HOG AND POULTRY CAFOS IN NC AND GEOSPATIAL ASSOCIATIONS WITH INFANT BIRTH OUTCOMES

by

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Executive Summary

Concentrated animal feeding operation (CAFO) facilities can emit air- and water-borne contaminants to adjacent environments. Recently there has been increasing concern that these facilities may cause adverse health effects in nearby neighborhoods and residents. North Carolina has a large number of CAFOs, with more than 2000 swine and 4000 poultry facilities state-wide. This study sought to determine whether proximity to CAFOs within NC was associated with adverse health outcomes in families, with a particular focus on birth outcomes. Low birth weight and preterm birth are both risk factors for chronic diseases later in life. Using individual-level birth certificate data (NC Department of Vital Statistics), the NC swine CAFO permit data (NC Department of Environmental Quality), and the NC poultry CAFO locations (Environmental Working Group), this study investigated associations between CAFO size and distance to residence with birth outcomes, and specifically gestational age and infant birth weight. Two models were constructed, one using distance to the nearest CAFO and the second model using kernel density layers; both models were adjusted for potential confounding variables (e.g. maternal race, education, age, etc.) and stratified by infant sex. Results suggest that mothers living within 2 – 5 mi of a poultry CAFOs were 1.13 and 1.14 ($p<0.01$) times as likely to deliver preterm or low birth weight (LBW) infants, respectively, compared to those living greater than 5 mi from a CAFO. On average, infants (both sexes) born in households within 1 mi, 1 – 2 mi, and 2 – 5 mi radius from a poultry CAFO were born 0.1, 0.08, and 0.09 weeks earlier than those living farther away ($p < 0.001$). Models using the more sophisticated kernel density approach suggest that the number and size of adjacent hogs CAFOs may influence these outcomes. Although the magnitude of these effects was small, these findings suggest distance to poultry

CAFOs may be a risk factor for preterm birth in NC, and interestingly, these effects may be sex-specific.

Introduction

Concentrated animal feeding operation (CAFO) facilities are major sources of meat and dairy products that sustain the US food supply. More than six thousand CAFO facilities are spread across North Carolina, most of which are predominantly hog and poultry CAFOs (1,922 hog and 3,968 poultry CAFOs included in this study). Within NC, most of the two thousand hog CAFOs cluster in the southeastern region of the state, while the four thousand poultry CAFOs are distributed more widely across the entire state.[1,2] However, both hog and poultry CAFOs can potentially lead to environmental contamination in adjacent environments and increase concerns for health impacts on local communities. Due to both historic and socioeconomic reasons, African American and Latino populations are disproportionally exposed to contaminants associated with hog CAFOs.[3]

Both hog and poultry farms can release and airborne environmental contaminants, including but not limited to nitrogen oxide, hydrogen sulfide, methane, ammonia, carbon monoxide, particulate matter, and other odorous chemicals. Atmospheric concentrations of these airborne contaminants at CAFO facilities can be around two orders of magnitude higher than background levels.[4] And most research suggests that airborne contaminants and odor from one hog CAFO can influence communities as far away as 5 mi from a facility, although certain atmospheric conditions (e.g. wind speed) may carry these contaminants further away.[3–5]

Surface runoff can facilitate the transport of nutrients and multiple endocrine disrupting chemicals (EDCs) to local waters, posing risks for both aquatic ecosystems and public health. In southeastern NC, surface runoff from both CAFO sites and spray fields that apply animal manure is the biggest source of EDCs in southeastern NC.[6] EDCs from CAFO facilities typically include natural and synthetic hormones (both estrogenic and androgenic) but can also include antimicrobial chemicals. While natural hormones naturally exist in animal manure, artificial steroids and antimicrobial chemicals are applied to promote growth of animals and disinfect facilities. Some of these chemicals include 17β-estradiol (E2), trenbolone, and triclocarban, etc. In general, estrogenic chemicals are more frequently reported than androgenic chemicals in animal manure.[7,8]

Previous epidemiological studies have associated exposure to CAFOs with a wide range of health effects, including respiratory diseases (asthma, chronic obstructive lung diseases, and chronic bronchitis), allergies, infectious diseases, and anxiety. [9–11] Anemia, respiratory disease, and infectious diseases, as discussed in a recent study by Kravchenko et al., are significant risk factors for adverse birth outcomes such as preterm birth and low birth weight. The same study found a positive correlation between the density of hog farms in a zip code and multiple adverse health outcomes. For example, they found that living in zip codes with more than 215 hogs/km^2 was associated with an 8%, 30%, and 39% increase in odds of an emergency department visit due to kidney disease, tuberculosis, and health conditions in low birth weight infants, respectively.[9] Therefore, adverse birth outcomes such as preterm birth and low birth weight may be associated with proximity to CAFOs in North Carolina.

Nationwide, preterm birth and low birth weight, occurring in approximately 8-10% of US infants in 2016, has been a significant health concern.[12] Infants born preterm or with low birth weight are at greater risk for adverse health outcomes later in life including respiratory problems, diabetes, obesity and neurodevelopmental outcomes.[13] The potential impact of CAFOs on birth outcomes in NC communities is therefore worth further investigation to fully understand potential health risks.

While most previous studies conducted in North Carolina focus on hog farms, only a very limited number of studies have focused on adverse health effects associated with proximity to poultry farms.[2] This gap in our understanding is worth noting given that poultry farms have been associated with allergenic fungi in poultry dust, estrogens, particulate matter, and gaseous contaminants.[11] At the same time, there are more than two times more poultry CAFOs than hog CAFOs. Statewide, distribution of poultry CAFOs is also more widespread than that of their hog counterparts.[2,14]

Objectives and Hypothesis

With such a large number of both hog and poultry CAFOs, North Carolina is an ideal state to investigate the potential associations between CAFOs and health outcomes. This study sought to examine the geospatial associations between hog and poultry CAFOs (including number of animals and number of farms) and birth outcomes (preterm birth and low birth weight) at the individual household level. This study hypothesized that 1) preterm birth (PTB) and low birth weight (LBW) are positively associated with proximity to both hog and poultry CAFOs, and 2) CAFO density, proximity to CAFOs, and the number and size of animals in CAFOs are positively associated with PTB and LBW in households nearby.

Methods

This study includes birth outcome data collected from births occurring in NC in 2016. Birth outcome data were obtained from birth certificates from the North Carolina Department of Vital Statistics. The dataset included information on the birthweight and gestational age of each baby born in North Carolina, as well as geocoded address (including longitude and latitude) of each household at the time of birth. In addition, the dataset also includes the following variables: plurality (e.g. singleton or twins), baby's length, mother's body mass index (BMI), alcohol use, tobacco use, race, ethnicity, education background, and mother's age. All protocols used in this study were approved by Duke University's Institutional Review Board prior to study initiation.

Information on hog and poultry CAFO facilities were collected from two sources. The hog CAFO dataset was obtained from the Permitted Animals Facilities in NC, a dataset managed by the North Carolina Department of Environmental Quality (DEQ) (n = 1,922 CAFOs). The poultry CAFO dataset was obtained from the Environmental Working Group (EWG) (n = 3,987 CAFOs).[2,14] Both datasets include allowable animal counts, date of issuance, growth stage of animals at a facility, amount of waste produced, and geocoded location of the CAFO (longitude and latitude). Figure 1 includes a map of all the permitted hog and poultry farms in the state of NC.

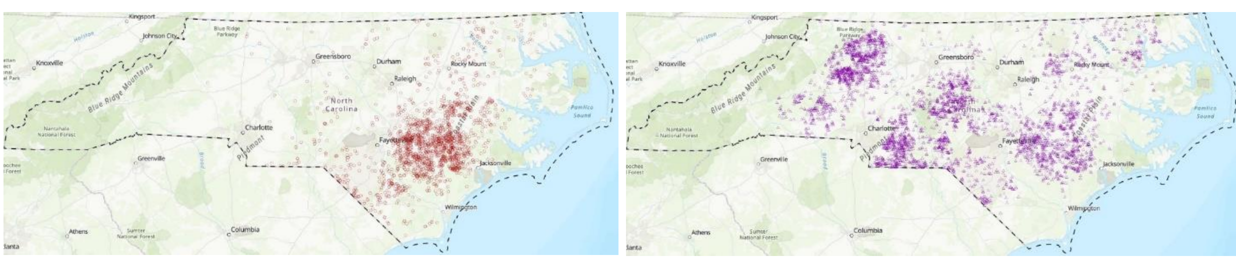

Fig.1 Distribution of hog (red, left) and poultry (purple, right) CAFO facilities in North Carolina. (Sources: maps developed using ESRI ArcGIS Pro and data provided by the DEQ and EWG.)

Geospatial Models

Two different models were established to estimate the relative impact of CAFO facilities on birth outcomes, a distance model and a kernel density model. The distance model was constructed with the Buffer tool of ArcGIS Pro program. Two NC maps were developed based on distribution of hog and poultry CAFOs, respectively. In one map, the entire North Carolina area was categorized into four regions: within 1 mi, 1 – 2 mi, 2 – 5 mi, and beyond 5 mi from the nearest hog CAFO. The other map categorized the same distance zones based on poultry CAFOs (Fig.2).

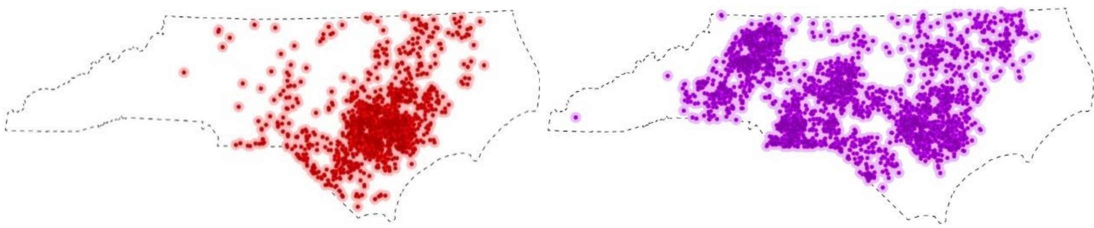

Fig.2. Areas within 1 mi, 1 – 2 mi, 2 – 5 mi, and > 5 mi from a hog (left) or poultry (right) CAFO in North Carolina, from dark to light color.

The kernel density analysis was restricted to babies born in households within 5 mi from at least one CAFO facility. This model used the Kernel Density tool (ArcGIS Pro) to estimate relative impact of CAFOs on a certain location. Again, two different map layers were created based on poultry and hog facilities. The Kernel Density tool assumes a stationary dispersion function that describes a decline of relative impact of a CAFO from a central population value (at the location of a CAFO facility), as distance increases. For hog CAFOs, the population values were calculated by multiplying number of hogs and a coefficient that reflects growth stage of hogs in the facility. The reference coefficients for hog farms were determined by the NC DEQ based on average weight of animals in certain growth stages (Table 1). The reference coefficients for poultry CAFOs were average waste per bird per year on the farm. Multiplying animal count and animal weight (or waste) is a method used in previous research.[15]

Table 1. Relative weight coefficients for swine at different growth stage. Coefficient values are obtained from NC DEQ.

Swine Growth Stage	Relative Weight Coefficient
Wean-feeder	30
Wean-finish	135
Feeder-finish	135
Boar-stud	400
Farrow-wean	433
Farrow-feeder	522
Farrow-finish	1417

Each household location is assigned a kernel density score that reflects relative cumulative impact of CAFOs near the location. The scores of the hog layer ranged 0 - 4846 in the hog kernel density layer and that of the poultry layer ranged 0 – 2925. All households living beyond 5 mi from CAFO facilities had a value of zero, and were excluded from the kernel density analyses. For statistical analysis, the natural logarithm of all kernel density scores was taken to normalize distribution of the scores.

Fig.3. The kernel density layers of relative influence of hog (left) and poultry (right) CAFOs. Darker color represents stronger influence.

Statistical analyses

Gestational age and birth weight were predicted by distance zones and kernel density scores, respectively. Both logistic linear regression and continuous generalized linear regression models were used in this study. Distance categories were used to predict 1) odds ratios for preterm birth and low birth weight (logistic regression models) and 2) change in gestational age and birth weight (continuous generalized linear models). Preterm birth (PTB) was defined as < 37 complete weeks gestational age and low birth weight (LBW) was defined as < 2,500 g birth weight. All singletons born in NC in 2016 were included in the analyses (n = 111,068). Kernel density scores (natural log transformed) were used to predict odds for preterm birth and low birth weight (logistic regression models). The following variables were included as confounding variables based on our expectation of their association with birth outcomes: infant sex, maternal age, education, smoking history, race, Kotelchuck prenatal care index, and pre-pregnancy body mass index (Table 2). After testing models that included both sexes (sex used as a confounding variable), sex-specific analyses were repeated. Analyses by sex provided insights into potential sex-specific effects of CAFOs. Results were considered statistical significance where $p < 0.05$.

Results

All singletons born in NC in 2016 are included in this study (n=111,068). Population demographics and information on the co-variates included in the regression models are described in Table 2.

Table 2. Demography of the population and confounding variables used in this study (n = 111,068).

Scale	N	%
Infant sex		
Male	57,080	51.4
Female	53,988	48.6
Marital status		
Married	66,200	59.6
Not Married	44,868	40.4
Smoke before and during pregnancy		
Yes	14,016	12.6
No	97,052	87.4
Mother's education		
High school or below	41,114	37.0
Some college education	35,537	32.0
Bachelor's degree	22,333	20.1
Graduate degree	12,084	10.9
Mother's race		
Non-Hispanic black	26,080	23.5
Hispanic	16,801	15.1
Other	6,580	5.9
Non-Hispanic white	61,607	55.5
Mother's prenatal care	(Classified from Kotelchuck prenatal care index)	
Inadequate	20,233	18.2
Intermediate	6,524	5.9
Adequate	30,260	27.2
Adequate plus	54,051	48.7
Mother's BMI (median and IQR)	25.5	(22.0-30.6)
Mother's age years (median and IQR)	28	(24-32)

Distance Models

Logistic regression models were run for hog and poultry farms together, and all births occurring more than 5 miles away from a CAFO were used as the reference population when estimating the Odds Ratios. Compared to infants born more than 5 mi from a poultry CAFO, infants born within 2 – 5 mi from at least one poultry CAFO had a 7.8% higher odds (p<0.01) of being born preterm (e.g. <37 weeks), while infants born less than 1 mile away had a 2.9% higher odds that was not statistically significant. In stratified analyses, females had a 12.7% higher odds for preterm birth (p < 0.01) if they lived 2-5 mi from a poultry CAFO, while results in male infants were null. There were no statistically significant associations observed between distance to a hog CAFO and preterm birth (Table 3).

Infants born to families living either < 1 mi, or 2 – 5 mi from a poultry CAFO had 12.4% and 9.3% higher odds (p<0.05), respectively for low birth weight (<2,500 g). Among these infants, females had 16.0% and 13.6% higher odds for low birth weight (p < 0.01) if they lived <1 mi or 2-5 mi from a poultry CAFO, respectively. Odds ratios for low birth weight were greater than 1.0 but not statistically significant for male infants. There were no statistically significant associations observed between distance to a hog CAFO and low birth weight (Table 3).

Table 3. Odds ratios of preterm birth and low birth weight (LBW) in households 1, 2, and 5 mi away from the nearest CAFO, compared to those outside of the 5 mi radius. Models adjusted for the following co-variates: mother's age, prenatal BMI, Kotelchuck prenatal care index, maternal race, maternal education, smoking history, and marital status.

		Hog			Poultry		
		1 mi	2 mi	5 mi	1 mi	2 mi	5 mi
Preterm Birth	All infants	1.00	1.09	0.96	1.03	1.00	**1.08****
	Male	1.12	1.07	1.01	1.03	1.01	1.04
	Female	0.86	1.11	0.91	1.03	0.99	**1.13****
Low Birth Weight	All infants	0.90	0.98	0.94	**1.12***	1.07	**1.09****
	Male	0.98	0.92	0.97	1.08	1.05	1.05
	Female	0.84	1.03	0.91	**1.16***	1.09	**1.14****

Note: * p < 0.05, ** p < 0.01

Linear regression models were also conducted to examine changes in continuous gestational age and birth weight with proximity to a hog or poultry CAFO. Both female and male infants born within 5 mi from a poultry CAFO were born approximately 0.07 – 0.11 weeks earlier (or 0.5 – 0.8 days earlier), on average, compared to those born more than 5 mi from a poultry CAFO ($p < 0.05$). Females born within 2 – 5 mi from a poultry CAFO were born 0.015 kg (15 g) lighter, on average, than females born more than 5 miles from a CAFO. There were no clear spatial trends in gestational age or birth weight among the different distance categories examined within this study (i.e. within the 5 mi zone). However, both females and males born 2 – 5 mi from a hog CAFO were about 0.15 kg (15 g) heavier ($p<0.05$) than those born > 5 mi away (Table 4).

Table 4. Average changes in gestational age (weeks) and birth weight (kg) in households 1, 2, and 5 mi away from the nearest CAFO, compared to those outside of the 5 mi radius. Models adjusted for the following co-variates: mother's age, prenatal BMI, Kotelchuck prenatal care index, maternal race, maternal education, smoking history, and marital status.

		Hog			Poultry		
		1 mi	2 mi	5 mi	1 mi	2 mi	5 mi
Gestational Age (weeks)	All infants	0.051	-0.016	0.028	**-0.100***	**-0.078**	**-0.086***
	Male	-0.023	-0.001	0.029	**-0.109**	**-0.086**	**-0.077***
	Female	**0.129***	-0.032	0.028	**-0.089***	**-0.070***	**-0.095***
Birth Weight (kg)	All infants	0.018	0.005	**0.015**	**-0.016***	-0.008	**-0.012**
	Male	0.011	0.004	**0.015***	-0.015	-0.015	-0.010
	Female	0.025	0.005	**0.016***	-0.017	-0.001	**-0.015***

Note: * p < 0.05, ** p < 0.01, *** p < 0.001

Kernel Density Models

An alternate model (kernel density model) was also run to examine impacts on birth outcomes based on the density of the farms and potential interactions between hog and poultry farms. Increases in hog kernel density scores (a reflection of the accumulative impact from CAFOs nearby) by 1 natural log unit was associated with a 6.6% higher odds for preterm birth among female infants born within 5 mi from a hog CAFO (Table 5). These kernel density scores were not statistically significant for low birth weight. However, increase in poultry kernel density scores by 1 natural log unit was associated with a 5.9% decrease in odds for preterm birth among female infants born within 5 mi from a poultry CAFO ($p < 0.05$).

Table 5. Change in odds ratios of preterm birth and low birth weight (LBW) per natural log unit change in Kernel Density scores. Models adjusted for the following co-variates: mother's age, prenatal BMI, Kotelchuck prenatal care index, maternal race, maternal education, smoking history, and marital status.

		Hog	Poultry
Preterm Birth	All infants	**1.047***	0.967
	Male	1.030	0.993
	Female	**1.066***	**0.941***
Low Birth Weight	All infants	1.024	0.980
	Male	1.041	0.964
	Female	1.008	0.995

Note: * $p < 0.05$

Discussion

Birth outcomes and distance to CAFOs

Overall, this study found that proximity to poultry CAFOs was positively associated with increased odds for preterm birth and low birth weight among infants although results varied depending on the infant's sex and the distance to farms and the method used to evaluate spatial impacts (i.e. the kernel density approach vs. a simple distance approach). Females born 2 – 5 mi from a poultry CAFO had higher odds for preterm birth and low birth weight. Because gestational age and birth weight are intimately intertwined (e.g. babies born early are often of lower birth weight), the increased odds of low birth weight is likely a reflection of the shorter average gestational age. Results from the continuous linear regression model found that all infants born within 5 mi from a poultry CAFO tend to be born 0.07 to 0.1 weeks earlier, which translates to approximately 0.5 – 0.8 days early. Although a change in gestational age of less than one day may have limited clinical significance, the observed shift for a large population may still be significant, and suggests that there could be more preterm births at the population level.

Households with higher hog kernel density scores had higher odds for preterm birth. Kernel density scores are calculated from the number and size of animals from facilities nearby, proximity to CAFOs, and the density of CAFO facilities within a 5 mi radius. Overall, higher kernel density scores suggest dense distributions of large CAFOs. The result suggests that within 5 mi, proximity, size, and density of hog CAFOs are positively associated with preterm birth.

However, contrary to the initial hypothesis, households with higher poultry kernel density scores were found to have lower odds for preterm birth, which was in contrast to the logistic and continuous regression models performed. Kernel density analyses were only performed on households living within 5 mi from at least one CAFO facility, and therefore included a much smaller population for the statistical analyses (i.e. kernel models did not include populations living >5 miles from a CAFO). This finding suggests that proximity to a poultry CAFO within a 5 mi zone may not be significantly different, but when comparing to populations living > 5 mi from a CAFO there is a significant difference. It may be speculated that residents within 5 mi from poultry CAFO are exposed to contaminants through non-distance-related pathways, such as occupational exposure or municipal water. For example, if residents living within 5 mi from a CAFO have the same probability of sharing the same contaminated water source or work at CAFO facilities, effects of waterborne contaminants and occupational exposures may blur the spatial trend within the 5 mi radius. To verify the hypothesis, more research and analyses of data that includes measurements of contaminants in municipal water sources and job information of local residents are needed.

Some studies have found that contaminant concentrations can vary spatially with distance to CAFOs, and these contaminants may be contributing to adverse health outcomes. For example, a modelling study investigating emissions from poultry CAFOs in Poland suggests that atmospheric concentrations of hazardous gas and particulate matter decreases to background level 3 – 5 km (1.6 – 3 mi) away from poultry CAFOs, while the concentration can be an order of magnitude higher than the background level at the location of the CAFO facility[4]. However, other studies also suggest that, under certain weather conditions, contaminants and odors from CAFO facilities can travel more than 5 mi from a CAFO facility. While odorous chemicals may not directly incur significant adverse health effects, simply being influenced by odor can lead to increased anxiety, which can lead to stress, which is itself, a risk for adverse health outcomes over the long term.[16]

Maternal health is a significant predictor for adverse birth outcomes such as preterm birth and low birth weight. Therefore, it is possible that maternal exposure to airborne contaminants leads to adverse maternal health, which indirectly increases odds for preterm birth and low birth weight. Studies have found that residential exposure to microbial endotoxins, particulate matter, hydrogen sulfide, and nitrate exposure from CAFOs were all associated with higher risk of respiratory disease and anemia.[9,17] Both respiratory diseases (i.e. asthma) and anemia are significant risk factors for adverse birth outcomes.[18] For example, in a cross-sectional study from the UK, maternal asthma increased odds for preterm birth by 50%.[19] However, it is difficult to accurately quantify CAFO-related exposures and relate these exposures directly to health outcomes[17]. Obtaining maternal health data in NC community may help verify the hypothesis in further studies.

Within 5 mi, a clear relationship between birth outcomes and proximity to CAFOs was not observed for poultry CAFOs. It was initially hypothesized that proximity to CAFO was positively associated with adverse birth outcomes, and presumably, this would be linear with distance to the farm. The lack of expected pattern within 5 mi may suggest other variables are influencing birth outcomes, such as other types of exposures. For example, within a certain area, differences in distance may be meaningless if contaminants are waterborne and well distributed.[20] Multiple neighboring communities usually share the same water source, exposing multiple communities to the same contaminant levels. More than a half of CAFOs in NC are located within 500 m of a stream.[20] Therefore, contaminant discharge via surface runoff or flooding events may be a significant source of exposure for local residents.

Location of spray fields and occupational exposures may be additional factors influencing the results.[21] Animal manure is often sprayed on agricultural lands (known as spray fields) to recover nutrients. These areas, after CAFO sites, are another major source of contaminants from surface runoff, such as estrogenic chemicals. The amount of surface runoff from spray fields is related to the amount of manure applied, magnitude of rainfall, and terrace of the area.[22] Due to a lack of information on spray field numbers and locations, spray fields were not considered in the models in these analyses. Residents within 5 mi of a CAFO may have relatively similar chance of being exposed to contaminants from spray fields or working in a CAFO, and thus have similar exposure levels. This could result in exposure misclassification in the analyses herein and may have obscured trends related to proximity to CAFOs.

Sex-specific effects of CAFOs

Most associations between CAFOs and adverse birth outcomes were observed among female infants, while outcomes in male infants were typically nonsignificant. The possible sex-specific effects of CAFOs may be related to exposure to endocrine disruptors such as artificial hormones or antimicrobials applied in CAFOs that impact fetal development. A study by Orlando et al. on a cattle CAFO suggests that effluent from the facility contains complex mixtures of androgenic and estrogenic hormones that potentially alter the hypothalamic–pituitary–gonadal axis in fathead minnows. The research group concluded that the effluent may have sex-specific reproductive toxicity.[23] Another study found that exposure to cattle CAFO effluent contains primarily estrogen (approximately 1 pM E2 equivalence).[24] Previous studies indicate that that total estrogen level in hog and poultry waste range between 1,000 – 20,000 ng/L and 1,000 – 4,000 ng/L, respectively, which is two to three orders of magnitude higher than those found in cattle manure.[24,25] Therefore, the environment around poultry and hog CAFOs is likely to have higher estrogen levels which could have public health implications. While a large number of estrogenic chemicals exists in hog farms, a study involving 22 EDCs in a hog CAFO from southern Taiwan found that estrone contributes about 50% of total estrogenic activity caused by all EDCs.[7] More research is needed to understand the relative impacts of these synthetic hormones and their impact on fetal growth and development.

Limitations and future studies

This research should be interpreted within the context of several important limitations. The kernel density model assumes even dispersion of airborne contaminants within the 5 mi radius used in this study. Incorporating wind velocity and direction would allow more accurate modelling of household levels of exposure via inhalation. And, as discussed above, considering the locations of spray fields, community water sources, and occupational exposures may also enhance robustness and accuracy of the models. In addition, having individual measures of exposure to CAFOS, for example, air or water monitoring data may provide further insights.

This research study only examined birth outcomes in 2016. In future studies, birth outcome data from other years should be assessed using the same model to determine if similar trends are observed. Comparing results from different years would allow us to evaluate the observed patterns overtime. The sex-specific effects on birth outcomes, particularly preterm birth, if observed in other years, would be a noteworthy finding.

Conclusion

Overall, this study found that density of hog CAFOs and proximity to poultry CAFOs were statistically significant predictors of birth outcomes. Female infants born 2 – 5 mi from a poultry CAFO has elevated odds of preterm birth and low birth weight, suggesting that exposures from CAFOs may have sex-specific effects on birth outcomes. The lack of statistically significant trend within the 5 mi zone may suggest that atmospheric dispersion may not be the only exposure pathway for local residents. It is speculated that NC communities near CAFOs may be exposed to contaminants through different media and pathways, including air, water, and occupational exposure. A more comprehensive study will be needed to identify locations of drinking water sources, incorporate wind velocity and direction, and distinguish between occupational exposures and residential exposures.

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