Identifying exposure pathways mediating adverse birth outcomes near active surface mines in Central Appalachia

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Background: Previous work has determined an association between proximity to active surface mining within Central Appalachia and an increased risk of preterm birth (PTB) and low birthweight (LBW). Multiple potential exposure pathways may exist; however, including inhalation of particulate matter (airshed exposure), or exposure to impacted surface waters (watershed exposure). We hypothesize that this relationship is mediated by exposure to contaminants along one or both of these pathways.

Methods: We geolocated 194,084 birth records through health departments in WV, KY, VA, and TN between 1990 and 2015. We performed a mediation analysis, iteratively including within our models: (a) the percent of active surface mining within 5 km of maternal residence during gestation; (b) the cumulative surface mining airshed trajectories experienced during gestation; and (c) the percent of active surface mining occurring within the watershed of residency during gestation.

Results: Our baseline models found that active surface mining was associated with an increased odds of PTB (1.09, 1.05–1.13) and LBW (1.06, 1.02–1.11), controlling for individual-level predictors. When mediators were added to the baseline model, the association between active mining and birth outcomes became nonsignificant (PTB: 0.48, 0.14–1.58; LBW 0.78, 0.19–3.00), whereas the association between PTB and LBW remained significant by airshed exposure (PTB: 1.14, 1.11–1.18; LBW: 1.06, 1.03–1.10).

Conclusions: Our results found that surface mining airsheds at least partially explained the association between active mining and adverse birth outcomes, consistent with a hypothesis of mediation, while mediation via the watershed pathway was less evident.

Keywords: Mediation; Surface mining; Maternal health; Environmental health; Preterm birth; Low birthweight; Coal mining

Introduction

Communities within the Central Appalachia region, containing areas within Virginia, West Virginia, Kentucky, and Tennessee, experience some of the most severe economic and health disparities across the United States. Although poverty has generally decreased since the mid-1900s, the region has not experienced corresponding expected health gains, and continues to lag behind national poverty estimates, with increased rates of unemployment, lower levels of postsecondary education, and lower life expectancy. Surface mining became more widespread in the 1990s, and represented over 60% of coal mined in 2019. Within Central Appalachia, coal production has declined in the 2010s and there were nearly double the amount of surface mines as underground mines in 2019, despite relatively levels of coal production. Surface mining has disrupted the local environment, where the forest is cleared, rocks and topsoil are loosened through explosives to expose the underlying coal seams, and the resultant rubble is dumped into nearby valleys and headstreams.

These surface mining activities have been previously associated with adverse health outcomes. For example, a county-level cross-sectional analysis found higher rates of respiratory disease, hypertension, and kidney disease among populations living in counties with greater coal production, as compared with those living further away from coal mining.

What this study adds

Previous work published in Environmental Epidemiology has determined an association between living near surface mining activities within Central Appalachia and an increased risk of adverse birth outcomes. The exposure pathways underlying this association; however, remain unclear, including inhalation of particulate matter versus exposure to contaminated water. This work aims to identify the potential exposure pathways underpinning this relationship, which may be mediated by one or both pathways. Our results suggest that the association between surface mining and adverse birth outcomes is driven in part by exposure to airsheds near active surface mining activities, while mediation via watersheds was less clear.
activities. However, the relative importance of the exposure pathways underlying these associations remains less clear. Previous research outlining the public health impacts of surface mining activities has proposed two possible biological mechanisms to explain these relationships. First, there is evidence that inhalation of particulate matter is increased near-surface mining activities. Within Central Appalachia, surface mining activities result in increased emissions of acidic aerosols such as sulfur dioxide and nitrous dioxide, as well as particulate matter smaller than 10 \( \mu \) in diameter (PM\(_{10}\)) as a result of trucks hauling coal. Studies have found that particulate matter collected from nearby surface mines results in increased inflammatory responses and vascular tissue damage in a rodent model and increased carcinogenic markers in human lung cells, which is consistent with the higher rates of cardiovascular and lung disease observed in the region. Exposure to air pollution is known to result in a range of adverse health outcomes across life stages, including adverse birth outcomes.

Second, exposure to heavy metals in drinking water contaminated by surface mining activities has also been proposed as a causal pathway linking adverse health outcomes and proximity to surface mining activities. However, little research is available that quantifies the \textit{in situ} exposure to heavy metals, water quality, and sources of drinking water used within Appalachian counties. Although associations between metals in water and increased rates of cancer and chronic disease have been noted, researchers have called for a more thorough investigation of these associations linked specifically to exposure to waterborne contaminants and dose of exposure, whereas controlling for behavioral risk factors such as tobacco use. Despite this lack of evidence, other studies within the field of aquatic ecology have noted elevated concentrations of heavy metals and nonmetallic ions downstream of active and historic surface mining activities, resulting in the loss of aquatic biodiversity within Appalachian headwater streams. Given that these streams are inevitably hydrologically connected to source waters for regional drinking water supplies, degradation of aquatic ecological health potentially indicates important concurrent public health risks.

Surface mining activities have more specifically been shown to correlate with adverse birth outcomes, such as birth defects, low birthweight (LBW), and premature birth. Among nearly 2 million births across four Central Appalachian states, Ahern et al. suggested that rates of birth defects were higher in areas with mountaintop removal as compared with areas with no mountaintop removal, after controlling for covariates. Other studies have further suggested that air pollution containing fine particulate matter, such as particulates resulting from surface mining activities, can reach the fetal placenta and trigger inflammatory responses, which may, in turn, explain associations between air pollution and adverse birth outcomes such as LBW and preterm birth (PTB). Within the Central Appalachia region, Ahern et al. have documented an independent risk of LBW among women living within an area with coal mining activities in West Virginia. More recently, Buttling et al. suggested an increased risk of LBW and PTB among women living within 5 km of an active surface mine. Here, this work builds upon the findings outlined in Buttling et al., to examine the potential underlying pathways mediating the documented association between active surface mining activities and adverse birth outcomes. More specifically, we aim to explore airshed and watershed exposure pathways as potential mediators of the association observed between proximity to active surface mining activities and adverse birth outcomes.

We undertake a mediation analysis within a logistic regression modeling framework to examine the odds of PTB and LBW associated with proximity to surface mining activities during gestation may be mediated by airshed or watershed pathways, or both, and examine the potential additive effects of these mediators.

### Methods

#### Data

We obtained birth records for four states across Central Appalachia, provided by departments of health in Kentucky (KY), Tennessee (TN), Virginia (VA), and West Virginia (WV) (Figure 1). This dataset is described in detail in Buttling et al. Briefly, a total of 409,394 birth records were obtained from departments of health with street addresses of reported maternal addresses. Records were removed due to missingness in street addresses with many records reporting only mailing addresses (such as a rural route or P.O. box), resulting in a final dataset comprising 194,084 births between 1990 and 2015 with a geocoded maternal residential address. Our previous analysis shows differences in maternal characteristics of births from the original and final dataset are minimal and an additional analysis using a zip-code level exposure variable that allowed the inclusion of most of the original records resulted in similar effect estimates.

The exposure variable of interest within this dataset was the proportion of land designated as “active surface mining” within a 5-km radius of the maternal address during the majority gestation year. Pre-mining areas were defined as areas that were classified as actively mined in future years of the study period. Mined areas <40 acres in size were removed from the analysis, as the Office of Surface Mining Reclamation and Enforcement reported that economically viable mines are generally at least 40 acres in size.

More specifically, yearly active surface mining activities were defined using a combination of land cover change and mining permits, obtained from Marston and Kolivras for the years 1986 through 2015 using 30 m resolution Landsat remote sensing imagery. Specifically, this dataset used remote sensing technology and satellite imagery to quantify changes in the extent of surface mining areas greater than 40-acres over the corresponding years among areas where mining permits were requested. For each year, barren land on which vegetation had been removed was identified, and pixels that were tied to other types of land disturbance (such as clear-cutting of timber) were manually excluded. The remaining barren pixels lying within areas permitted for mining within the United States Geological Survey-defined Appalachian coalfields were designated as places where active mining was likely taking place. Active surface mining was delineated from postmining areas through classification of vegetation, where actively mined areas tend to have major land disruption and degradation, whereas postmining areas tend to show some revegetation through reclamation efforts.

To assess the accuracy of the mined area dataset, Marston et al. applied a standard validation process within remote sensing to the identified mined layer. Specifically, 2,250 points were placed within eight randomly selected counties across the Appalachian coalfield region of Central Appalachia. Data from these counties had not previously been used for the initial identification (training) of mined areas. The classification of these points (mined or not) was compared with aerial imagery from the National Agricultural Imagery Program (NAIP, 1 m resolution), land cover data from the National Land Cover Dataset, and Landsat images that were not used for initial classification. The overall classification accuracy was 0.88, or 88%, and the kappa coefficient to measure agreement was also 0.88, indicating “strong” agreement. When errors were identified, they tended to be along the edges of mined areas. If a pixel at the edge of a cleared area is half barren and half forested, the classification process will classify that pixel as one or the other, with the potential for error to occur.
Airsheds for each of the active surface mines in each year of analysis were estimated using the HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT4) atmospheric trajectory model, which uses meteorological data to compute atmospheric trajectories, particle dispersion, and air concentrations. Detailed methods using HYSPLIT4 to characterize airsheds of surface mines are described in further detail in McKnight et al. Briefly, we modeled individual airsheds of each active surface mine in the study area. The results of this process were raster data sets (e.g., a pixelated or gridded surface where each pixel or grid square corresponds to a specific geographical location and has an associated value) comprised of frequency values relating to air movement from surface mines per gridded cell. To quantify total exposure in pregnancy from all mines, we summed the frequency values of all airsheds extracted at each maternal address location for the cumulative amount of air from surface mines experienced at the maternal residential address. Watersheds were classified using 10-digit hydrologic unit codes (HUC10) within the United States Geological Survey’s Watershed Boundary Dataset, which represent the areal extent of surface water drainage using an aggregated collection of hydrologic unit data and amount of active surface mining within watersheds for each year of the study period was calculated.

Analysis
We employed mediation analyses to explore the potential exposure pathways that could explain associations between living in close proximity to active surface mining activities and increased odds of PTB and LBW described in Buttling et al., accounting for prem丁ing differences and additional individual-level covariates available on birth records. Mediation analyses are helpful in exploring the underlying mechanisms underpinning a known relationship between an exposure and outcome. Generally, mediation is suggested when four criteria are met, as outlined in Table 1.

Our independent variable of interest was the percent of the land within a 5-km radius of the maternal residential address that was designated as an active surface mine during the majority year of gestation (n = 23,733). Participant characteristics by exposure status are reported in Buttling et al. (2021), and are included in Supplementary Information (eTable S5; http://links.lww.com/EE/A185; http://links.lww.com/EE/A185. Our dependent variables of interest included (1) PTB, defined as birth before 37 weeks of gestation; (2) low birthweight (LBW), defined as birthweight less than 2,500 grams; and (3) term low birthweight (TLBW), defined as birth occurring at ≥37 weeks gestation and birthweight less than 2,500 grams. Using these criteria, we tested whether mediation between proximity to active surface mining activities during the year containing the majority of the pregnancy (majority gestation year) and these adverse birth outcomes occurred via the airshed pathway or the watershed pathway. We quantified these potential mediators (Figure 2), respectively, as: (1) the cumulative potential exposure to air pollutants via the airshed experienced at the maternal residential address during the majority gestation year, and (2) the percent of land experiencing active surface mining within the watershed of residency during the majority gestation.
The cumulative potential exposure to airborne pollutants via the airshed is outlined in further detail within McKnight et al. Briefly, these values represent the cumulative frequency of air originating from active surface mines, as modeled via the HYSPLIT4 atmospheric trajectory model. Residential addresses associated with higher values have higher potential exposure to surface mining air pollution, including fine particulate matter.

We firstly employed a Sobel test using the bda package in R software to quantify whether mediators significantly influenced the relationship between the independent and dependent variables. We performed a logistic regression analysis using the stats package within the R software. Covariates within our model included categorical variables found on birth records including maternal age ("18–35 years," "<18 years," ">35 years"); highest education attained by the mother at the child's birth ("8th grade or less," "9th–12th grade [includes high school graduates]," "Post-high-school education [with or without degree]"); race ("White," "Black," "Other"); ethnicity ("Hispanic," "Not Hispanic"); self-reported tobacco use during pregnancy ("Yes," "No"); sex of the child ("Male," "Female"); payment type for birth medical services ("Medicaid," "Private Insurance," "Self-Pay," "Other"); state ("Kentucky," "Tennessee," "Virginia," and "West Virginia"); and continuous percent of land within 5 km of maternal residence that was not actively experiencing mining activities during the majority gestation year but would be subsequently mined in later years (referred to as "pre-mining" activities), to account for any temporal baseline difference before active mining. Because mining activities tend to show spatial autocorrelation (e.g., active mining tends to move progressively across the landscape and is therefore closely correlated with premining landcover), we further included an interaction term between the amount of pre-mined land and surface mining land within a 5-km buffer of maternal residence. Lastly, to allow for nonlinear temporal trends observed within the data and account for serial autocorrelation, we included a spline with 4 degrees of freedom in the year covariate using the stats package within R software. This approach is a mixed effect modeling approach, similar to including random effects described above, including the independent variable of interest (e.g., % surface mining activities in a 5-km buffer).

To explore hypothesized mediation pathways, we tested three model types that iteratively built on each other (Figure 3). Our base adjusted model (Model 0) included the suite of fixed effects described above, including the independent variable of interest (e.g., % surface mining activities in a 5-km buffer). Model 1 included the same suite of variables as Model 0, with the addition of the airshed mediator variable alone, whereas Model 2 included the watershed mediator alone. Lastly, Model 3 included the addition of both the airshed and watershed mediators. All models included an interaction term between premining surface area and active surface area as described above, plus an interaction term between the mediator(s) and exposure variable. We report model performance metrics, including McFadden's pseudo-$R^2$ statistic, Akaike Information Criterion (AIC), and mean adjusted error (MAE) and root-mean squared error (RMSE) measures. AIC represents a measure of model predictive power as a trade-off with model complexity, with lower values generally representing models with better fit. MAE and RMSE represent model precision and bias, with values closer to zero representing better model fit, whereas pseudo-$R^2$ values represent variance explained by the model, with values between 0.2 and 0.4 representing reasonable model fit across a range of applications.

**Results**

**Sobel test**

Results of the Sobel test suggesting evidence of whether mediation is occurring are presented in Table 2. For each dependent variable of interest, we conducted an independent Sobel test exploring whether mediation is occurring via the airshed pathway (M = air) and the watershed pathway (M = water), with the independent variable of interest defined as proximity to surface mining. Evidence suggested that mediation was occurring via the airshed pathway for PTB, LBW, and TLBW outcomes (p < 0.001), whereas evidence was less clear for mediation of TLBW. There was further evidence suggesting that mediation may be occurring via the watershed pathway for PTB (p = 0.012) but mediation was less clear for other birth outcomes.

**Unadjusted model results**

We first explored unadjusted model results for each dependent variable of interest, as outlined in Table 3. Specifically, the results of these unadjusted models are used to test whether the independent variable was significantly associated with the

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### Table 1. Mediation Criteria, adapted from

| Criteria Assessed                                                                 | Statistical Test(s) Used | Unadjusted regression model | Adjusted regression model |
|---------------------------------------------------------------------------------|--------------------------|-----------------------------|---------------------------|
| Independent variable significantly influences the mediator                      |                          |                             | Sobel test                |
| Independent variable significantly influences the dependent variable (in absence of the mediator) |                          |                             |                           |
| Mediator significantly and uniquely influences the dependent variable           |                          |                             |                           |
| The effect of the independent variable on the dependent variable shrinks with the addition of the mediator |                          |                             |                           |

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### Table 2. Unadjusted model results

| Model | Independent variable | Mediation pathway | Adjusted R² | AIC | RMSE | MAE |
|-------|----------------------|-------------------|-------------|-----|------|-----|
| 0     | % surface mining land | Airshed           | 0.23        | 62  | 0.8  | 0.4 |
| 1     | % active mining land | Watershed         | 0.21        | 65  | 0.9  | 0.5 |
| 2     | % pre-mining land    | Airshed           | 0.25        | 61  | 0.8  | 0.4 |
| 3     | % active mining land | Watershed         | 0.23        | 63  | 0.9  | 0.5 |

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**Figure 2.** Directed acyclic graph outlining potential mediators of the association between surface mining and adverse birth outcomes.
mediator, a key criterion indicating mediation. Towards this, we found that proximity to surface mining strongly influenced both hypothesized mediator pathways ($p < 0.001$). We further conducted unadjusted models on the dependent variables of interest before conducting adjusted models. Across all outcomes, both mediation pathways were generally strongly significant, with the exception of TLBW. Of note, results tended to be more strongly significant among the airshed mediation pathways, as opposed to the watershed mediation pathway.

### Table 2.

| Sobel Test Exploring Mediation via Airshed and Watershed Pathways from Surface Mining Operations on Birth Outcomes | Z value | Significance |
|---|---|---|
| $M = \text{air}, X = \text{surface mining}$ | | |
| Preterm birth | 14.20 | $9.78 \times 10^{-46}$*** |
| Low birthweight | 5.66 | $1.53 \times 10^{-08}$*** |
| Term low birthweight | 1.12 | 0.261 |
| $M = \text{water}, X = \text{surface mining}$ | | |
| Preterm birth | 2.522 | 0.012* |
| Low birthweight | 1.158 | 0.247 |
| Term low birthweight | 1.857 | 0.063 |

Significant codes: 0 = ***; 0.001 = **; 0.01 = *.

### Table 3.

| Unadjusted Model Exploring Birth Outcomes by Exposure to Surface Mining via Airshed and Watershed Mediation | Covariates | $\hat{\beta}$ | SE | Significance |
|---|---|---|---|---|
| Preterm Birth | PTB – air | 0.138 | 0.009 | $<2 \times 10^{-16}$*** |
| | PTB – water | 0.061 | 0.015 | 2.69 $\times 10^{-05}$*** |
| Low Birthweight | LBW – air | 0.069 | 0.011 | 7.04 $\times 10^{-11}$*** |
| | LBW – water | 0.047 | 0.017 | 0.00473** |
| Term Low Birthweight | TLBW – air | 0.028 | 0.017 | 0.0928 |
| | TLBW – water | 0.069 | 0.026 | 0.00865** |
| Mediators | Surface mining – air | 0.228 | 0.002 | $<2 \times 10^{-16}$*** |
| | Surface mining – water | 0.729 | 0.002 | $<2 \times 10^{-16}$*** |

Significant codes: 0 = ***; 0.001 = **; 0.01 = *.

LBW, low birthweight; PTB, preterm birth; TLBW, term low birthweight.
of watershed mediation was less clear among all outcomes, and among TLBW, evidence of mediation via either airshed or watershed pathways was lacking. Table 4 and Figure 4 show whether the effect of the independent variable was reduced after the addition of the mediating variables, outlining the odds ratio and 95% CIs of proximity to surface mining in predicting each birth outcome. Beige lines represent the base model (Model 0) with no mediation variables, whereas pink represents the addition of the airshed variable alone (Model 1), maroon represents the addition of the watershed variable alone (Model 2), and brown represents the addition of both air and watershed variables together (Model 3). Across all outcomes, the odds of PTB, LBW, and TLBW as explained by proximity to surface mining were reduced with the addition of the airshed mediator, either alone (Model 1) or combined (Model 3). Interestingly, the association between surface mining and birth outcomes became nonsignificant among PTB and LBW in the models.
including the airshed mediator (pink/brown), but remained signifi-
cant among models with the watershed mediator alone (maroon),
with the exception of TLBW, which was not significant regardless
of the addition of mediators.

Discussion

Previous studies have suggested proximity to surface mining activ-
ities is associated with an increased odds of adverse health out-
comes, including adverse birth outcomes, and birth defects.1-2,4 The
direct and indirect causal pathways underlying these associa-
tions, however, remain less clear.4-6 Here, we aimed to clarify
these associations by exploring hypothesized mediating pathways
linking exposure to coal mining activities and resultant birth out-
comes. Overall, we found evidence that living within airsheds of
active surface mines is associated with higher odds of PTB and
LBW outcomes, with airsheds mediating the effect of living in close
proximity to surface mines on these birth outcomes. Specifically,
the airshed pathway met all four mediation criteria (Table 1): (1)
the airshed pathway was significantly associated with active sur-
face mining (Table 3); (2) proximity to active surface mining was
significantly associated with both PTB and LBW outcomes in the
absence of the airshed pathway (eTable S1; http://links.lww.com/
EE/A185 and eTable S2; http://links.lww.com/EE/A185, Model 0); (3)
the airshed pathway significantly and uniquely was associated
with PTB and LBW outcomes (eTable S1; http://links.lww.com/
EE/A185 and eTable S2; http://links.lww.com/EE/A185, Model 1); and
(4) the association between proximity to active surface min-
ing sites and both PTB and LBW outcomes was reduced with the
addition of the airshed pathway (Table 4). Evidence of mediation
was less clear for TLBW. Although criteria 1 and 4 were met, the
effect of proximity to active surface mining on TLBW was not
significant to suggest an association. Although mediation was not
clear, this outcome was strongly explained by maternal age at
birth, race, self-reported tobacco use, payment type for birth ser-
dices, and child sex, with the highest odds of TLBW among those
reporting tobacco use (OR: 3.06, 2.80, 3.35).

Evidence for mediation along the watershed pathway across
outcomes was less clear. Although the watershed pathway was
significantly associated with active surface mining, and the
effect of surface mining on the dependent variables was gener-
ally reduced with its addition, the watershed pathway was not
significantly and uniquely associated with the adverse birth out-
comes, as evidenced in Table 4 (Model 3). These findings are in
line with results from the Sobel test (Table 2), which suggested
mediation along the airshed pathway for PTB and LBW, but not
along the watershed pathway.

These findings suggest that the most likely exposure pathway
underlying the association between active surface mining and
PTB and LBW outcomes likely occurs via air, potentially influ-
enced by particulate matter emissions from coal mining activi-
ties. Evidence suggested mediation via the watershed pathway
was less likely, which is unsurprising given the pathway between
water pollution and drinking water is more complex than expos-
ure to air pollution. For example, the majority of residents in this
region are served by municipal drinking water, which is treated
before distribution and consumption;4 adverse changes to source
water quality will only have an impact if these treatment systems
fail. In addition, it is well-documented that changes in household
water quality can alter consumption source patterns: specific to
this region, a residential survey conducted in West Virginia found
that perceptions of poor water quality within the area resulted in
behavior changes among the respondents, such as consuming
bottled water over tap water.4 Exposure to developmental tox-
ics via contamination of surface or groundwaters, therefore,
represents a potential indirect exposure pathway, which might be
alleviated by water treatment before reaching the household tap
or alternative drinking water sources (e.g., bottled water).

These analyses should be considered within the context of
their associated limitations. First, we did not directly measure
air pollutants or water pollutants, but instead used proxy atmo-
spheric models and geological boundaries. For example, we used
satellite imagery to designate temporal surface mining activities
based on mine permits and barren land cover; whereas this classi-
ﬁcation likely represents active surface mining activities because
the change in landcover due to surface mining is stark, it does not
capture on-the-ground information about mining activities
and air or water emissions. Using these proxies, therefore, does
not quantify an individual's actual exposure to air and water
pollutants, heavy metals, etc., and future research could aim to
better characterize individual exposure via prospective studies.
Further, the time scale of the main exposure variable (proximity
to active surface mining) is annual due to limitations in obtaining
reliable imagery of surface mining activity on a monthly times-
scale.4 We calculated an airshed for each mine for every year of
the study time period and matched the relevant year’s cumulative
airshed frequency value to a birth record’s gestational majority
year. Given that we had one mine boundary for each year, we
were not able to calculate airsheds at a ﬁner time scale than one
year (e.g., at the gestational trimester level). Although we do not
expect that mine boundaries shift signiﬁcantly at a ﬁner time
scale, exploring exposure during the gestational trimester rep-
resents a promising opportunity for future study. Second, our analyses are limited to women with an identiﬁ-
able street address (e.g., excluding post ofﬁce boxes, etc.). It was
necessary; however, to restrict our analyses at this level to link
individual births to surface mining airsheds and watersheds. Our
previous analyses using ZIP code level exposures that allowed
for the inclusion of most birth records in the dataset showed that
ZIP code and street-level analyses provided similar results,22
increasing our conﬁdence that the current analysis is minimally
biased due to this limitation. Third, our analyses rely on second-
ary data sources and are therefore limited to socioeconomic and
demographic characteristics existing on birth records. Namely,
tobacco use within these records was self-reported, which may
d not represent actual tobacco use in pregnancy. Further, other
important characteristics such as illicit substance use, household
income, etc. were not included in our analyses, as these covari-
ates did not exist on birth records, and could be a source of
potential bias in the present analysis. However, while these non-
observed maternal characteristics could be associated both with
mothers’ place of residence and birth outcomes, active surface
mining is estimated yearly, such that birth outcomes from the
same area before or after active surface mining are compared
with births in which gestation occurs during active mining.
Future research could incorporate additional area-level socio-
demographic characteristics within a hierarchical framework.

Conclusions

Surface mining activities have dramatically altered the Central
Appalachia landscape, and the environmental and public health
consequences are still being characterized. Although previous
literature links proximity to surface mining activities and resul-
tant adverse birth outcomes, the exposure pathways underlying
these associations remain poorly understood. Our study rep-
resents a novel mediation analysis using nearly 200,000 geolo-
cated birth records spanning four states in Central Appalachia
from 1990 to 2015 to explore airshed and watershed exposure
pathways as mediators of the relationship between surface min-
ing activities and adverse birth outcomes. Our findings suggest
that the airshed pathway mediates the association between sur-
face mining activities and PTB and LBW outcomes, but evidence
of mediation via the watershed pathway was less clear.
Acknowledgements

The authors would like to acknowledge the contributions made to compiling the datasets used in these analyses by the following individuals: M.M., L.M., and E.S. The authors would also like to thank A.M. and B.R. for their feedback while these analyses were being conducted.

Data use agreements with state health agencies prohibit authors from sharing birth record data used in the analysis. Satellite-derived datasets are publicly available, or available on request. Code required to replicate results are available upon request.

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