1)	371 (0.1)
WIC			
No	1,514,873 (61.7)	1,304,764 (60.7)	210,109 (68.7)
Yes	888,954 (36.2)	797,981 (37.1)	90,973 (29.7)
Unknown	51,393 (2.1)	46,488 (2.2)	4905 (1.6)
Urbanicity			
Urban	1,875,568 (76.4)	1,660,963 (77.3)	214,605 (70.1)
Rural	579,373 (23.6)	488,027 (22.7)	91,346 (29.9)

Note: SD = standard deviation.

(preterm birth, low birth weight) separately based on the presence of one or more CAFO within a 5 km buffer around mother's residence and CAFOs exposure intensity group (low, medium, and high) based on the number of CAFOs with a 5 km buffer around mother's residence. Using the binary exposure indicator, the presence of CAFOs was significantly associated with higher risk of preterm birth, but not low birth weight. Using the categorical exposures, we observed a significantly positive association between preterm birth and all levels of CAFOs exposure compared to no CAFO exposure group. Risk of preterm birth showed an increasing trend with higher levels of CAFOs exposure. Compared to the no CAFO exposure group, the ORs for preterm birth were 1.022 (95 % CI 1.003, 1.043), 1.066 (1.034, 1.100), 1.069 (1.042, 1.097) for low, medium, and high CAFOs exposure groups, respectively. For binary exposure, we conducted sensitivity analysis to confirm the robustness of findings. We found that the results using different buffer sizes (2 km, 10 km) were similar with original findings using a 5 km buffer (Supplemental Table 1).

To investigate the disparity in health response to CAFO exposure, we conducted stratified analyses by each characteristic. The Breslow-Day test showed significant differences in the ORs for PTB across each stratum of mother's race/ethnicity ($p = 0.009$),

Table 2
Odds ratios of preterm birth and low birth weight by CAFOs exposure level.

CAFO exposure	Birth outcomes	
	PTB	LBW
Binary exposure		
No CAFO	Reference	Reference
Presence: Yes	1.044 (1.029, 1.060)	1.001 (0.985, 1.018)
Intensity exposure		
Unexposed	Reference	Reference
Low	1.022 (1.003, 1.043)	0.993 (0.971, 1.015)
Medium	1.066 (1.034, 1.100)	1.019 (0.984, 1.055)
High	1.069 (1.042, 1.097)	1.004 (0.975, 1.034)

Note: CAFOs exposure intensity group (low, medium, high) was based on the number of CAFOs within a 5 km buffer around residence. Exposure levels were defined as unexposed (number of CAFOs = 0), low (number of CAFOs = 1), medium (number of CAFOs = 2), and high (number of CAFOs >2) exposure. Models were adjusted for child's sex, mother's age, mother's race/ethnicity, mother's education, prenatal BMI, prenatal care, smoking, marital status, plurality, WIC status, and urban/rural indicator. Each birth outcome was analyzed separately.

mother's education ($p < 0.0001$), WIC status ($p < 0.0001$), and urbanicity ($p = 0.001$), except for mother's age ($p = 0.247$). Results for LBW were similar, with significant differences across each stratum of mother's race/ethnicity ($p = 0.001$), mother's education ($p < 0.0001$), WIC status ($p < 0.0001$), and urbanicity ($p < 0.0001$), except for mother's age ($p = 0.306$). Table 3 shows the odds ratio for the risk of adverse birth outcomes by maternal characteristics and urbanicity, comparing risk for the CAFO exposure group to the no CAFO exposure group, from each stratified model. CAFO-related risks of preterm birth and low birth weight were both highest in infants with other race/ethnicity mothers. Infants with older mothers (>35 years) had a significantly positive association between CAFO exposure and preterm birth. Infants with mothers with high education (associate/bachelor's degree or higher) had significant positive associations for both preterm birth and low birth weight, while the risks of both outcomes were protective in infants with less educated mothers (12th grade or less, no diploma). The risk was the highest in infants with mothers receiving WIC and higher in infants living in urban areas for both outcomes.

4. Discussion

In this study, we investigated the risk of adverse birth outcomes associated with CAFOs exposure in PA and evaluated disparities in

Table 3
Odds ratios for the risk of preterm birth and low birth weight comparing the CAFOs exposure group to the no exposure group (binary), by maternal characteristics and urbanicity.

Characteristics	Birth outcomes	
	PTB	LBW
Mother's race/ethnicity		
Non-Hispanic White	1.054 (1.036, 1.071)	1.013 (0.994, 1.032)
Non-Hispanic Black	0.998 (0.934, 1.067)	0.902 (0.843, 0.966)
Other	1.081 (1.041, 1.124)	1.042 (1.000, 1.085)
Mother's age		
<18 years	0.995 (0.899, 1.100)	1.011 (0.911, 1.122)
18–35	1.041 (1.024, 1.057)	1.002 (0.984, 1.020)
>35	1.073 (1.029, 1.118)	0.991 (0.944, 1.040)
Mother's education		
12th grade or less, no diploma	0.908 (0.875, 0.941)	0.882 (0.849, 0.917)
High school graduate or GED completed	1.038 (1.011, 1.066)	0.994 (0.966, 1.023)
Some college credit, but not a degree	1.069 (1.033, 1.107)	1.026 (0.987, 1.067)
Associate/bachelor's degree or higher	1.135 (1.108, 1.164)	1.072 (1.041, 1.104)
Unknown	0.898 (0.710, 1.134)	0.988 (0.779, 1.254)
WIC status		
No	1.043 (1.024, 1.062)	0.996 (0.975, 1.018)
Yes	1.081 (1.055, 1.109)	1.037 (1.009, 1.065)
Unknown	1.016 (0.903, 1.143)	0.960 (0.846, 1.090)
Urban/rural		
Urban	1.058 (1.040, 1.076)	1.017 (0.998, 1.038)
Rural	1.008 (0.981, 1.036)	0.974 (0.944, 1.004)

Note: CAFOs exposure group was based on the presence of one or more CAFOs within a 5 km buffer around mother's residence. Models were adjusted for child's sex, mother's age, race/ethnicity, education, prenatal BMI, prenatal care, smoking, marital status, plurality, WIC status, and urban/rural indicator.
Each birth outcome and characteristic were analyzed separately.

exposure to CAFOs and associated health outcomes. We found that presence of CAFOs was associated with higher risk of preterm birth with an increasing trend with higher levels of CAFOs exposure. Higher risk of preterm birth associated with CAFOs exposure was associated with some maternal characteristics such as infants with other race/ethnicity mothers, infants with older mothers, infants with high educated mothers, infants with mothers receiving WIC, and infants living in urban areas. Results for low birth weight were similar with those of preterm birth for some characteristics such as mother's race/ethnicity, education, WIC status, and urbanicity, although some findings were not statistically significant.

Our results provide evidence that maternal exposure to CAFOs is associated with higher risk of preterm birth. Although the metrics to assess maternal exposure to CAFOs were different across studies (e.g., proximity, presence or absence, density of CAFOs), previous studies suggest that residential exposure to CAFOs during pregnancy was positively associated with risk of adverse birth outcomes [8,16,17]. Maternal exposure to CAFOs may contribute to adverse birth outcomes including preterm birth and low birth weight via several pathways such as maternal exposure to air pollution (e.g., $PM_{2.5}$) or water quality. Evidence suggests that maternal exposure to air pollution may be associated with systemic inflammation in placenta and/or maternal/cord blood, intrauterine infection, or oxidative stress, which can lead to endothelial dysfunction and vasoconstriction [4,18]. Other possible mechanisms include increased maternal susceptibility, endocrine disruption, and epigenetic alterations [19].

We found that the CAFOs exposure group had higher percentages of NHW mothers and low educated mothers than the total population or the no CAFO exposure group. Several studies have investigated disparities in relation to CAFOs exposure and reported inconsistent findings. Some studies found that CAFOs were generally located in areas with higher percentages of racial/ethnic minority subpopulations or low SES communities [12,20], whereas other studies observed opposite or mixed findings [13,21]. Our earlier work in NC showed disproportionate siting of CAFOs in areas with high percentages of persons who were NHB, Hispanic, in poverty, and less educated, whereas other work in Iowa and Wisconsin observed that AFOs/CAFOs were less likely to be located in disadvantaged communities [15,22,23], although within communities with CAFOs, some disparities were observed in relation to the intensity of CAFO exposure. Further, our study found suggestive evidence of higher risks of adverse birth outcomes associated with CAFOs exposure for some maternal characteristics such as mothers who were older or received WIC (as a proxy for low SES). Studies evaluating disparities in exposure to CAFOs or health associations in relation to CAFOs exposure are limited, especially for fetal and child health. Mendrinos et al. [8] investigated associations between maternal residential proximity to CAFOs during pregnancy and adverse birth outcomes (PTB, LBW). They found higher percentages of mothers that are Hispanic or supported by Medicaid in the high CAFOs exposure group. Another study examining the association of swine CAFOs with birth weight found that mothers in the exposed group were generally younger, more likely to be Hispanic, and less educated [16]. In addition to disparities in the level of exposures, there may exist disparities in health response associated with CAFOs exposure (i.e., the response to a given increment of exposure). Further studies considering disparities in both exposure and health association are needed to better understand complex disparity patterns related to CAFOs exposure. Different findings across locations may result from heterogeneity in population characteristics, exposure assessment and methodologies, characteristics of CAFOs (e.g., type of animal), and intersectionality (e.g., racial/ethnic minority and low SES). Thus, more studies on different populations and locations are needed to better understand the complexities in disparity patterns.

Our study has several limitations. We assigned the ZIP code centroids for the facilities that were not exactly matched or participants with no geocode information so exposure misclassification may exist. Although our analysis included several confounding factors in the model, there may exist residual confounding from unmeasured covariates or exposure assessment. For example, we could not consider maternal mobility during pregnancy due to data availability. Assessing accurate CAFOs exposure is challenging due to complexities of multi-faceted CAFOs exposure. To better capture complex CAFO exposure, accurate exposure assessment or more refined exposure methods are needed to disentangle pathways of effects such as through air pollution, water quality, or odor. While we confirmed the robustness of our findings using various buffer sizes, different buffer sizes in CAFO exposure assessment may not accurately reflect actual exposure level due to variations in air quality, water quality, and people's activity patterns. No single buffer size may most accurately reflect the various pathways through which CAFOs impact health, and future work is needed with more detailed exposure methodologies. Although we considered several variables related to environmental justice and potentially vulnerable populations, some factors (e.g., maternal education as an indicator of SES) may not fully reflect true effect. As no single variable can fully represent the complex features of environmental justice, further studies using a wide range of variables are needed to better understand the various ways in which CAFOs may impact disadvantaged communities.

Our findings add to a growing body of literature on health outcomes associated with CAFOs exposure, suggesting that presence of CAFOs increases risk of preterm birth. Our results also suggest that some maternal characteristics may be associated with higher risk of CAFO-associated preterm birth or low birth weight. This study can inform future studies on disparities in exposure and health burden associated with CAFOs exposure.

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Ethics statement

This study was approved by the Yale University Institutional Review Board (IRB protocol ID: 2000034337) and a waiver of informed consent was granted by the IRB.

Data availability statement

The authors do not have permission to share data.

CRediT authorship contribution statement

Ji-Young Son: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Michelle L. Bell:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e34985.

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