Maternal Residential Proximity to Central Appalachian Surface Mining and Adverse Birth Outcomes

Lauren G. Buttling

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Julia M. Gohlke, Chair
Charlotte Baker
Korine N. Kolivras

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ABSTRACT

Maternal residency in Central Appalachian coalfields has been associated with low birth weight at the county-level. To refine the relationship between proximity and adverse birth outcomes, this study employs finer spatial scales of exposure. Spatiotemporal characterizations of surface mining boundaries in Central Appalachia between 1986-2015 were developed using Landsat data. The maternal address field on births records from VA, WV, KY, and TN were geocoded and assigned amount of surface mining within a 5km radius of residence (street-level). Births were also assigned exposures based on the amount of surface mining within residential ZIP code tabulation area (ZCTA) (ZIP code-level). Using linear and logistic regression, associations between surface mining activities during gestation and birth weight, preterm birth, low birth weight, and term low birth weight were determined, adjusting for available demographic factors. An increase in surface mining activities was negatively associated with birth weight at the street-level ($\beta = -8.93$g; (95% CI = -12.69 -5.7, *P*= <0.001) and ZIP code-level ($\beta = -4.41$g ; 95% CI = -6.30, -2.52, *P*= <0.001). Small, statistically significant associations were also found between preterm birth and mining within 5km of residence (OR = 1.003; 95% CI = 1.001, 1.005, *P*= 0.003) and within maternal ZCTA (OR = 1.002; 95% CI = 1.001, 1.003, *P*=0.001). Relationships were also found between amount of mining within 5km of residence and low birth weight and term low birth weight outcomes. This study found subtle, but significant associations between proximity to active surface mining during gestation and adverse birth outcomes.

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GENERAL AUDIENCE ABSTRACT

Central Appalachian surface mining produces air, water, and noise pollution, all of which have been associated with increased risk of adverse birth outcomes. Previous studies examining associations between surface mining and adverse birth outcomes rely upon relatively coarse county-level data. This research compares outcomes from hundreds of thousands of individual birth records and proximity of maternal home address to surface mines for a fine-scale, epidemiological study. Surface mining boundaries between 1986-2015 were developed using satellite imagery. Birth records from VA, WV, KY, and TN were geocoded and assigned the amount of surface mining within a 5km radius of residence. Births were also assigned exposures based on the amount of surface mining within residential ZIP code since geocoding led to a considerable loss of records. Associations between proximity to surface mining during gestation and birth weight, preterm birth (PTB), low birth weight (LBW), and term low birth weight (tLBW) were determined by linear and logistic regression, adjusting for available demographic factors. Results demonstrate significantly decreased birth weights were found near active mining operations. Mothers living near active surface mining also saw a slight increase in the odds of their birth being PTB, LBW or tLBW. These results suggest there is a subtle, but significant relationship between proximity to surface mining and adverse birth outcomes.

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Table of Contents

List of Figures

List of Tables

Chapter 1. Literature Review

1.1 Particulate Matter ($PM_{2.5}$)

Surface mining refers to the extraction of coal through mountaintop removal, contour, area, highwall, and auger mining. All of these methods remove partial or total mountaintops to access seams of coal. This method allows for nearly total recovery of coal and requires a smaller workforce than underground mining.[1] However, the waste associated with surface mining can be equal to or greater than the amount of coal produced. This leads to the need for a waste rock haulage system and a waste rock disposal area.[2] Since 1990, surface mining has produced approximately half of the coal in Appalachia.[3] This has led to the deposition of approximately 6.4 billion cubic meters of earth deposited into valleys leading to mountaintop leveling and buried headwater streams.[4] Thus, surface mining in Central Appalachia has been shown to historically impact the region's topology, hydrology, and potentially human health.

There is a need to study the gestational impacts of differing levels of ambient air pollution exposure as growing evidence suggests air pollution can alter fetal metabolic processes and increase risk of disease.[5] To further clarify this relationship, a systematic review concluded that further environmental epidemiology research should be conducted on placental biomarkers, which have been shown to determine fetal origin of disease and birth outcomes.[6] Acute or sustained inflammation in pregnant mothers caused by air pollution can trigger premature birth or early labor. This was supported by a time-series analysis, which demonstrated late-pregnancy exposure to elevated $PM_{2.5}$ was associated with premature birth.[7] Another study quantified children's lifelong economic loss due to preterm birth-associated IQ loss, which were attributable to $PM_{2.5}$.[8]

Studies have provided evidence of increased particulate matter exposure and similar health impacts near Central Appalachian surface mining sites.[9,10] Residence in Central Appalachian coalfields has been shown to increase risk of having a birth at low-birth weight.[11,12] Overall, multiple studies have shown that inhalation of particulate matter can lead to adverse birth outcomes and Central Appalachian surface mining may be chronically exposing residents in coalfields.[9,13,14] State environmental and health agencies have not conducted long-term exposure studies of residential areas. One study conducted by BATTELLE sampled air quality after blasting events and found no conclusive evidence between blasting and residential areas' air quality.[15] This study did not analyze long-term exposure of other surface mining activities associated with increased particulate matter.

1.2 Vibration and Noise

Surface mining has also been associated with increased vibration and noise pollution impacting surrounding residential communities. Active surface mines use multiple types of airblasts to fragment rocks, leading to ground vibration and sound exposure.[16] While safe airblast measures have been determined regarding residential structure stability, they have not been adapted for those in close proximity to surfaces mines. These chronic exposures are noted by the U.S. Department of the Interior as "annoyances" and "affect relatively few people over a long period of time".[16] Evidence has shown that noise pollution and vibration may contribute to adverse maternal health and birth outcomes.[17,18] Environmental noise pollution studies have also shown an increased risk for arterial hypertension and cardiovascular diseases in residents.[19]

1.3 Diesel Haul Truck Activity

The increase in diesel truck activity due to active surface mining also increases expectant mothers' exposure to vibration, noise, and air pollution. In one study, 14 diesel haul trucks completed a cumulative 44,337 working hours from January 1, 2006 to December 31, 2006. That is an average of 8.68 working hours per truck for 365 days/year. This led to a cumulative use of 1,215,335 gal of diesel fuel being converted to an estimated 13,490 tons of CO_2 emitted.[20] Increased proximity to major roadways has been associated with an increased risk of term low birth weight and preterm birth.[21,22] Other studies support this conclusion and emphasize that low birth weight is partly attributable to both motorized vehicle noise and air pollution, while preterm birth is most related to vehicle air pollution.[23] Noise and air pollution generated by roads may also increase risk of maternal pre-eclampsia and hypertensive disorders during gestation.[17]

1.4 Innovation

Air quality monitoring in residential areas in relation to surface mining has primarily been conducted as short-term studies as opposed to long-term monitoring. While there have been studies that have attempted to determine residential exposure to air pollution from surface mining, one of the most comprehensive studies by BATTELLE only sampled air for two weeks in February during blasting events.[15] There is a great need for an interdisciplinary research approach to study this area as the region’s residents are relatively isolated and difficult to surveil.

Previous epidemiological studies have utilized county-level data to determine associations between surface mining exposure and adverse birth outcomes and other health indicators. These studies characterized mining activity within Central Appalachian counties and matched to county of maternal residence.[11] Due to the large cohort of those potentially exposed during a wide time period, a more personalized and refined approach is needed to determine mothers’ individual exposure. A novel method should be developed to define individual’s proximity to surface mining. Previous exposure studies have utilized distance and zones of distance to the nearest mine.[24] These measures do not fully account for the size of the nearest surface mining operation or the cumulative effects of being near multiple mining sites.

Results of a comprehensive study of historical surface mining exposures and birth outcomes in Central Appalachia would improve characterization of human exposure and inform environmental health policy and public health practices.[25] This study could provide Central Appalachian policymakers and public health professionals with a scientific basis for future environmental health policies, surface mining permit processes, or allocation of funding for maternal health campaigns. In general, the public and departments of public health are interested in better understanding all factors that have a historical impact on birth outcomes and potential future outcomes.[26]

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Chapter 2. Maternal Proximity to Central Appalachian Surface Mining and Adverse Birth Outcomes

Lauren G. Buttling[a], Molly X. McKnight[b], Michael L. Marston[b], Korine N. Kolivras[b], Shyam Ranganathan[c], Julia M. Gohlke[a*]

[a]Department of Population Health Sciences, Virginia Tech, Blacksburg, Virginia, USA
[b]Department of Geography, Virginia Tech, Blacksburg, Virginia, USA
[c]Department of Statistics, Virginia Tech, Blacksburg, Virginia, USA
* Corresponding author E-mail: jgohlke@vt.edu

Mailing address:
Virginia Tech
VA-MD College of Veterinary Medicine
Department of Population Health Sciences
205 Duck Pond Drive
Blacksburg, VA 24061
United States

Keywords: surface mining, environmental epidemiology, rural health, birth outcomes

2.1 Abstract

Background: Maternal residency in Central Appalachian coalfields has been associated with low birth weight at the county-level. To refine the relationship between proximity and adverse birth outcomes, this study employs finer spatial scales of exposure.

Methods Spatiotemporal characterizations of surface mining boundaries in Central Appalachia between 1986-2015 were developed using Landsat data. The maternal address field on births records from VA, WV, KY, and TN were geocoded and assigned amount of surface mining within a 5km radius of residence (street-level). Births were also assigned exposures based on the amount of surface mining within residential ZIP code tabulation area (ZCTA) (ZIP code-level). Using linear and logistic regression, associations between surface mining activities during gestation and birth weight, preterm birth, low birth weight, and term low birth weight were determined, adjusting for available demographic factors.

Results: An increase in surface mining activities was negatively associated with birth weight at the street-level ($\beta = -8.93$g; (95% CI = -12.69 -5.7, P= <0.001) and ZIP code-level ($\beta = -4.41$g ; 95% CI = -6.30, -2.52, P= <0.001). Small, statistically significant associations were also found between preterm birth and mining within 5km of residence (OR = 1.003; 95% CI = 1.001, 1.005, P= 0.003) and within maternal ZCTA (OR = 1.002; 95% CI = 1.001, 1.003, P=0.001). Relationships were also found between amount of mining within 5km of residence and low birth weight and term low birth weight outcomes.

Conclusions: This study found subtle, but significant associations between proximity to active surface mining during gestation and adverse birth outcomes.

2.2 Introduction

Since 1990, surface mining, typically through mountaintop removal or contour mining, has made up over half of Appalachian mining activities.[1,2] This method allows for nearly total recovery of coal and requires a smaller workforce than underground mining.[3] However, the waste associated with surface mining can be equal to or greater than the amount of coal produced.[4] Previous research has also established a relationship between the inhalation of particulate matter and adverse birth outcomes[5-9] A few studies have provided evidence of increased particulate matter exposure and related negative health outcomes near Central Appalachian surface mining sites[6,10] Therefore, Central Appalachian surface mining may be chronically exposing pregnant mothers living in coalfields to $PM_{2.5}$.[6]

$PM_{2.5}$ from surface mining includes particulates that can be small enough to reach the fetal bloodstream and trigger maternal inflammatory pathways.[6,11] Specifically relevant to coal truck emissions, increased exposure to traffic-related particulate matter during gestation has been associated with an increased risk of low birth weight (<2,500g), preterm birth (birth at <37 weeks gestation), and term low birth weight (born at ≥37 weeks gestation and weighing <2,500g).[12-15] Researchers concluded that there is an increased risk of early pregnancy loss and decrease in fetal cell viability in female mice at increased concentrations of diesel particulate emissions.[16] In a study of one surface mine, 14 diesel haul trucks each averaged 8.68 working hours per 365 days/year. Increased proximity to major roadways has also been associated with an increased risk of low birth weight (LBW), preterm birth (PTB), and term low birth weight (tLBW).[9,17,18]

Previous studies have demonstrated increased adverse birth outcomes in Appalachian coalfields compared to other regions at a relatively coarse county-level scale, comparing coal producing to non-coal producing counties.[19,20] Through use of Landsat satellite imagery and individual birth records, this study determines the association between birth outcomes and surface mining by developing a fine-scale spatiotemporal characterization of historical surface mining activities from 1986-2015 to determine proximity to active surface mining using maternal residential addresses, mailing address, or ZIP code from 1990-2015. We hypothesize that increased exposure to active mining is associated with an increase in the odds of adverse birth outcomes and decrease birth weight at both street and ZIP code-level spatial scales.

2.3 Methods

Birth Records

A uniform dataset was created from 409,394 birth records geocoded to the Central Appalachian counties as defined by the Appalachian Regional Commission, which were provided by TN, VA, WV, and KY health departments as detailed in Suppl. Figure 2.8.1.[21] Formatting of birth records varied by state and changed over the time period of study, requiring several data processing steps. For the street-level analysis, records were geocoded to street address using residential or mailing address and parsed to remove strings related to P.O. boxes. The merged street-level dataset is comprised of 194,084 records with mother's geocoded street address, the outcome variables, and covariates, described in more detail below, for data analysis.

A ZIP code-level analysis was also conducted to preserve a greater sample size of 364,981 records, which contained maternal ZIP code, while still providing a more fine-scale analysis than existing studies. The ZIP code-level dataset was determined by including all street-level birth records with a valid ZIP code and all those where the respective ZIP code tabulation areas (ZCTA) boundary intersects with at least 2% of a county classified as within Central Appalachia by the Appalachian Regional Commission.[21] This accounts for ZCTAs that cross county lines and where ZCTA centroids may be outside of a Central Appalachian county. All 364,981 birth records with valid ZIP codes generated from the ArcGIS Pro postal locator and no missing demographic covariates were included in the ZIP code-level analysis.

This study was reviewed and approved by the Virginia Tech Institutional Review Board (# 16-898), Virginia Department of Health IRB (# 40221), West Virginia Department of Health and Human Resources, Kentucky Cabinet for Health and Family Services IRB(# FY17-23), and Tennessee Department of Health IRB (# 972154).

Surface Mines

Active surface mines within Central Appalachian surface mining permit boundaries were determined for each year between 1986-2015 using Landsat imagery characterization, as described in detail in Marston and Kolivras.[22] Evidence of mining activity was determined by transitions from vegetative land cover to bare ground, while considering seasonality and surface mining permit boundaries. For the purposes of this study, all active mining boundaries were filtered for continuous polygons of 40 acres or more, in order to better ensure the land was occupied by a functioning surface mine (Figure 2.3.1).[23] For each year of analysis, land was further characterized into pre-mining areas, which was defined as land that was not experiencing active mining during the exposure year, but will have active mining in later years and post mining, which was classified as land actively mined in prior years of analysis, but no evidence of active mining during the exposure year.

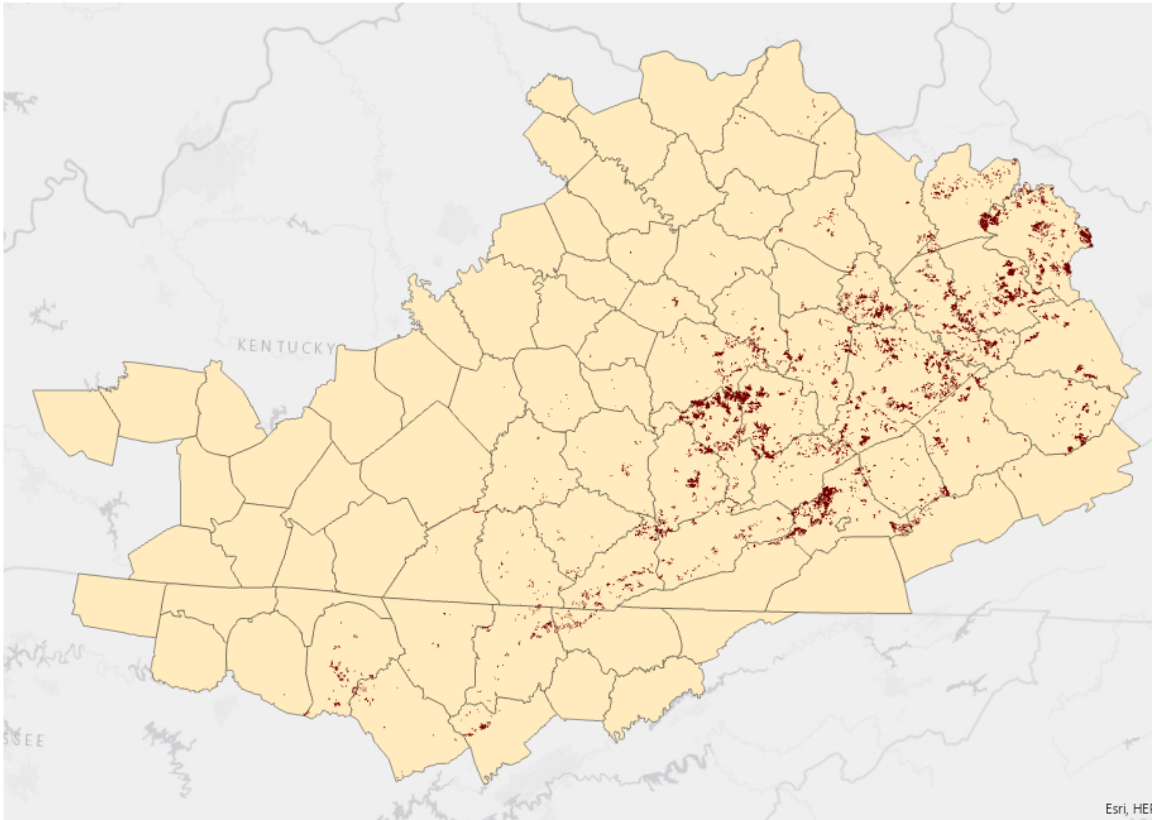

Figure 2.3.1. All active surface mining from 1990-2015 in Central Appalachian counties

Exposure Variables

For the street-level analysis, the amount of pre, active, and post mining within a 5km, circular buffer of mother's address was quantified using ArcGIS Pro GeoAnalytics tools. The exposure period for a given birth was determined to be the year of the majority of gestation (≥ 50% of gestation), 1989 to 2015. Birth records missing gestation length (0.1%) were removed from analysis as their exposure year could not be determined. Exposure year was matched to the respective surface mining polygons for each birth record to determine the area of each buffer's intersection with surface mine boundaries (Suppl. Figure 2.8.2). These intersections were calculated in square meters and percent area of the total buffer. All birth records that did not have any measurable polygon intersection were given a value of 0 for the generated exposure metrics.

A similar methodology was used for the ZIP code-level analyses, with calculation of the percent of land defined as mining within the ZCTA boundaries of mothers' residential or mailing address during the majority year of gestation.

Covariates and Outcome Variables

Demographic variables included in birth records were considered covariates in statistical analyses. Mother's age was included and categorized into groups of those under 18, 18-35, and over 35 years for analysis since previous studies have shown increased risk of adverse birth outcomes at younger and older maternal ages.[24] Parity was determined from the child's birth order or by number of previous children living (Kentucky births) and categorized into 1, 2, 3, and 4 or more births based on studies which have shown an association between number of previous births and risk of adverse birth outcomes.[25,26] Mother's education was classified as 8th grade or less, 9th to 12th grade, or any post high school education with or without a degree. Payment method for delivery cost recorded if mothers paid by Medicaid, private insurance, self-pay, or another form of payment and can serve as an indicator of socioeconomic status.[27,28] Kentucky records from 1990-2013 did not include any information on payment and those from West Virginia only determined if Medicaid was used from 1990-2013, leaving only 99,595 street-level records and 173,232 ZIP code-level records for analysis. Mother's race was categorized as White, Black, or other based on the maternal race field from KY, WV, and TN birth records and child's race field for VA records.[29] Mother's Hispanic origin was reported with exception of West Virginia records from 1990-2013, which did not report mother's Hispanic origin. Child's sex and any tobacco use during pregnancy were classified from birth records. 11% of records were removed from the street and 9% from the ZIP code- level datasets after removing missingness in all covariates other than payment method and mother's Hispanic origin (see Suppl. Figure 2.8.1).

This study only included singleton births due to the differing rates of adverse birth outcomes in plural births.[30] Gestation lengths of 21 to 45 weeks and birth weights of 200 grams or greater were considered valid for our study sample.[31,32] Gestation length and birth weight were used to determine the outcome variables, PTB, LBW, and tLBW.

Statistical Analyses

The street and ZIP code-level analyses were completed using linear regression to determine the change in birthweight and 95% confidence interval per 1% increase of a boundary's land occupied by mining activity. Logistic regression was used to estimate the odds ratio and 95% confidence interval of a PTB, LBW, or tLBW outcome per 1% increase in mining activity. Models were run in R using the glm() function. Birth weight, PTB, LBW, or tLBW were dependent variables in separate regression models. Models were adjusted for demographic variables including categorized mother's age, mother's race, mother's reported tobacco use during pregnancy, mother's education, previous births, child's sex, and majority year of gestation. Payment method was omitted from the primary analysis as its inclusion removed 48.7% and 52.5% of records from the street and ZIP code-level analysis, respectively. Mother's Hispanic origin was not used in the primary analysis as it removed 6.3% and 3.4% of records from the street and ZIP code-level analysis respectively. Both of these covariates were included in a secondary analysis. Majority year of gestation was included in the model using a spline with 4 degrees of freedom. The spline was created using the bs() function in the spline package from the library, splines.

2.4 Results

Street-Level Population Characteristics

Of the residential addresses able to be geocoded to the street-level, mothers were primarily between 18 and 35 years of age (90%), mostly white (97%), with some high school education (56% had a highest education of 9-12th grade), and did not smoke during pregnancy (70%). Twelve percent of births were exposed to active mining within 5km of maternal residence during gestation (Table 2.4.1).

The incidence rate of adverse birth outcomes changed over the study period in both births unexposed and exposed to active mining within 5km of maternal residence (Figures 2.4.1-2.4.4). Birth weight and PTB rates appeared to be minimally different between the two groups until 2005, where births in mining areas exhibited a consistently lower average birth weight and higher rates in PTB. A study of national trends has shown that from 1990 and 2013, induced labors and cesarean deliveries increased in popularity throughout the United States.[33] Births became much more likely to occur during weeks 37–39 than past 40 weeks. Results from this study argue that the average U.S. birth weight would have increased over this time period, if rates of induced labors and cesarean deliveries remained unchanged. The rate of PTB in Central Appalachia also followed national trends, with an observed nationwide increase in PTB from 1998–2006. PTB rates peaked nationwide and in our study area in 2006 and PTB rates have been generally decreasing every year since.[34]

Table 2.4.1. Characteristics of singleton births unexposed and exposed to active mining included in the street and ZIP code-level analyses

	Street-Level		**ZIP Code-Level**	
	No Mining Within 5km n=170,351	**Active Mining Within 5km n=23,733**	**No Mining in ZCTA Boundary n=261,608**	**Active Mining ZCTA Boundary n=103,373**
Mother's State of Residence				
Kentucky	149,652(87.8%)	19,711(83.1%)	230,610(88.2%)	88,652(85.8%)
Tennessee	10,215(6.0%)	1,279(5.4%)	9,265(3.5%)	2,269(2.2%)
Virginia	3,195(1.9%)	1,533(6.5%)	13,923(5.3%)	9,290(9.0%)
West Virginia	7,289(4.3%)	1,210(5.1%)	7,792(3.0%)	3,180(3.1%)
Child's Sex				
Male	87,776(51.5%)	12,279(51.7%)	134,632(51.5%)	53,298 (51.6%)
Female	82,575(48.5%)	11,454(48.3%)	126,958(48.5%)	50,093(48.4%)
Mother's Race				
White	165,163(97.0%)	23,258(98.0%)	252,692(96.6%)	100,331(97.0%)
Black	2,747(1.6%)	275(1.2%)	3,349(1.3%)	814(0.8%)
Other	2,441(1.4%)	200(0.8%)	5,549(2.1%)	2,246(2.2%)
Mother's Age (years)				
18-35	153,784(90.3%)	21,566(90.9%)	235,196(89.9%)	93,105(90.1%)
<18	7,765(4.6%)	1,058(4.5%)	13,907(5.3%)	5,747(5.6%)
>35	8,802(5.2%)	1,109(4.7%)	12,487(4.8%)	4,539(4.4%)
Previous Births				
0	74,310(43.6%)	10,403(43.8%)	113,921(43.6%)	45,424(43.9%)
1	57,750(33.9%)	8,202(34.6%)	88,245(33.7%)	35,201(34.1%)
2	25552(15.0%)	3,567(15.0%)	39,146(15.0%)	15,281(14.8%)
3	8,192(4.8%)	1,066(4.5%)	12,787(4.9%)	4,990(4.8%)
4 or more	4,547(2.7%)	495(2.1%)	7,491(2.9%)	2,495(2.4%)
Mother's Education (years)				
<9	6,458(3.8%)	607(2.6%)	13,138(5.0%)	4,663 (4.5%)
9-12	95,633(56.1%)	13,729(57.8%)	156,211(59.7%)	63,554 (61.5%)
>12	68,260(40.1%)	9,397(39.6%)	92,241(35.3%)	35,174 (34.0%)
Reported Tobacco Use During Pregnancy				
No	119,868(70.4%)	15,962(67.3%)	179,547(68.6%)	68,303(66.1%)
Yes	50,483(29.6%)	7,771(32.7%)	82,043(31.4%)	35,088(33.9%)
Payment				
Medicaid	53,957(31.7%)	9,320(39.3%)	77,278(29.5%)	34,967(33.8%)
Private Insurance	27,801(16.3%)	4,213(17.8%)	38,952(14.9%)	14,747(14.3%)
Self-Pay	2,729(1.6%)	195(0.8%)	4,051(1.5%)	786(0.8%)
Other	1,182(0.7%)	198(0.8%)	1,734(0.7%)	713(0.7%)
NA	84,682(49.7%)	9,807(41.3%)	139,575(53.3%)	52,178(50.5%)
Mother's Hispanic Origin				
Not Hispanic	157,789(92.6%)	22,116(93,2%)	250,195(95.6%)	99,506(96.2%)
Hispanic	1,913(1.1%)	100(0.4%)	2,502(1.0%)	482(0.5%)
NA	10,649(6.3%)	1,517(6.4%)	8,893(3.4%)	3,403(3.3%)

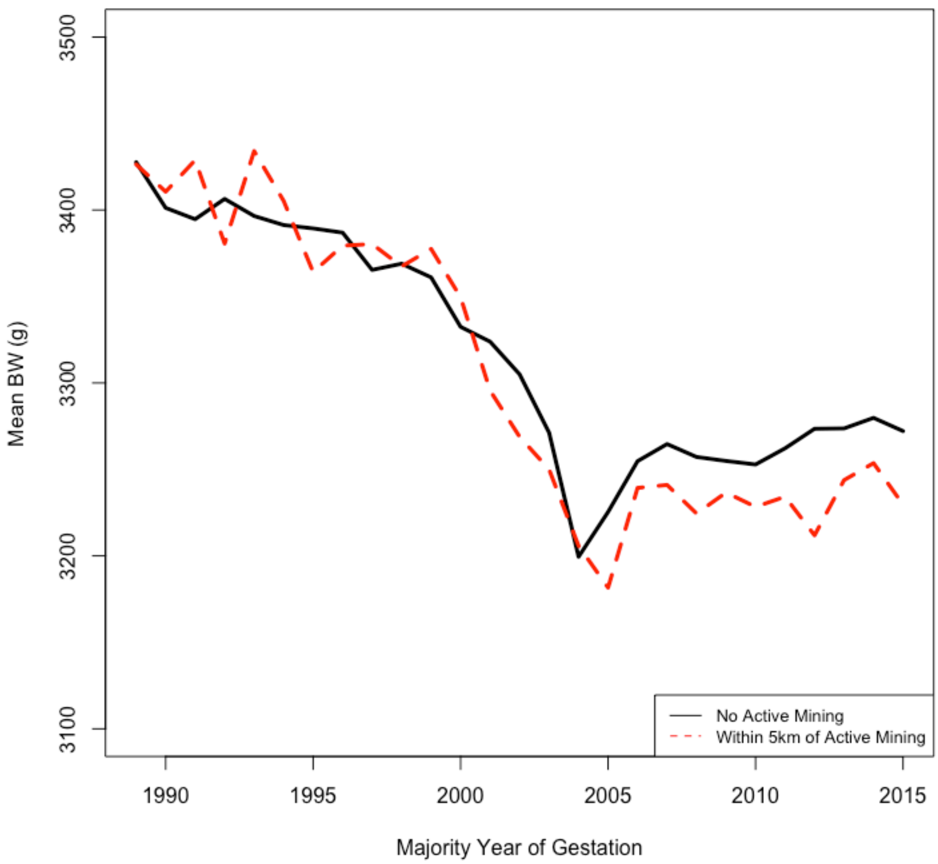

Figure 2.4.1. Average birth weight over time for residence within 5km of active mining versus not within 5km of active mining in Central Appalachia from 1989-2015

Figure 2.4.2. Incidence rate of preterm birth (per 100,000 births) within 5km of active mining and those unexposed from 1989-2015

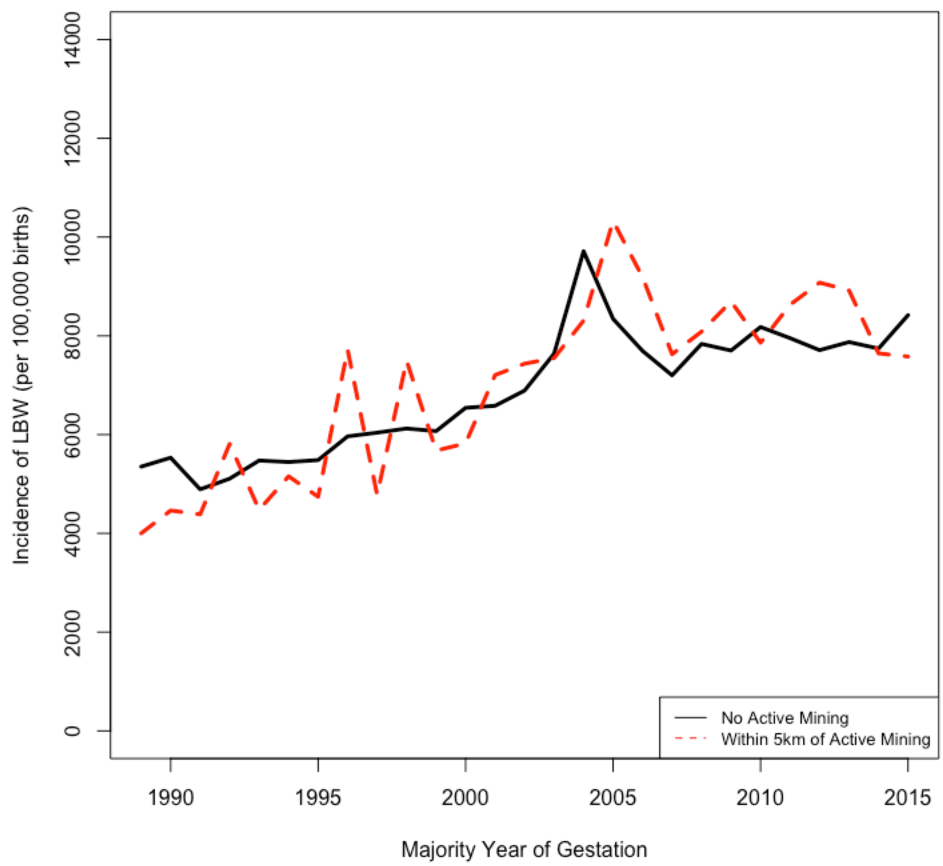

Figure 2.4.3. Incidence rate of low birth weight births (per 100,000 births) within 5km of active mining and those unexposed from 1989-2015

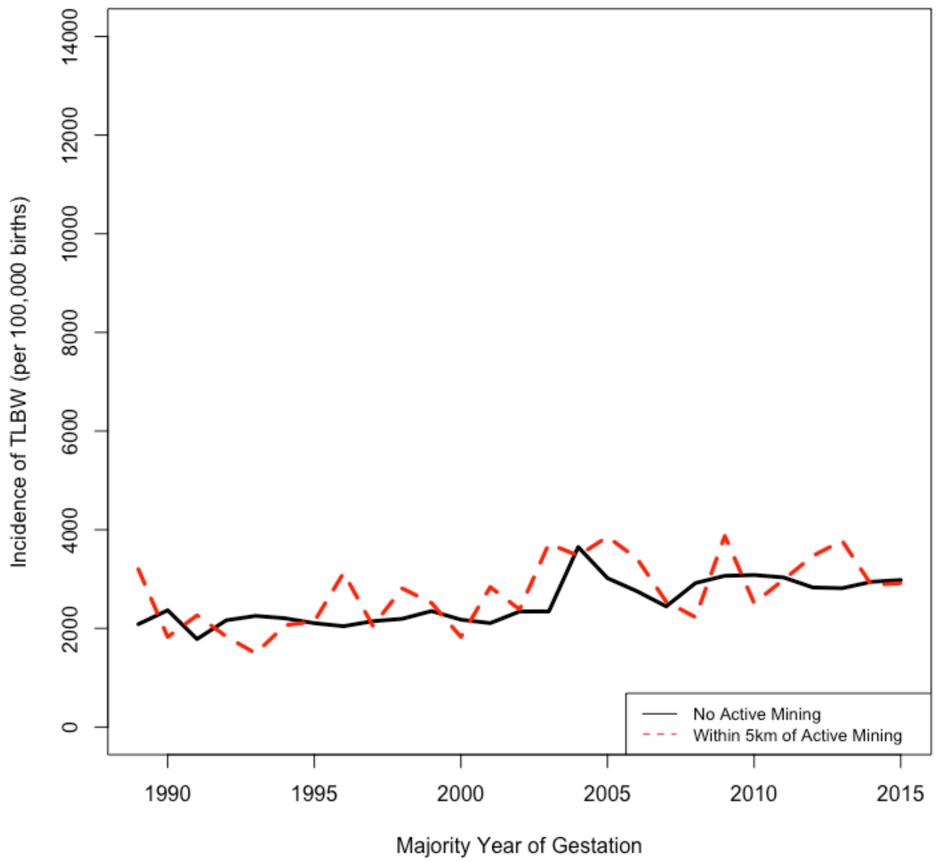

Figure 2.4.4. Incidence rate of term low birth weight births (per 100,000 births) within 5km of active mining and those unexposed from 1989-2015

Street-Level Model Results

For those births within 5km of active mining, the percent of a 5km buffer occupied by active mining ranged from <0.001% to 15.76%. In the adjusted linear regression analyses, the continuous exposure model suggests an 8.93 g decrease in birth weight for every 1% increase of active mining within a 5km buffer of maternal residence ($\beta = -8.93$g; 95% CI = -12.69 -5.7, P= <0.001). Using these regression results with a maximum observed exposure of 15.76% within a 5 km buffer of residence, active mining is associated with a decrease in birth weight of up to 140.7g.

In the adjusted logistic regression analyses, every 1% increase in mining within 5km of maternal residence was associated with a 0.3% increase in the odds of a PTB (OR = 1.003; 95% CI = 1.001, 1.005, *P*= 0.003) and LBW (OR = 1.003; 95% CI = 1.001, 1.004, *P*= 0.004). A 4.8% increase in the odds of a PTB and LBW is suggested by this model in areas with 15.76% active mining within 5km buffers, the maximum percent within our study area and time period.

Every 1% increase in mining within 5km of maternal residence was associated with a non-significant 0.1% increase in the odds of tLBW (OR = 1.001; 95% CI = 1.000, 1.002, *P*= 0.121 (Table 2.4.2).

Table 2.4.2. Odds ratios (95% CIs) for associations between adverse birth outcomes and amount of active mining within 5km of maternal residence in adjusted logistic model

	Active Mining within 5km of Maternal Residence (per 1% increase)	
Outcome Variable	**OR (95% CI)**	***P*-value**
Preterm	1.003(1.001,1.005)	0.003
Low Birth Weight	1.003(1.001,1.004)	0.004
Term Low Birth Weight	1.001(1.000,1.002)	0.121

This regression was adjusted for mother's age, mother's race, mother's tobacco use during pregnancy, mother's education, mother's race, parity, year of majority of gestation, and child's sex

In order to gauge if there are lingering health effects after active mining operations are completed, amount of post mining areas within the 5km buffer around the maternal residence were added to the regression models. Proximity to land that was formerly active, but not during exposure year was compared to effect sizes for active mining operations in the same regression model. For those births within 5km of post mining activities, the percent of a 5km buffer occupied by post mining ranged from <0.001% to 41.74%. When adjusting for exposure to active mining and all other covariates, a 1% increase in post mining activities within the 5km buffer was associated with an additional 2.28g decrease in birth weight (β = −2.28g; 95% CI = -3.63 -0.94, P= <0.001). These regression results could then be associated with a decrease in birth weight of up to 95.2g in areas with the highest post-mining. The other outcome variables were also analyzed and showed similar relationships between exposure to post mining areas and adverse birth outcomes (Suppl. Table 2.8.1). Since post mining areas are typically next to active mining areas in the current year, the amount of each within a 5km buffer are correlated (R^2: 28.9); therefore, collinearity may make it difficult to tease apart individual impacts.

In models including payment method and Hispanic origin of mother, a negative association between amount of surface mining within 5km and birth weight (β = -10.48g; 95% CI = -15.59, -5.36, P=<0.001) was found, in the same direction, but with slightly higher effect sizes than models described above (Suppl. Figure 2.8.2). However, because these models remove all birth records received from WV between 1990-2009 and those from KY between 1990-2013, inclusion of these variables reduced our sample size in mining areas by 56.4% (Table 2.4.1.).

ZIP Code-Level Population Characteristics

The ZIP code-level analysis allowed for the inclusion of an additional 170,897 records of Central Appalachian residents that could not be included in the street-level analysis. ZIP code-level exposures allow us to capture outcomes of mothers who reported a P.O. box address, did not have a complete address recorded, or were unable to be geocoded to street address. Comparable to the street-level dataset, the residential addresses able to be geocoded to Central Appalachia's ZCTA boundaries, mothers were between 18 and 35 years of age (90%), and mostly white (97%), with some high school education (60% had a highest education of 9-12th grade), and the majority did not smoke during pregnancy (68%). Twenty eight percent of births were exposed to active mining activity within maternal ZCTA during the year in which the majority of gestation occurred (Table 2.4.1).

ZIP Code-Level Model Results

For those births with any active mining within maternal ZCTA during gestion year, the percent of the respective ZCTA boundary occupied by active mining ranged from <0.001% to 19.72%. In the adjusted linear regression analyses, the continuous exposure model estimated a 4.11 g decrease in birth weight for every 1% increase of mining area within the maternal ZCTA boundary (β = −4.11; 95% CI = -5.90, -2.32, *P*= <0.001). Using these regression results with a maximum observed exposure of 19.72%, active mining within maternal ZCTA is associated with a decrease in birth weight up to 81.0g.

In the adjusted logistic regression analyses, every 1% increase in mining within the ZCTA was associated with a significant 0.2% increase in the odds of PTB (OR = 1.002; 95% CI = 1.001, 1.003, *P*=0.001). Active mining within maternal ZCTA was associated with up to a 3.9% increase in the odds of a PTB in the ZCTA and year with the most active mining.

Every 1% increase in active mining was associated with a non-significant 0.1% increase in the odds of a birth being classified as LBW (OR = 1.001; 95% CI = 1.000, 1.002, *P*= 0.056).

Every 1% increase in mining was associated with a significant 0.1% increase in the odds of a birth being classified as tLBW compared to births with no mining within 5km of maternal residence (OR = 1.001; 95% CI = 1.000, 1.001, *P*= 0.012) (Table 2.4.3.). Active mining within 5km could then be associated with a 2.0% increase in the odds of tLBW in the ZCTA and year with the highest percent of active mining.

Table 2.4.3. Odds ratios (95% CIs) for associations between adverse birth outcomes and amount of active mining within maternal ZCTA in adjusted logistic model

	Active Mining within ZCTA Boundary (per 1% increase)	
Outcome Variable	**OR (95% CI)**	***P*-value**
Preterm	1.002(1.001,1.003)	0.001
Low Birth Weight	1.001(1.000,1.002)	0.056
Term Low Birth Weight	1.001(1.000,1.001)	0.012

This regression was adjusted for mother's age, mother's race, mother's tobacco use during pregnancy, mother's education, mother's race, parity, year of majority of gestation, and child's sex

The amount of land within maternal ZCTA that was classified as post mining was also determined. For those births with any post mining in their respective ZCTA, the percentage of land occupied by post mining ranged from <0.001% to 40.59%. When adjusting for exposure to active mining and all other covariates, a 1% increase in post mining activities within the 5km buffer was associated with an additional 3.40g decrease in birth weight ($\beta = -3.40$; 95% CI = -4.16, -2.64, P= <0.001). The relationship between PTB, LBW, and tLBW and exposure to post mining areas within maternal ZCTA was similar to that of the street-level analysis (Suppl. Table 2.8.3).

In sensitivity models including payment method and Hispanic origin of mother, results demonstrated a negative association between amount of mining within maternal ZCTA boundaries and birth weight (β = -8.17g; 95% CI = -10.89, -5.45, P=<0.001) (Suppl. Table 2.8.4). Because this adjustment removed all birth records received from WV between 1990-2009 and those from KY between 1990-2013, inclusion of payment method and maternal Hispanic origin in regression models reduced our sample size in mining areas by 49.0%(Table 2.4.1).

2.5 Discussion

This analysis showed that increased proximity to surface mining at both spatial scales was associated with higher odds of adverse birth outcomes and demonstrated a negative relationship between birth weight and mining after controlling for individual-level covariates available across birth records. Previous studies have associated adverse health and birth outcomes with proximity to surface mining activities and associated particulate matter crustal compounds[5,10,19,20,35-37]. This is the first study to apply a quantification of active surface mines at a fine spatial resolution to street-level and ZIP code-level assessment of maternal proximity to surface mining during gestation.

Our findings add to the understanding of the effect of prenatal exposure to surface mining on PTB, LBW, tLBW, and birth weight. A recent study estimated the change in odds of LBW associated with the amount of coal produced in West Virginia counties from 2005 and 2007 through use of individual birth records.[20] All West Virginia counties were included, which include areas outside of Central Appalachia. This study suggested that residence in a county with high amounts of coal production was associated with 16% increased odds of LBW (95% CI = 8%, 25%) after adjustment for available risk factors. These ORs are higher than those in our study, perhaps because of differences in the covariates available from the West Virginia Birthscore Dataset, such as mother's marriage status, alcohol consumption, and prenatal care, as well as the inclusion of non-Central Appalachian mining activity and coal produced from underground mining. Epidemiological studies have examined the relationship between diesel exhaust exposure during pregnancy and adverse birth outcomes. In studies examining the composition of traffic-related $PM_{2.5}$ in Los Angeles, the amount of diesel exhaust was shown to increase the odds of a PTB by 11%(95% CI = 7%, 15%) and a 5% (95% CI = 1%, 12%) increase in the odds of a birth being tLBW per interquartile range (IQR) increase.[12,13] The results indicate that diesel exhaust may be the primary pollutant of concern in our study.

Limitations of this analysis include potential confounding from unmeasured covariates. We did not have information on mother's alcohol use or non-tobacco drug exposures during pregnancy, prenatal care, maternal BMI, paternal demographics, marital status, or income. The current address-level analysis is also limited by the ability to geocode rural addresses with a high match rate. P.O. boxes accounted for approximately half of those birth records that provided an address. Relationships between particulate matter from surface mining activities and specific trimester of exposure were not accounted for in this analysis as satellite imagery varies in quality and visibility by month, which limits accuracy of remote sensing analyses on a monthly time scale.[8,38] Surface mining activities outside of Central Appalachia, but neighboring the study area, other industries, and traffic-related sources of air pollution are not accounted for in this analysis. This study also assumed that mothers spent the totality of their pregnancy at the address or ZIP code listed on their birth records.

Despite these limitations, our study provides evidence to the growing literature of health disparities on an understudied and underserved population of Central Appalachian mothers. This study adds to the knowledge of the potential health impacts of living near surface mining in Central Appalachia by analyzing individual birth records at two previously unstudied spatial scales, across a relatively long time period.

2.6 Conclusion

This study found small but statistically significant associations between amount of active surface mining within close proximity to residence during gestation and the odds of preterm birth, low birth weight, term low birth weight, and decreased birth weight. These trends justify further research into the health burden associated with land use change, socioeconomic factors, and access to health resources in Central Appalachia.

2.7 Acknowledgements

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2.8 Supporting Information and Supplemental Figures

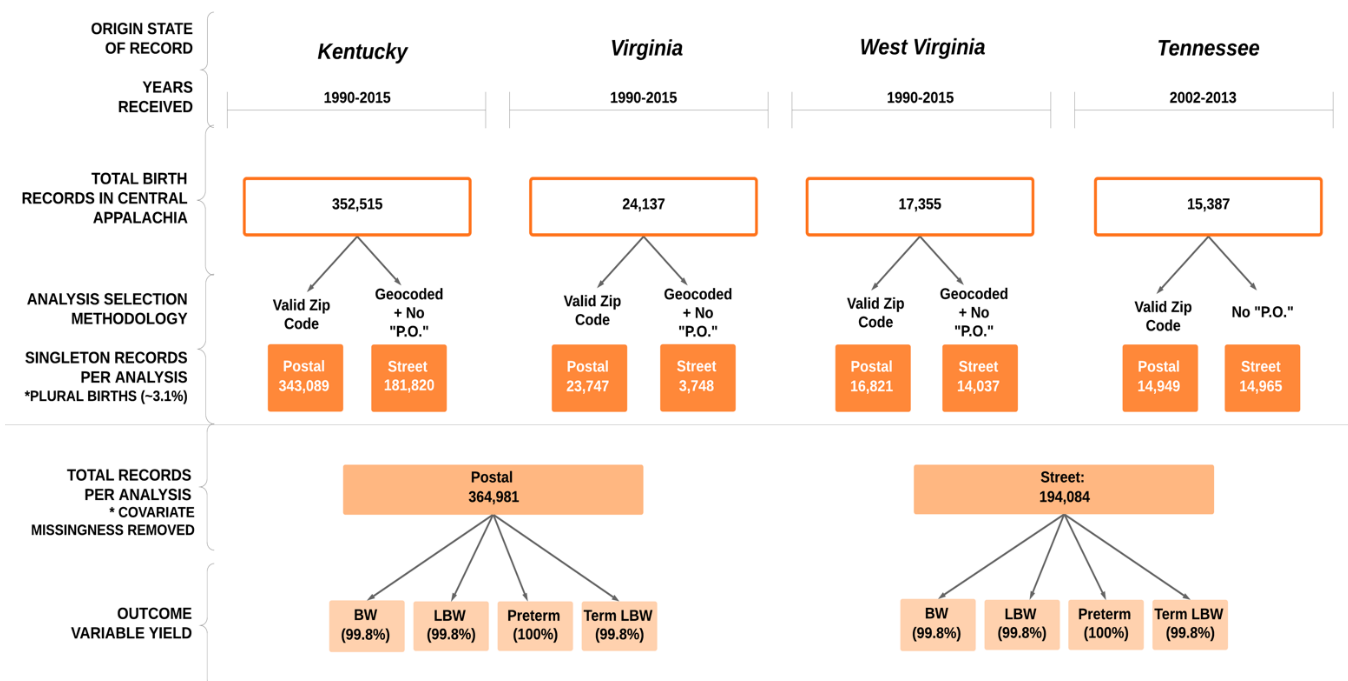

Figure 2.8.1. Flow diagram of birth record data processing

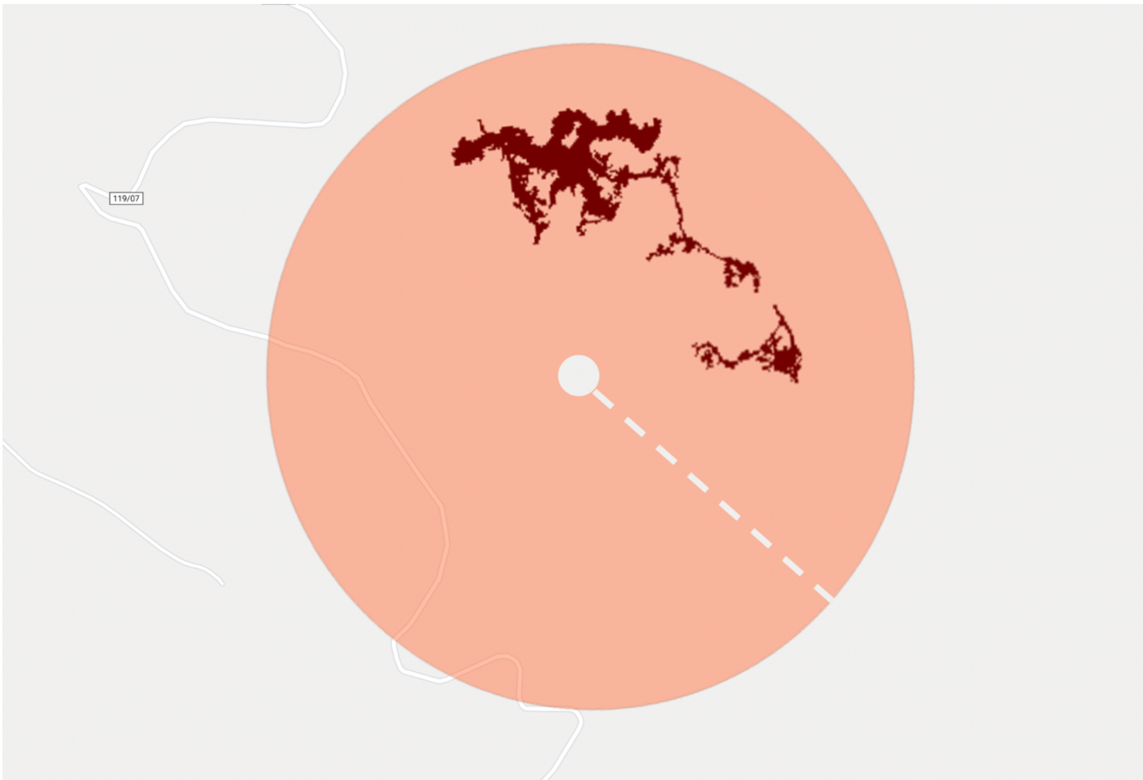

Figure 2.8.2. A 5km buffer of a mother's address(orange) overlaid with 2010 active surface mining polygons(maroon) (address and surface mine location altered for privacy)

Table 2.8.1. Odds ratios (95% CIs) for associations between adverse birth outcomes and amount of active and post mining within 5km of maternal residence in adjusted logistic model

	Amount of Mining within 5km of Maternal Residence			
	Active Mining (per 1% increase)		Post Mining (per 1% increase)	
Outcome Variable	**OR (95% CI)**	***P*-value**	**OR (95% CI)**	***P*-value**
Preterm	1.001(0.998,1.003)	0.501	1.001(1.000,1.002)	0.001
Low Birth Weight	1.004(1.002,1.007)	0.018	1.000(0.999,1.001)	0.913
Term Low Birth Weight	1.001(1.000,1.002)	0.123	1.000(1.000,1.000)	0.661

This regression was adjusted for mother's age, mother's race, mother's tobacco use during pregnancy, mother's education, mother's race, parity, year of majority of gestation, and child's sex

Table 2.8.2. Odds ratios (95% CIs) for associations between adverse birth outcomes and amount of active within 5km of maternal residence when logistic regression models were further adjusted for payment method and mother's Hispanic origin

	Active Mining within 5km of Maternal Residence (per 1% increase)	
Outcome Variable	**OR (95% CI)**	***P*-value**
Preterm	1.007(1.004,1.010)	<0.001
Low Birth Weight	1.003(1.001,1.004)	0.001
Term Low Birth Weight	1.001(0.999,1.002)	0.465

This regression was adjusted for mother's age, mother's race, mother's tobacco use during pregnancy, mother's education, mother's race, parity, year of majority of gestation, child's sex, payment method, and mother's Hispanic origin

Table 2.8.3. Odds ratios (95% CIs) for associations between adverse birth outcomes and amount of active and post mining within maternal ZCTA boundary in adjusted logistic model

	Amount of Mining within Maternal ZCTA Boundary			
	Active Mining (per 1% increase)		Post Mining (per 1% increase)	
Outcome Variable	**OR (95% CI)**	***P*-value**	**OR (95% CI)**	***P*-value**
Preterm	0.999(0.998,1.001)	0.350	1.001(1.001,1.002)	<0.001
Low Birth Weight	1.000(0.999,1.001)	0.878	1.000(1.000,1.001)	0.013
Term Low Birth Weight	1.001(1.000,1.001)	0.013	1.000(1.000, 1.000)	0.478

This regression was adjusted for mother's age, mother's race, mother's tobacco use during pregnancy, mother's education, mother's race, parity, year of majority of gestation, and child's sex

Table 2.8.4. Odds ratios (95% CIs) for associations between adverse birth outcomes and amount of active within ZCTA boundary when logistic regression models were further adjusted for payment method and mother's Hispanic origin

	Active Mining within ZCTA Boundary (per 1% increase)	
Outcome Variable	**OR (95% CI)**	***P*-value**
Preterm	1.004(1.003,1.006)	<0.001
Low Birth Weight	1.003(1.001,1.004)	<0.001
Term Low Birth Weight	1.001(1.000,1.002)	0.043

This regression was adjusted for mother's age, mother's race, mother's tobacco use during pregnancy, mother's education, mother's race, parity, year of majority of gestation, child's sex, payment method, and mother's Hispanic origin

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Chapter 3. Conclusions

3.1 Conclusions

This research has demonstrated the amount of active surface mining near maternal residence is associated with preterm birth, low birth weight, term low birth weight, and an overall decrease in birth weight. Births with the highest amount of mining within 5km of maternal address during the year in which the majority of gestation occurred saw statistically significant decreases in birth weight up to 140.7g and a 4.8% increase in the odds of a PTB or LBW birth. At the ZIP code-level, births with the highest amount of mining within maternal ZCTA boundary saw a significant decrease in birth weight up to 81.0g, a 3.9% increase in the odds of a PTB, and a 2.0% increase in the odds of a tLBW birth. These results also highlight the importance of analyzing exposure data at multiple spatial scales as our finer street-level spatial scale provides a unique, individual exposure, while the ZIP code scale is more representative of the population as it includes those lost in the geocoding process. Analyses that additionally included payment method and mother's Hispanic origin variables drastically decreased our street-level sample size by 56.4% and our ZIP code-level sample size by 49%; however, the associations generally mirror that of our primary models. Our results also suggest a relationship between post mining, when no increases in air pollution would be expected, and adverse birth outcomes, which should be explored further. These results help fill a significant gap in the literature in regard to the relationship between exposure to surface mining and rural, maternal health in Central Appalachia. Community-based environmental health education programs may be helpful in disseminating information on how to minimize exposure during gestation.

3.2 Recommendations for Future Work

Future work should further explore different measures of proximity to pre, active, and post surface mining activity. Future analyses would benefit by utilizing exposure data from differing buffer sizes, both greater than and less than 5km to better establish how proximity to surface mines may affect the relationship. Maternal proximity to roads likely used by haul trucks may be used in a future study to analyze exposure to roadways and traffic-related emissions. An exposure study related to diesel exhaust from haul trucks could be conducted using average haul truck activity, amount of coal produced in the regions, and birth records. Variables identifying surface mining-associated watersheds and airsheds have been determined as a part of a larger study and can be added to these regression models. Airshed modeling by Molly McKnight has determined the cumulative influence of active mining airsheds on individual births. Watershed modeling by Ethan Smith has found the drinking water systems that are most likely to be influenced by mining activity. These models can determine if the mining airsheds or watersheds mediate the relationship between proximity to surface mining activities and adverse birth outcomes.

Due to the 2019 release of Drug Enforcement Agency's (DEA) opioid transaction database, there is potential for a study to analyze this data at the county and ZIP code-level to determine if there is a relationship between opioid distribution and adverse birth outcomes in Central Appalachia. The number of oxycodone or hydrocodone pills distributed to a county per capita can be used to indicate areas of high opioid abuse due to overprescribing and distribution from pharmaceutical companies. To best understand the relationship between county or ZIP code-level opioid distribution and adverse birth outcomes, researchers should first create a methodology which best determines which localities mothers are most likely to receive their prescription.