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Examining the Relationship Between Low Birth Weight Occurrence and Passive Measures of Environmental Arsenic by Census Tract in Escambia and Santa Rosa Counties, Florida

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ABSTRACT: Arsenic is a public health concern because of its widespread distribution and high toxicity, even when doses are small. Low birth weight (LBW) occurrence, birth weights less than 2500g, may be associated with prenatal exposure of arsenic from environmental factors and consuming contaminated drinking water and food. The objective of this study was to examine whether mothers living in areas of Escambia and Santa Rosa counties with varying levels of background arsenic in surface soil and water were associated with the occurrence of LBW. Inverse distance weight in ArcGIS was used to interpolate arsenic concentrations from environmental samples and estimate arsenic concentrations by census tracts in the two counties. After excluding multiple births and displaced geocoding addresses, birth data were obtained for the years of 2005 (n=5845), 2010 (n=5569), and 2015 (n=5770) from the Bureau of Vital Statistics at the Florida Department of Health to assess temporal differences. Generalized linear models were used to analyze and compare the association between child and maternal demographic information, socioeconomic characteristics, and the environmental estimates of arsenic with LBW. No significant association was found between environmental arsenic concentration and LBW, suggesting that environmental contamination of the pregnant mother's census tract may not be a useful proxy in assessing risk for LBW.

KEYWORDS: Pregnancy, arsenic, smoking, low birth weight, environmental health

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Introduction

Chronic exposure to arsenic during pregnancy can affect fetal growth and development, leading to low birth weight (LBW) and other adverse birth outcomes.^{1–3} LBW infants, infants whose birth weights are less than 2500g, are at risk for many developmental complications, and arsenic exposure during pregnancy increases this risk.^{4,5} Arsenic exposure in infants may result from placental transfer of arsenic concentrations from mother to child.⁶ Concerns have been raised that pregnant women living in areas with high arsenic levels in soil and drinking water may have increased risk for LBW. Chronic exposure to arsenic during pregnancy has been found to increase the likelihood of stillbirth and neonatal deaths.⁷ Arsenic exposure could eventually lead to stunted growth in young children.⁸ Humans are exposed to arsenic through ingestion, inhalation, and dermal contact from contaminated sources.⁹ A common cause of arsenic exposure among pregnant women is the ingestion of arsenic-contaminated foods and lifestyle choices, including firsthand or secondhand tobacco smoke.^{1,10,11}

In this study, the relationship between residence in areas suspected to have higher environmental arsenic levels in private drinking wells and soil and LBW was investigated. In a previous study, it was found that individual counties in the state of Florida, including Escambia and Santa Rosa, had high distributions of arsenic in the environment from both natural and anthropogenic

sources.¹² As part of a United States Environmental Protection Agency (USEPA) program to assess pollution and community health in Escambia and Santa Rosa counties, surface soil samples were collected from 126 sites with test results identifying arsenic levels that ranged from 0.13 to 14.0mg/kg, with a mean of 1.38.¹³ Although generally low, 33 of those sites exceeded Florida's residential soil cleanup target level of 2.1 mg/kg. Arsenic concentrations from private drinking wells in the two counties have been recorded by the Florida Department of Health and Department of Environmental Protection. For this study, the relationship between environmental arsenic proximity and LBW was investigated. The objective of this study was to examine whether mothers in Escambia and Santa Rosa counties living in areas with higher levels of background arsenic in surface soil and water were at a higher risk for delivering a newborn with LBW.

Material and Methods

Ethics review and consent

The study was approved by the Florida Department of Health Institutional Review Board Committee on July 12, 2018 (Florida Department of Health [FDOH] IRB Study # 2018012). This study was approved by the University of Illinois Urbana-Champaign Institution Review Board Committee on November 29, 2017 (IRB Study #18359). Due to the nature of



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the data, informed consent from the mothers was not deemed necessary and was waived by both Institutional Review Board committees.

Data sources

Birth data. The study areas of interest were Escambia and Santa Rosa County in the Florida Panhandle. Both areas are predominantly rural, with the largest principal city being Pensacola. To measure LBW, we obtained data on birth weight, child and maternal demographic information, and residential location data from the Bureau of Vital Statistics at the Florida Department of Health. Only singleton births were used for our study, meaning records with multiple births were excluded from the study. The data sets included infant information, such as a birth month, birth year, gestational age, sex, birth weight, plurality, and birth facility. Parental information, such as mother and father's age, residential address, race, and ethnicity, were also included in the data set. Data that account for social and lifestyle characteristics, such as Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) program enrollment, tobacco use during pregnancy, and alcohol use, were also included in the data set.

Surface soil and private well data. One hundred and sixty-five surface soil samples were used for this study (Escambia County, $n=104$; Santa Rosa County, $n=61$). One hundred and seven surface soil arsenic concentrations were compiled from multiple sites around Escambia and Santa Rosa Counties using secondary data from previous studies.¹³ The sampling tool in ArcGIS was used to identify additional sampling points by borrowing the strength from known sampling sites, allowing better estimation of arsenic concentrations at previously unsampled sites. From this method, an additional 58 sites were sampled, 41 in Escambia County and 17 in Santa Rosa County. At each location, 8 to 10 soil cores from the surface layer (0–10 cm) were collected using a soil auger. These cores were homogenized and placed in a sterilized bag for storage. After the samples were collected, 250 g of the soil from each site was processed and shipped to Waypoint Analytics (Champaign, IL) for total arsenic analysis. For our study, we also focused on private drinking well arsenic concentrations in Escambia and Santa Rosa counties. Water contamination data were obtained from the Florida Department of Environmental Protection (FDEP). Our data set contained 50 wells that were classified as private wells that are classified for domestic use. These private wells were sampled and tested multiple times between 1991 and 2018 to monitor arsenic concentrations changes over time. The soil and water arsenic concentrations were highly skewed, so log-transformation was used for this study.

Spatial analysis

Residential address geocoding. Residential addresses for the mothers were provided as part of the vital statistics data set and

geocoded using the geocoding toolbox in ArcGIS. To geocode, full addresses were submitted to the ArcOnline World Geocoding Service through ArcGIS. Births that occurred in Escambia and Santa Rosa Counties for which the mother resided in other counties were excluded from the study as we had no way to account for how long they have been in either of the two counties.

Spatial interpolation of environmental data. For this study, spatial interpolation techniques were used to estimate arsenic concentrations in surface soil and private well data, respectively. Inverse distance weight (IDW) was used in ArcGIS to interpolate arsenic concentrations from soil samples and predict arsenic concentrations with the assumption that each measured sampling point was influenced by the distance between points, meaning points that are closer together have a stronger weight than points further away. A separate IDW was performed to predict the estimate of arsenic concentrations from private well data. Private well IDW were only assessed for census tracts that contained private wells. Census tracts with no private wells present were not included in the interpolation. The results of the IDW interpolation were depicted as a GIS raster grid, which was used to calculate the zonal statistics (mean of the arsenic concentrations) by census tract.

These zonal statistics were then spatially joined to the census tract shapefiles by adding mean soil and private well arsenic concentrations to the census tract shapefile data, respectively. The same mean soil and private well arsenic concentration estimations were used for all 3 data sets: 2005, 2010, and 2015. The mean environmental arsenic concentrations from both the soil and private wells were spatially joined to the geocoded birth data for Escambia and Santa Rosa counties at the census tract level. The final data sets consisted of point data for each birth, along with covariates, and mean private well and surface soil arsenic estimation for each of the three years.

Statistical analysis

Generalized linear models (GLMs) were used to estimate the relationship between LBW probability and arsenic concentrations from surface soils and private water wells, demographic data, birth data, and social and lifestyle covariates listed in Tables 1 and 2. Parental ages were recategorized into two groups representing mothers: under the age of 25 years and age 25 years and older. Parental races were categorized into three groups: white, black, and other races. Other races include Asian, Native American, Pacific Islander, and people who identified as more than one race. Parental education was recategorized into two categories to represent parents who had a less than high school education and those who had a high school education or higher. The birth facility was recategorized into two groups representing hospital births and nonhospital births (i.e., ambulance births and at-home births). Medical pay source or insurance information was recategorized into private insurance, nonprivate insurance, and other (self-pay or affiliated program pay). Maternal

tobacco and alcohol usage refers to whether mothers used tobacco and alcohol during pregnancy. Maternal tobacco usage notes if mothers smoked during pregnancy, quit while pregnant, or did not smoke during pregnancy. For all groups, missing or not available data were classified as not available.

A logistic regression model was fitted for each of the three years. The outcome (dependent) variable for each model was LBW, and explanatory (independent) variables included arsenic concentration from surface soils and private water wells, demographic (parents race, ethnicity, age, and education) and birth data (infant sex and birth facility), and social and lifestyle covariates (medical source pay, maternal alcohol, and tobacco usage, and WIC enrollment). Medical source pay and WIC program enrollment were used as proxies for socioeconomic status. Variance inflation factors (VIF) were used to assess the explanatory variables for multicollinearity. Stepwise selection was used to optimize our model for the best fit. Pseudo R^2 was reported for each model to explain how well the best-fitted variables of the model explain LBW. Receiver operator characteristic (ROC) curves were constructed to determine model prediction accuracy for the probability of LBW occurrence at the census tract level and to quantify the area under the curve (AUC) (Supplemental Figure S1). R code for this study was archived on GitHub.¹⁴ All data were analyzed using R version 3.4.1.¹⁵

Results

Descriptive statistics

After excluding multiple births and displaced geocoding addresses, birth data were obtained for the years of 2005 ($n=5845$), 2010 ($n=5569$), and 2015 ($n=5770$). Arsenic levels in soil samples across both counties ranged from 0.58 to 121.0 mg/kg, with a mean of 5.75 mg/kg. Arsenic concentrations in private wells across both counties ranged from 0 to 3.3 $\mu\text{g/L}$ with a mean of 0.45 (SD=0.61), which are below the maximum contaminant level (MCL) in drinking water and do not pose an immediate threat to human health according to the EPA.¹⁶ Tables 1 and 2 show the distribution (N and %) of demographics, birth, and social and lifestyle characteristics. For all three years, most births were to non-Hispanic white parents aged 25 years or older with a high school education or higher (Table 1). Of the newborns born, men were slightly more common (51%) than women in all three years. Most of the newborns were born with birth weights equal to or greater than 2500 g. For all three years, roughly 9% to 10% of the infants were born with birth weights lower than 2500 g. Most of the births took place at the hospital to parents with predominantly nonprivate insurance. Approximately half of the mothers were enrolled in WIC, and fewer than 11% of the mothers had a history of alcohol and tobacco usage for each year (Table 2).

Results of the GLMs

The results of the logistic regression are noted in Figure 1A to C and expressed as odds ratios. In all three models, private well

and surface soil arsenic concentrations in the environment were shown to have no significant association with LBW occurrence. For the year of 2005, our study found that the probability of infant born from mother with private health insurance experiencing LBW occurrence was 31% less likely to occur when mothers had private insurance compared with mothers with nonprivate and other forms of medical payment (odds ratio [OR]=0.69; confidence interval [CI]=0.49-0.98). Infants born of mothers of other races (excluding black and white) were 54% (OR=0.46; CI=0.25-0.80) less likely to experience LBW compared with infants born to black or white mothers, whereas the probability of infant born of white mother were 58% less likely to experience LBW occurrence (OR=0.42; CI=0.32-0.57).

For the year of 2010, no significant association was found between LBW occurrence and arsenic concentrations associated with surface soil and private wells. Infants born from mothers who had other or private insurance were 75% (OR=0.25; CI=0.15-0.40) and 23% (OR=0.77; CI=0.60-0.99) less likely to have LBW occurrence compared with mother with nonprivate insurance, respectively. Infants born to mothers from other races (excluding black and white) were predicted to have a 44% decrease in LBW occurrence compared with infants born to black and white mothers (OR=0.56; CI=0.33-0.90). Infants born to white mothers were predicted to have a 52% decrease in LBW occurrence compared with black mothers and mothers of other races (OR=0.48; CI=0.37-0.63). Infants born to mothers aged 25 years and above were 38% more likely to experience LBW occurrence compared with infants born to mothers under the age of 25 years (OR=1.38; CI=1.08-1.76).

For the years 2015, environmental arsenic concentrations associated with private wells and surface soils were found to have no significant association with LBW in our GLM. Our findings showed that infants born to white fathers were 3.15 times as likely to experience LBW occurrence compared with black fathers and fathers of other races (OR=3.15; CI=1.67-6.11). Infants born of fathers above the age of 25 years were predicted to have a 32% decrease in the likelihood of LBW occurrence (OR=0.68; CI=0.46-0.99). Infants of mothers who had other forms of medical payment were 50% less likely to experience LBW occurrence compared with private and nonprivate insurance (OR=0.50; CI=0.31-0.78). Infants born to mothers of other races, excluding black and white, are 68% less likely to experience LBW occurrence compared with white and black mothers (OR=0.32; CI=0.14-0.65).

Infants born to white mothers had an 84% decreasing probability of experiencing LBW occurrence compared with black mothers and mothers of other races (OR=0.16; CI=0.08-0.30). Infants born from mothers who used tobacco were 95% more likely to experience LBW occurrence (OR=1.95; CI=1.3-2.86).

Prediction model of LBW occurrence

Predicted probability models were created to estimate the risk of LBW occurrence by census tract for the three years. By calculating the measures of effect from our best-fitted GLMs for each

Table 1. Demographic and birth characteristics of parental and infants for the years of 2005, 2010, and 2015.

DEMOGRAPHIC AND BIRTH CHARACTERISTICS (N AND %)	2005 (N=5845)	2010 (N=5569)	2015 (N=5770)
Maternal age			
< 25	2493 (42.7)	2236 (40.2)	1885 (32.7)
≥ 25	3351 (57.3)	3333 (59.8)	3885 (67.3)
Not available	1 (0.0)	0 (0.0)	0 (0.0)
Paternal age			
< 25	1539 (26.3)	1338 (24.0)	1022 (17.7)
≥ 25	3896 (66.7)	4231 (76.0)	4001 (69.3)
Not available	410 (7.0)	0 (0.0)	747 (12.9)
Maternal ethnicity			
Hispanic	217 (3.7)	218 (3.9)	241 (4.2)
Non-Hispanic	5553 (95.0)	5243 (94.1)	5436 (94.2)
Other or Unknown Hispanic	75 (1.3)	108 (1.9)	91 (1.6)
Not available	0 (0.0)	0 (0.0)	2 (0.0)
Paternal ethnicity			
Hispanic	179 (3.1)	176 (3.2)	189 (3.3)
Non-Hispanic	4461 (76.3)	4158 (74.7)	4427 (76.7)
Other or Unknown Hispanic	53 (0.9)	1235 (22.2)	82 (1.4)
Not available	1152 (19.7)	0 (0.0)	1072 (18.6)
Maternal race			
Black	1286 (22.0)	1278 (22.9)	1276 (22.1)
Other races	331 (5.7)	315 (5.7)	371 (6.4)
White	4228 (72.3)	3976 (71.4)	4121 (71.4)
Not available	0 (0.0)	0 (0.0)	2 (0.0)
Paternal race			
Black	813 (13.9)	810 (14.5)	896 (15.5)
Other races	229 (3.9)	1412 (25.4)	270 (4.7)
White	3655 (62.5)	3347 (60.1)	3533 (61.2)
Not available	1148 (19.6)	0 (0.0)	1071 (18.6)
Maternal education			
< High school	1058 (18.1)	901 (16.2)	730 (12.7)
≥ High school	4783 (81.8)	4649 (83.5)	5031 (87.2)
Not available	4 (0.1)	19 (0.3)	9 (0.2)
Paternal education			
< High school	584 (10.0)	467 (8.4)	443 (7.7)
≥ High school	4109 (70.3)	3910 (70.2)	4252 (73.7)

(Continued)

Table 1. (Continued)

DEMOGRAPHIC AND BIRTH CHARACTERISTICS (N AND %)	2005 (N=5845)	2010 (N=5569)	2015 (N=5770)
Not available	1152 (19.7)	1192 (21.4)	1075 (18.6)
Sex of infant			
Female	2842 (48.6)	2755 (49.5)	2839 (49.2)
Male	3003 (51.4)	2813 (50.5)	2931 (50.8)
Not available	0 (0.0)	1 (0.0)	0 (0.0)
Birth weight			
Birth weight \geq 2500 g	5303 (90.7)	5028 (90.3)	5199 (90.1)
LBW (< 2500 g)	542 (9.3)	541 (9.7)	569 (9.9)
Birth facility			
Hospital	5793 (99.1)	5538 (99.4)	5724 (99.2)
Out of hospital	51 (0.9)	26 (0.5)	44 (0.8)
Not available	1 (0.0)	5 (0.1)	2 (0.0)
Source pay			
Private insurance	2173 (37.2)	1869 (33.6)	1907 (33.1)
Nonprivate insurance	2957 (50.6)	2982 (53.5)	3009 (52.1)
Other	713 (12.2)	714 (12.8)	849 (14.7)
Not available	2 (0.0)	4 (0.1)	5 (0.1)

Abbreviation: LBW, low birth weight.

Table 2. Social and lifestyle characteristics of mothers for the years of 2005, 2010, and 2015.

SOCIAL AND LIFESTYLE CHARACTERISTICS	2005	2010	2015
Mother in WIC program			
Yes	2796 (47.8)	3079 (55.3)	2841 (49.2)
No	3038 (52.0)	2453 (44.0)	2924 (50.7)
Not available	11 (0.2)	37 (0.7)	5 (0.1)
Maternal tobacco use			
Yes	605 (10.4)	606 (10.9)	547 (9.5)
Yes, but quit	127 (2.2)	53 (1.0)	0 (0.0)
No	5112 (87.5)	4870 (87.4)	5196 (90.1)
Not available	1 (0.0)	40 (0.7)	27 (0.5)
Maternal alcohol use			
Yes	26 (0.4)	32 (0.6)	43 (0.7)
No	5816 (99.5)	5530 (99.3)	5722 (99.2)
Not available	3 (0.1)	7 (0.1)	5 (0.1)

Abbreviation: WIC, Women, Infants, and Children.

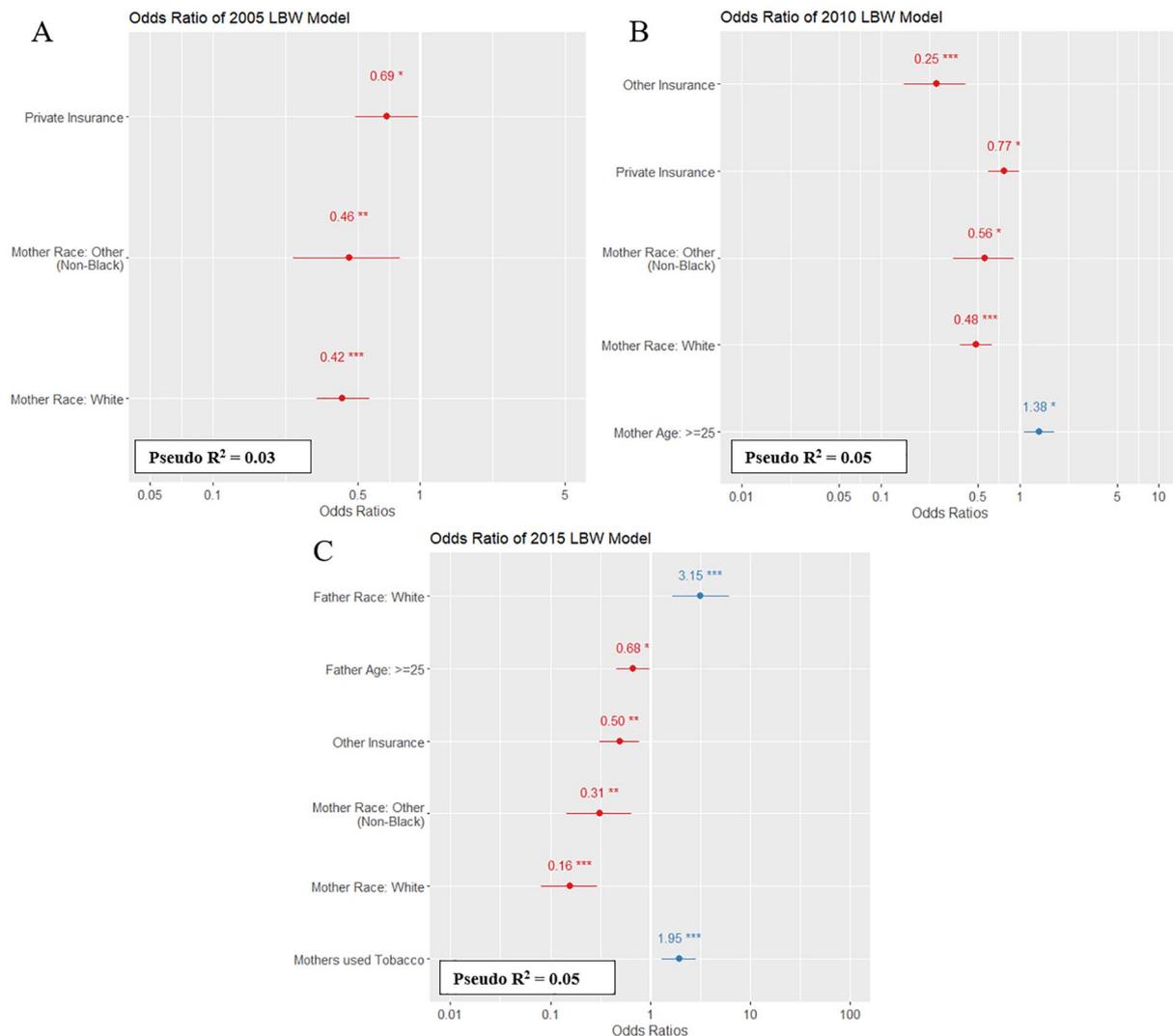


Figure 1. Odds ratios of GLM for the years of (A) 2005, (B) 2010, and (C) 2015. GLM indicates generalized linear model; LBW, low birth weight. P-value (reference): *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

year in R, we were able to predict the likelihood of LBW occurrence at the census tract level for both counties. The models predicted higher incidences of LBW in smaller census tract clusters in Escambia County and Santa Rosa County for all years (Figure 2A to C). These areas with high predicted probabilities were primarily around the urban area of Pensacola and neighboring cities. In all years, low and moderate cases of LBW were predicted for most of the census tracts in both counties, and this could be due to the distribution of mothers above the age of 25 years who gave birth, which was significant in our logistic regression model. The distribution of LBW incidences may account for drastic changes we see in 2010 compared with the other year as more census tracts were noted to have predicted LBW occurrence. From the ROC plot, estimates of the AUC were used to test the validity and utility of all the predictors used in our LBW predictive models (Supplemental Figure S1). From the AUC, we found that all the models were similar in predicting the outcome of LBW occurrence for each year: 2005 model (AUC=0.60), 2010 (AUC=0.65), and 2015 (AUC=0.60).

Discussion

Concentrations of arsenic in soil and water were not associated with the incidence of LBW by census tract, meaning no significant association was found between environmental arsenic concentrations in the census tract of maternal residence and the occurrence of LBW. Many studies have noted a relationship between arsenic exposure and LBW.¹⁷⁻¹⁹ However, some studies have found inconsistencies in the relationship when looking at arsenic concentrations and LBW.²⁰⁻²⁵ Limitations in this study may account for the lack of association between environmental arsenic and LBW. One limiting factor is the lack of direct exposure measurements for mothers, which would explain how much background arsenic is absorbed by the mother and the infant.

Mothers can be exposed to arsenic through water, soil, food, or dust, with its main routes of exposure being ingestion of food and contaminated water and inhalation of polluted air and chemicals.²⁶ Arsenic can persist in pregnant mothers' tissues for up to 7 days but can vary; however, repeated measures

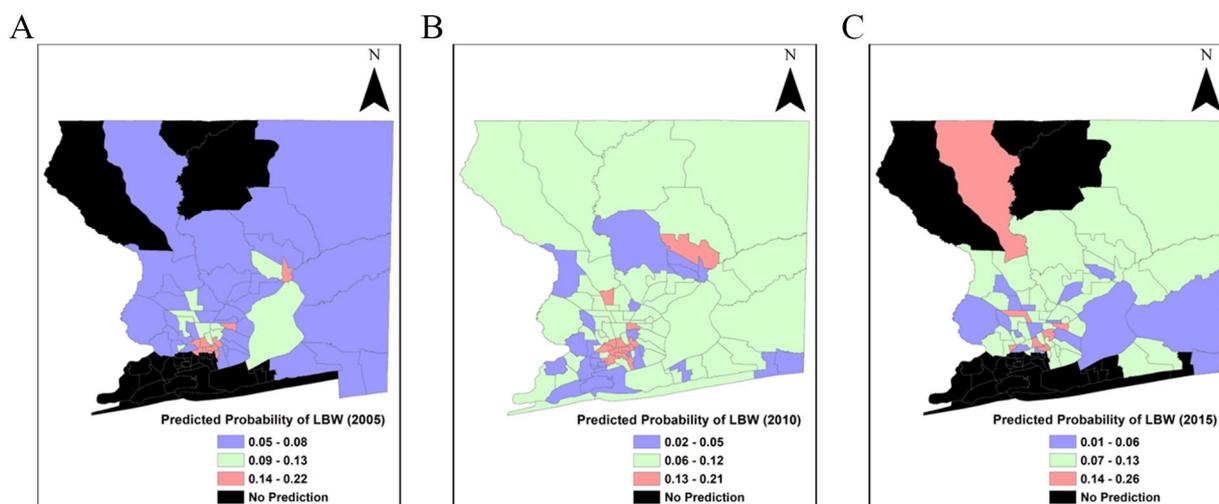


Figure 2. Maps created from the response predictions of the GLMs depicting the predicted probability of LBW in Escambia and Santa Rosa for each of the three years (2005, 2010, and 2015). GLM indicates generalized linear model; LBW, low birth weight.

of exposure to arsenic due to diet, smoking, or drinking water can prolong exposure during pregnancy.²⁷ Food source could be local, domestic, or imported, depending on the mother's preference, which can be hard to assess in studies that focus on passive measures. Passive measures of arsenic exposure are sometimes not the most reliable indicators of associations due to lack of knowledge of direct exposure and different routes of arsenic exposures the mothers may encounter. This limitation could be strengthened by assessing biomarkers for arsenic exposure in pregnant mothers and comparing those concentrations with the confounding factors associated with LBW. Using biomonitoring, Laine et al²⁸ found that more than half the mothers in their study had arsenic concentrations in their drinking water that exceeded 10 µg-As/L (the World Health Organization guideline limit) and was linked to urinary concentration in mothers and infant gestational age and length.

Also, humans are exposed to other xenobiotics and inorganic pollutants, which might cause LBW and should be accounted for in future studies. This study could also be strengthened by increasing the sample size of private wells in both counties. The usage of spatial autocorrelation techniques is reliant on a large and highly disturbed sample population to estimate arsenic concentration accurately. With our small sample size, it may be difficult to compare soil samples, which were a mix of secondary and collected data and private well data. The private wells were secondary data that rely on self-reporting from well owners and government assistance in monitoring concentration. Access to these unreported private wells could strengthen our spatial autocorrelation techniques (IDW) and give a more precise estimate of arsenic from private drinking wells.

It was also found that the mothers' education level and social lifestyle choices, such as maternal tobacco usage, while pregnant increased the likelihood of LBW in infants. Tobacco has been known to contain heavy metals such as lead and arsenic and that arsenic in biological samples of smokers was found to be higher

than nonsmokers.²⁹ Similar to previous studies, a strong association between maternal smoking and the occurrence of LBW and preterm births were reported was noted in 2015.³⁰⁻³² It is known that smoking while pregnant and secondhand exposure to tobacco during late pregnancy could lead to LBW and preterm births.³³ Smoking has been linked to LBW, and the more tobacco smoked during pregnancy has been linked to intrauterine growth retardation, thus affecting birth weight.³⁴ Maternal smoking has been significantly associated with LBW, regardless of the mother's age.³⁵ Mannocci et al³⁶ also showed that smoking, female births, and lower educational attainment (less than high school) were associated with LBW.

In addition to social lifestyle choices, socioeconomic status can affect pregnancy and infants' birth weight; the mother's education level, insurance type, and WIC enrollment were used as a proxy for socioeconomic status in this study. We found that mothers with high school education or higher had a lower risk of birthing an infant with LBW. Maternal stress is often defined as a mix of low education and income, marital status (single), age, and ethnicity and associated stressors, and has been found to increase the risk of LBW and preterm births.³⁷ It has also been noted that high poverty and low education at the neighborhood level were found to increase the risk of LBW. Women from poor neighborhoods and education levels below 14 years of schooling have been found to have increased risk of adverse birth outcomes such as LBW, preterm birth, stillbirth, neonatal, and postnatal death.^{38,39}

In this study, higher predicted LBW was noted in areas with higher populations and, by relation, more births. These higher populated urban areas may see less environmental arsenic due to better water treatment practices and government assistance compared with rural regions.⁴⁰ The prediction models had high accuracy in reporting LBW occurrence, as noted in the ROC curves and, thus, the GLM results may provide useful insight into factors related to LBW.

Conclusions

In conclusion, no significant association was found between environmental arsenic concentrations and the occurrence of LBW, suggesting that the environmental contamination of the pregnant mother's census tract level may not be a useful proxy in assessing risk for LBW occurrence. Results showed that smoking and the mother's race was associated with LBW in infants. In addition, women who had private insurance had a lower risk of giving birth to LBW infants in both Santa Rosa and Escambia County, Florida. These findings are consistent with previous studies and relevant to assisting in future public health studies focused on vulnerable populations. Future research should measure arsenic biomarkers in expectant mothers to allow us to assess how direct exposure to arsenic from the environment affects both mothers and infant birth outcomes as part of a cohort study.

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Author Contributions

MSR: Conceptualization; Methodology, Investigation, Formal Analysis, Visualization, Writing – original draft preparation, Writing – Reviewing and Editing.

MOHR: Supervision, Conceptualization, Methodology.

RLS: Supervision, Conceptualization, Methodology, Validation, Writing – Reviewing and Editing.

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Supplementary Material

Supplemental material for this article is available online.

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