

Mortality Rates in Appalachian Coal Mining Counties: 24 Years Behind the Nation

Michael Hendryx

ABSTRACT

Appalachia has higher morbidity and mortality compared to the nation, and suffers greater socioeconomic disadvantages. This article investigates the relationship of coal mining to elevated mortality rates in Appalachia. Total mortality rates for the years 1999–2004 were investigated in a national county-level analysis that included coal mining as the primary independent variable. Counties in Appalachia where coal mining is heaviest had significantly higher age-adjusted mortality compared to other Appalachian counties and to other areas of the country. Elevated mortality rates persisted in Appalachian coal mining areas after further statistical adjustment for smoking, poverty, education, rural-urban setting, race/ethnicity, and other variables. After adjustment for all covariates, Appalachian coal mining areas were characterized by 1,607 excess annual deaths over the period 1999–2004. Adjusted mortality rates increase with increasing coal production from 1 to 7 million tons. These findings highlight environmental inequities that persist in Appalachian coal mining areas. Reducing these inequities will require development of alternative economies and promotion of environmental justice through regulatory and allocative policy changes.

APPALACHIA HAS LONG been characterized by social inequalities and health disparities.^{1–4} Recently, the contributions that the coal mining industry makes to these inequalities and disparities has come under closer attention. Coal mining areas are linked to higher population hospitalization rates for some cardiovascular and respiratory conditions,⁵ and to higher reported rates of some forms of chronic illness and poorer reported health status.⁶ Compared to other parts of Appalachia, coal mining areas are also characterized by poor socioeconomic conditions including higher levels of poverty and lower education rates.⁷

The purpose of the current study was to extend prior research on the community health impacts of the Appalachian coal mining industry through an examination of mortality rates. The study tests whether mortality rates are elevated in Appalachian coal mining areas, and whether elevated mortality, if found, is due solely to socioeconomic conditions or if an additional effect specific to coal mining persists. The study also examines temporal trends in mortality in coal mining areas. Three hypotheses are tested:

1. Coal mining areas of Appalachia will be associated with higher total mortality rates compared to the rest of Appalachia and the nation, both before and after adjustment for socioeconomic covariates.
2. Mortality rates will be higher in Appalachia compared to the nation, but these rates will not remain elevated after controlling for socioeconomic effects.
3. Elevated mortality in Appalachian coal mining areas will be present over the time period 1979 to 2004.

METHODS

Design

The study is a retrospective investigation of national mortality rates for the years 1979–2004. The level of analysis is the county (N = 3,141; missing data on covariates reduced the sample by 61 cases for regression analyses). The study is an analysis of anonymous, secondary data sources and meets university Internal Review Board standards for an exception from human subjects review.

Data

Mortality data were obtained from the Centers for Disease Control & Prevention (CDC) measuring county-level mortality rates per 100,000, age-adjusted using the 2000

Dr. Hendryx is Associate Professor, Department of Community Medicine, at West Virginia University in Morgantown, West Virginia.

US standard population.⁸ Total mortality rates were examined for all internal causes, excluding causes from external factors (homicide, suicide, motor vehicle accidents, other accidents.) All ages were included. Analyses for hypotheses 1 and 2 use mortality figures for the years 1999–2004 combined, and analysis of hypothesis 3 uses annual mortality figures for the years 1979 through 2004.

Coal production data were obtained from the Energy Information Administration (EIA)^{9–14} measured as tons of coal mined in every county each year for the years 1999–2004. Levels of coal mining were not normally distributed across counties. To estimate exposure, two primary analyses were conducted. The first examined mortality based on dividing counties across the country into four groups: Appalachian counties with no coal mining, Appalachian counties with coal mining up to four million tons combined over the six years 1999–2004, Appalachian counties with coal mining greater than four million tons, and other counties in the nation with no coal mining (104 non-Appalachian counties where coal mining took place were deleted from the analysis.) The choice of 4 million tons divided Appalachian coal mining counties approximately in half, with 65 Appalachian counties mining less than 4 million tons over these years, and 67 with more than 4 million tons. The second method estimated per capita exposure, found by dividing county tons mined by the county population from the 2000 Census; counties were grouped into four levels: no mining in Appalachia, per capita exposure up to 200 tons per person, per capita exposure greater than 200 tons, and no mining in the rest of nation (used as the referent).

A series of supplementary analyses were conducted to test for the robustness of findings across alternative specifications of coal mining. One set of analyses examined coal mining effects when the higher category of coal mining was based on integer levels from one to seven million tons. A second set correspondingly examined per capita exposure effects at 50-ton increments from 50 to 400 tons per capita. A third set examined whether differences in mortality rates were related to surface mining versus underground mining. A fourth set examined whether mortality rates in coal mining areas were elevated only in Appalachian coal mining areas or in coal mining areas throughout the nation.

Coal production figures for years prior to 1999 are not readily available for all counties, therefore, tests of hypotheses 1 and 2 were constrained to mortality rates from the period 1999 to 2004. There is, however, considerable historical evidence that Appalachian counties characterized by heavy coal mining during recent years were also heavy coal mining areas in previous years and decades, simply as a consequence of the presence of economically minable coal in these areas.^{15–18} Therefore, the test of hypothesis 3 examined historical mortality rates from 1979 to 2004, using coal production data from 1999–2004 to identify heavy coal mining counties in Appalachia.

Data on covariates were obtained from the 2005 Area Resource File,¹⁹ CDC Behavioral Risk Factor Surveillance System (BRFSS),²⁰ and the Appalachian Regional Commission.²¹ Selection of covariates was based on previously

identified risk factors or correlates of elevated mortality.^{22–32} Covariates included smoking rates; percent male population; percent of the population with college and high school education; poverty rates; race/ethnicity rates (percent of the population who were African American, Native American, Non-white Hispanic, Asian American, using White as the referent category in regression models); percent without health insurance; physician supply (number of active MDs and DOs per 1,000 population); rural-urban continuum codes grouped into metropolitan, micropolitan, and rural; Southern state (yes or no, South equal to Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia); and Appalachian county (yes or no as defined by the 417 counties or independent cities in 13 states recognized by the Appalachian Regional Commission). CDC smoking rates were available for states and some county-based metropolitan areas; the state average was used when the specific county rate was not available.

Analysis

Analyses were conducted using bivariate correlations, general linear models and ordinary least squares multiple regression models to test for the association between coal mining and mortality, without and with control for covariates.

RESULTS

Table 1 shows total age-adjusted mortality rates for the four groups of counties before adding covariates. Mortality rates were highest in heavy coal mining areas of Appalachia, and were lowest in non-coal mining areas outside Appalachia. Other areas of Appalachia, either without mining or with lower levels of mining, had intermediate mortality rates.

Bivariate correlations were examined to test for multicollinearity among independent variables. The county poverty rate was highly correlated to percent of the population without health insurance ($r = .82$); therefore, the insurance variable was dropped from further analysis.

Table 2 shows multiple regression results that consider effects of covariates on mortality. Results for each model specification, total tons or tons per capita, were almost identical. Appalachian counties with lower levels of mining were not associated with differences in mortality, but counties characterized by high levels of coal mining had significantly higher mortality after accounting for effects of age, smoking, poverty, education, race/ethnicity, rural-urban setting and other measures. Higher mortality was also predicted independently from smoking, lower education, poverty, African American or Native American race, living in the South, and urban setting. A greater supply of physicians was related to higher mortality. A greater percentage Hispanic population was related to lower mortality. The Table 1 and Table 2 findings support the first two study hypotheses.

Based on the 2000 US Census, the population of Ap-

TABLE 1. AGE-ADJUSTED MORTALITY PER 100,000 FOR 1999–2004 BY COUNTY TYPE¹

<i>Appalachian coal-mining</i> <i>≥4 million tons</i>	<i>Appalachian coal-mining</i> <i><4 million tons</i>	<i>Other</i> <i>Appalachian</i>	<i>Rest of nation</i>
950.2 a	890.7 b	884.1 b	820.2 c

¹Model F = 53.67 (df = 3, 2,973), $p < 0.0001$. Letters a, b, and c indicate means significantly different at $p < 0.05$ using post-hoc Ryan-Einot-Gabriel Welsch multiple range test.

palachian counties where mining exceeded 4 million tons was 3,883,143. The age-adjusted death rate in coal mining areas compared to non-Appalachian, non-mining counties before covariate adjustment translates to 5,048 excess annual deaths in Appalachian coal mining areas for the years 1999–2004. After covariate adjustment, the coefficient (41.39) for the mining effect measured in tons translates to 1,607 excess annual deaths in Appalachian coal mining areas.

To examine the stability of effects at different defined levels of “high” coal mining, the regression models were repeated with all covariates for integer levels of high coal mining from 1 to 7 million tons, along with a model where Appalachia was included but the coal mining variables were not (see Figure 1). High levels of coal mining were significant at all levels, but the effect for Appalachia without coal mining was not. Furthermore, the coefficient for the coal mining effect increased from 1 to 5 million tons

before leveling off, suggesting a dose-response effect up to the 5 million ton level, beyond which the smaller number of counties meeting the definition of high mining suggests possible statistical power problems (N = 49 counties at 7 million tons). Even at one million tons, the estimated number of deaths was substantially higher than the estimate for the Appalachian region in general before inclusion of coal mining into the model. (Results are not shown for the corresponding tests of per capita exposure, but were significant at all levels from 50 to 400 tons, and the magnitude of the coefficient increased with increasing exposure.)

Models were also run separately for surface mining and underground mining, both within Appalachia and nationwide. Coal mining effects were significant for Appalachia and the combined analysis for both underground and surface mining, but not for coal-mining limited to ar-

TABLE 2. MULTIPLE REGRESSION RESULTS TO PREDICT 1999–2004 AGE-ADJUSTED MORTALITY

<i>Variable</i>	<i>Coal mining measured in tons</i>			<i>Coal mining measured in tons per capita</i>		
	<i>Unstandardized coefficient</i>	<i>Standard error</i>	<i>p<</i>	<i>Unstandardized coefficient</i>	<i>Standard error</i>	<i>p<</i>
Intercept	783.5	57.7	0.0001	785.2	57.7	0.0001
Coal mining <4 million tons	1.50	11.59	0.90	—	—	—
Coal mining ≥4 million tons	41.39	11.69	0.0004	—	—	—
Coal mining <200 tons per capita	—	—	—	8.58	10.82	0.43
Coal mining ≥200 tons per capita	—	—	—	40.76	12.69	0.0013
Appalachian region (no coal mining)	-3.16	5.99	0.60	-3.02	6.00	0.62
Smoking rate	4.70	0.54	0.0001	4.69	0.54	0.0001
Metropolitan county	51.66	4.20	0.0001	51.64	4.20	0.0001
Micropolitan county	21.47	4.14	0.0001	21.54	4.14	0.0001
Percent male	0.03	0.87	0.97	0.03	0.87	0.98
Primary care physicians per 1000	4.76	1.43	0.0009	4.79	1.43	0.0008
South region	29.10	5.05	0.0001	29.04	5.06	0.0001
Poverty rate	6.55	0.52	0.0001	6.56	0.52	0.0001
Percent African American	1.53	0.16	0.0001	1.54	0.16	0.0001
Percent Native American	1.90	0.24	0.0001	1.90	0.24	0.0001
Percent Hispanic	-1.75	0.17	0.0001	-1.72	0.17	0.0001
Percent Asian American	-0.90	0.80	0.26	-0.90	0.80	0.26
High school education rate	-1.79	0.41	0.0001	-1.77	0.41	0.0001
College education rate	-3.24	0.36	0.0001	-3.25	0.36	0.0001

¹Model adjusted $R^2 = 0.54$; F = 219.7 (df = 16, 2,959), $p < 0.0001$.

²Model adjusted $R^2 = 0.54$; F = 219.3 (df = 16, 2,959), $p < 0.0001$.

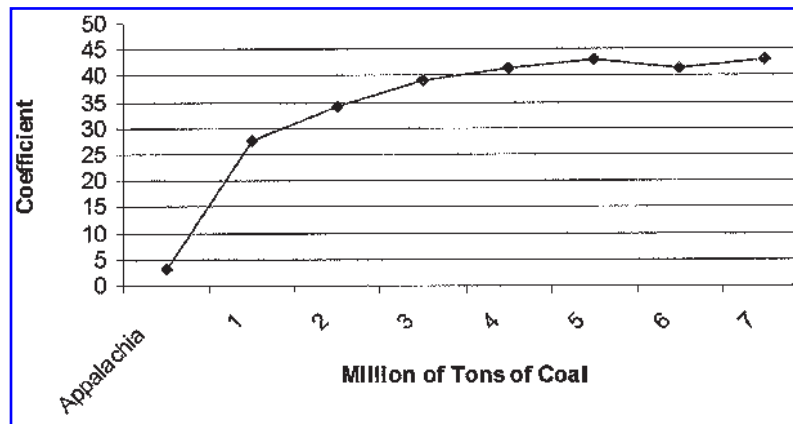


FIG. 1. Mortality per 100,000 in high Appalachian coal mining areas, 1999–2004, adjusting for all covariates, by level of mining. Appalachia refers to the effect of the Appalachia regional variable without consideration of coal mining. The Appalachia variable was not significant but all levels of mining were at $p < .009$ or better.

eas outside Appalachia (the analysis of non-Appalachian coal mining effects deleted Appalachian coal mining counties). Results are summarized in Table 3.

As the test of hypothesis 3, total age-adjusted mortality rates for the years 1979 to 2004 are shown in Figure 2 for three groups: Appalachian counties with coal mining ≥ 4 million tons, other Appalachian counties (either no mining or mining less than 4 million tons), and other counties in the nation. Mortality rates are significantly different across time ($p < .0001$), county type ($p < .0001$), and the time-county interaction ($p < .002$). Rates decline significantly over time for all groups, but are consistently highest for high coal mining areas of Appalachia. Compared to 1979, the mortality rates for 2004 were 13.3% lower in coal mining areas, 11.2% lower for other areas of Appalachia and 15.3% lower for the rest of the country; that is, the rate of decline was less for Appalachia and coal mining areas compared to the nation. Mortality rates for coal mining areas in 2004 are about the same as those for counties outside of Appalachia from 1980.

DISCUSSION

Results show that higher mortality in Appalachia is due to poverty, smoking, poor education, and race-related effects. Once these factors are accounted for, non-coal mining areas of Appalachia have death rates no different than the rest of the country. Coal mining areas, however, show

elevated age-adjusted mortality both before and after adjustment for covariates. This is the case when Appalachian coal mining is the focus, but not for coal mining areas outside of Appalachia. Age-adjusted mortality rates for Appalachian coal mining areas lag about 24 years behind national rates outside Appalachia.

Causes of elevated mortality in coal mining areas may reflect behavioral, cultural, and economic factors only partly captured through available covariates, but may also reflect environmental contamination from the coal mining industry. That effects were found for Appalachian coal mining areas but not coal mining areas elsewhere may reflect the unique relationship of mining activity to topography and population centers characteristic of Appalachia. Coal mining is a major industrial activity in eight Appalachian states.³³ Mountaintop removal mining methods have become more prevalent in Appalachia, and often occur close to population centers; in West Virginia, surface mining constituted 42% of total mining tonnage in 2006, compared to 19% in 1982.³⁴ Coal contains mercury, lead, cadmium, arsenic, manganese, beryllium, chromium, and many other toxic and carcinogenic substances³⁵ and the mining and preparation of coal at local processing sites releases tons of annual ambient particulate matter and contaminates billions of gallons of water.^{36–38} Coal preparation involves crushing coal into smaller particles, mixing coals of different qualities prior to sale, transporting coal via truck and rail, and remov-

TABLE 3. ADJUSTED REGRESSION COEFFICIENT FOR THE HIGH COAL MINING VARIABLE (≥ 4 MILLION TONS), BY MINING TYPE (SURFACE, UNDERGROUND, AND COMBINED), AND BY INCLUSION OR EXCLUSION OF NON-APPALACHIAN COAL MINING AREAS

	Surface mining	Underground mining	Combined
Coal mining in Appalachia only	43.25 ($p < 0.001$)	42.08 ($p < 0.001$)	41.39 ($p < 0.0004$)
Coal mining outside of Appalachia	-2.71 ($p < 0.84$)	15.84 ($p < 0.38$)	5.14 ($p < 0.65$)
Coal mining nationwide	17.21 ($p < 0.06$)	31.56 ($p < 0.002$)	21.50 ($p < 0.006$)

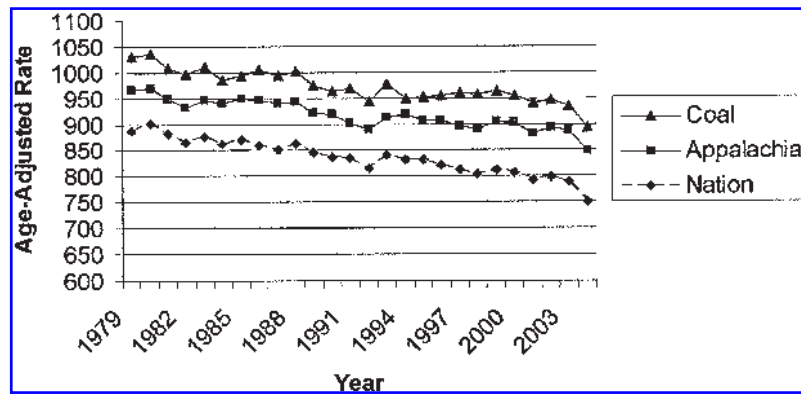


FIG. 2. Age-adjusted mortality per 100,000, 1979–2004, by county type (Appalachian coal mining, other Appalachian, or rest of nation). Model $F = 1422.7$ ($df = 3, 81,622, p < .0001$).

ing impurities through a chemical washing process. These preparation activities take place near the mining sites for both underground and surface operations. In addition to impurities removed by washing, chemicals used in the washing process may themselves be toxic.³⁹ The contaminated water, called slurry, is held in impoundment ponds or injected underground, where it poses risk of leaking into freshwater sources.⁴⁰ There are 111 impoundment ponds in West Virginia alone, holding more than 140 billion gallons of coal slurry.⁴¹

The environmental health impacts of the coal mining industry may operate through water and air transport routes. Shiber⁴² reports elevated arsenic levels in drinking water sources in coal mining areas of central Appalachia. Other studies of water quality near coal mining in Appalachia have been conducted^{43–45} showing that surface water and private well water are contaminated in ways consistent with coal slurry. Studies of local air quality in Appalachian coal mining communities have not been done, and constitute an important next step in this line of research. However, particle constituents in ambient air from coal mining or processing may occur at fine ($PM_{2.5}$) or coarse (PM_{10}) modes.⁴⁶ Coal particulates may also interact with diesel particulate matter; diesel engines are commonly used at mining and processing sites. Research has linked urban air pollution to premature mortality^{47,48} possibly from the exacerbation of acute or pre-existing illness. It may be the case that pollution from coal mining and processing activities has a similar effect.

Ironically, removal of coal impurities and crushing of coal into smaller pieces, although intended as an environmental protection step and to increase the efficiency of burning, result in impurities being left behind in the vicinity of coal mining communities. The coal cleaning process is described as “removing” impurities prior to burning,⁴⁹ but it would be more precise to say that these impurities are merely “relocated.”

Limitations of the study include the ecological design, the imprecision of covariates, and the limited availability of coal mining data. Individual causes of mortality and their relationship to mining or other variables may be suggested but cannot be proven with a county-level analy-

sis. Smoking was imprecisely estimated, and other behavioral contributions to mortality such as diet or alcohol consumption were not included, although these behavioral variables are known to correlate with other measures that were included such as education and poverty. Coal mining was measured only for the years 1999–2004; for the test of hypothesis 3 the reasonable but unproven assumption was made that this estimate reflected earlier mining activity. Mining effects in Appalachia were found for both underground and surface techniques (although the coefficient was slightly higher for surface mining); more specific forms, such as mountaintop removal versus other forms of surface mining could not be examined. Furthermore, key aspects of coal processing, including chemical washing and transportation, could not be linked to mortality data because of the lack of data specificity. Given that both surface and underground mining were related to mortality, it is important that future research examine population health effects from mining industry activity that are common to both methods, including relating operations of local coal processing facilities to measures of air and water quality and to health outcomes.

Ultimately, regardless of whether the persistently elevated mortality rates found in Appalachian coal mining areas result from environmental, social, economic, or behavioral causes, it is clear that serious health disparities persist in these areas and must be addressed. The underlying causes of health disparities are founded in economic, educational, and environmental injustices.^{50–52} To reduce and eliminate disparities requires that these root causes be attacked. For coal mining areas of Appalachia, this means that alternative and sustainable economies be developed, as a continued reliance on a coal-based economy will only perpetuate disparities. Results also highlight the need for improvements in environmental equity: people who live in these areas are subject to environmental degradation and exposure to pollutants in exchange for development of a relatively cheap energy source for many of the rest of us to enjoy.

The argument is often made that coal mining is an important economic contributor to the areas of Appalachia

where mining takes place,⁵³ and therefore that mining should be protected and encouraged. The first part of this argument is correct, but the second part is fallacious. Coal mining perpetuates poverty, environmental degradation, economic underdevelopment, and premature death. That it is an important part of a perpetually weak economy is no endorsement for its continuation. Coal mining remains an important part of these economies because underdeveloped infrastructure, blasted landscapes, poorly educated workforces, environmental health hazards, and chronically unhealthy populations perpetuate themselves over time and present strong discouragement to new business and population immigration.

Construction of more diverse, alternative economies should be undertaken. Such efforts could include sustainable timber or agriculture, development of marketable alternative energy such as wind power, investments in education and technology, and entrepreneurial ventures. Microcredit programs may be attempted as has been done successfully in parts of the developing world.⁵⁴ Business incubators to support small start-up ventures have been implemented in other parts of Appalachia⁵⁵ and may be extended to the coalfields. Ecosystem restoration to reclaim lands destroyed by mining may create jobs and business opportunities.⁵⁶ Regulatory and allocative policies may be implemented and enforced to require coal companies to reduce environmental impacts and to return greater portions of coal revenue to the places where the coal is mined, rather than to corporate offices located outside the region.

Finally, we should recognize that coal is mined primarily because there is a national and international market for it, whether or not it benefits the local population. Global initiatives are underway to increase use of alternative energy sources, and to re-calibrate the price of coal through consideration of environmental costs via carbon taxes or cap-and-trade programs. Such initiatives are critical to mitigate effects of climate change, and if implemented could dramatically reduce reliance on this polluting energy source.⁵⁷ Reductions in the external demand for coal will provide a crisis and an opportunity for the people of the Appalachian coalfields to redefine themselves and create healthier environments in a post-carbon world.

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Address correspondence to:

Michael Hendryx
 Department of Community Medicine
 West Virginia University
 One Medical Center Drive
 PO Box 9190
 Morgantown, WV 26506

E-mail: mhendryx@hsc.wvu.edu