

Review

Leigh-Anne Krometis*, Julia Gohlke, Korine Kolivras, Emily Satterwhite, Susan West Marmagas and Linsey C. Marr

Environmental health disparities in the Central Appalachian region of the United States

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Abstract: Health disparities that cannot be fully explained by socio-behavioral factors persist in the Central Appalachian region of the United States. A review of available studies of environmental impacts on Appalachian health and analysis of recent public data indicates that while disparities exist, most studies of local environmental quality focus on the preservation of nonhuman biodiversity rather than on effects on human health. The limited public health studies available focus primarily on the impacts of coal mining and do not measure personal exposure, constraining the ability to identify causal relationships between environmental conditions and public health. Future efforts must engage community members in examining all potential sources of environmental health disparities to identify effective potential interventions.

Keywords: air quality; Central Appalachia; coal mining; environmental health; health disparities; rural health; water quality.

Introduction

Some of the most severe health disparities in the United States (US) occur in rural Appalachia, particularly in Central

Appalachia near the borders of Virginia, West Virginia, Kentucky and Tennessee. Not surprisingly, in all three of the strategic plans it has produced since 2002, the National Institute on Minority Health and Health Disparities has recognized Appalachia as an area exhibiting persistent disparities that require further research. A recent analysis of health disparities in this region posits that, “at least as measured by traditional epidemiologic variables”, behavioral risk factors “seem insufficient to fully explain the region’s health disparities” [1], and yet studies specifically targeting environmental health disparities in the region are limited.

In order to identify primary research needs and engagement strategies to better define and confront these disparities, this paper aims to: (1) review primary health disparities in the region and past attempts to link these disparities with the unique environmental and economic landscape of Central Appalachia; (2) discuss existing regional research on environmental quality, exposure and outcomes, with a specific focus on water and air; and (3) identify research needs and challenges.

A history of health disparities

As in other regions where there is intensive natural resource extraction, the Appalachian region is often described as subject to the “resource curse”: poor economic conditions accompanying an abundance of minerals and fuels [2]. Historically, the region has been rich in natural resources such as timber, salt, gold, oil, iron ore, copper, and perhaps most notably, coal. Current land cover analysis indicates that, overall, 68% of the Central Appalachian region is forested, 27% is agricultural or pasture, 3% is developed (residential, commercial or industrial), 1% is wetlands or surface water and 1% is barren land, much of which is likely active mountaintop mining (Figure 1). Though barren land is small as an overall percentage, individual communities and counties can remain heavily impacted. Coal remains the source of one-third of electricity generation in the United States (US); however, production has sharply declined in the

*Corresponding author: Leigh-Anne Krometis, Biological Systems Engineering, Virginia Tech, 155 Ag Quad Lane, 312 Seitz Hall, Blacksburg, VA 24061-0303, USA, E-mail: krometis@vt.edu
Julia Gohlke and Susan West Marmagas: Population Health Sciences, Virginia Tech, 205 Duck Pond Drive, Virginia Maryland College of Veterinary Medicine, Blacksburg, VA 24061-0395, USA
Korine Kolivras: Geography, Virginia Tech, 220 Stanger St., 115 Major Williams Hall, Blacksburg, VA 24061, USA
Emily Satterwhite: Appalachian Studies, Religion and Culture, Virginia Tech, 280 Alumni Mall, 344 Lane Hall, Blacksburg, VA 24061, USA
Linsey C. Marr: Civil and Environmental Engineering, Virginia Tech, 1145 Perry St., Durham 411, Blacksburg, VA 24061, USA

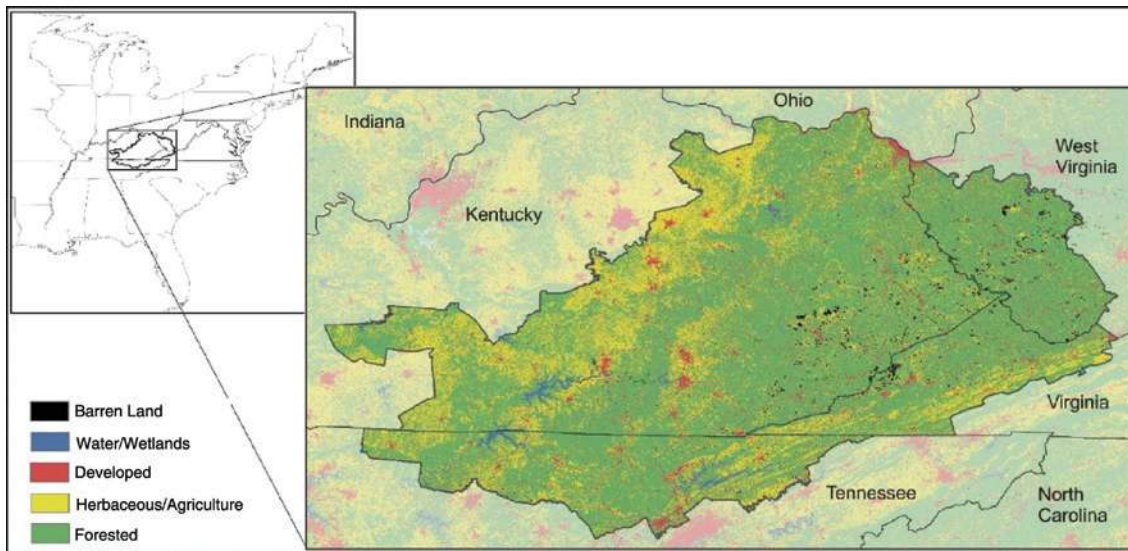


Figure 1: 2011 Land cover of the Central Appalachian region as currently defined by the Appalachian Regional Commission.

past decade as natural gas extraction in the region has become the predominant fossil fuel export [3, 4]. Despite this continuing trend, it is important not to discount coal's continuing impacts on the geography of Appalachia in the future: a recent geospatial model estimates that even under predictions of high natural gas production and low coal demand, almost 1000 km² of new mine development is expected in Central Appalachia in the next 20 years [5].

Although health trends in Appalachia have not been extensively documented, concerns related to poor health status in mining regions were noted almost 40 years ago [6] and these concerns remain today [7, 8]. Past studies indicate heightened incidences of chronic disease and premature mortality concentrated in Central Appalachia, with rates of cancer, cardiovascular and respiratory morbidity and mortality particularly elevated as compared to other regions of the US [9–14]. The most current available age-adjusted mortality data suggests these disparities are still present (Table 1). Note that, given the focus of this review on environmental risk factors rather than occupational risk factors, these data exclude the burden of disease associated with coal workers' pneumoconiosis ("black lung") and silicosis, which have been reviewed recently elsewhere [16].

Only a limited number of studies have been conducted to delineate the causes of observed health disparities, with the majority of research and outreach programs to date focused on lifestyle and behavioral risk factors. For example, obesity rates are particularly high in Appalachia; consequently, several cancer prevention programs have focused on increasing physical activity and promoting healthy eating, alongside increased screening initiatives in the broader region [17–19]. Reduced access to and

utilization of health care remains a complicating issue in Appalachia that likely results in delayed diagnosis, sub-optimal care, and ultimately worse outcomes from cancer, diabetes and cardiovascular and respiratory disease [20]. Most of rural Appalachia is designated as a health care shortage area (less than one primary care doctor per 3500 residents). Survey research indicates an overall poorer perception of health by communities in Appalachian counties versus non-Appalachian counties in the same states, and a need for low-cost health care services, particularly for dental, vision and mental health [21, 22]. Recently, Donohoe et al. [23] used a novel spatial access-to-care strategy incorporating driving time and distance to the nearest primary physician to demonstrate that residents in Appalachian counties have longer travel times to the nearest primary care doctor than residents in non-Appalachian counties in the same states.

In contrast to the comparatively thorough work related to socio-behavioral contributors to health in central Appalachia, for example, using standardized data collected through the Behavioral Risk Factor Surveillance System [24, 25], available investigations of environmental health disparities are very limited, and focus almost entirely on the impacts of coal mining, which remains both the dominant and the most regionally distinctive anthropogenic land-use. Ecological analyses have suggested county-level estimates of coal mining are a significant predictor of all-cause and cause-specific county mortality after adjusting for sociodemographic characteristics [26–29]. However, a similar ecological analysis suggested that mortality rates were associated with county-level sociodemographic characteristics including poverty rate, median household

Table 1: Mortality disparities in Central Appalachia (2010–2014).

Health outcome ^a	Rate per 100,000 in Central Appalachia ^b (95% CI)	Rate per 100,000 in the US (95% CI)
All mortality	1040.6 (987.4–1093.8)	734.6 (733.8–735.4)
All cancer mortality	224.8 (201.0–248.7)	170.5 (170.1–171.0)
Colorectal cancer mortality	19.2 (13.0–27.6)	13.8 (13.7–13.9)
Lung and bronchus cancer mortality	79.0 (65.4–93.6)	44.6 (44.4–44.8)
Heart disease mortality	243.7 (218.1–269.4)	171.3 (171.0–171.7)
COPD mortality	74.1 (60.6–88.7)	37.8 (37.6–38.0)
Demographics ^c	Percent of population in Central Appalachia	Percent of Population in the United States
Age, % ≥ 65 years	16.4	14.1
Gender, % female	50.9	51.5
Race and ethnicity, % minority	5.0	37.7
Education, % ≥ high school diploma	76.6	86.7
Living in poverty, %	24.4	15.5
Health insurance, % not covered	13.0	13.0

^aAge-adjusted mortality data obtained from CDC WONDER database and includes data from 2010 to 2014. CDC (2012). Deaths: Leading Causes for 2008. National Vital Statistics Reports, 60(6), 3. Cause of death for all cancer (C00-D48), colorectal cancer (C18.0, C18.1, C18.2, C18.3, C18.4, C18.5, C18.6, C18.7, C18.8, C18.9, C20), lung and bronchus cancer (C34.0, C34.1, C34.2, C34.3, C34.8, C34.9), heart disease (I00–I02, I11.0, I11.9, I13.0, I13.1, I13.2, I13.9, I20–25, I26–I28, I30–I51), COPD (J44.0, J44.1, J44.8, J44.9). ^bCentral Appalachia refers to the 82 counties spanning four states as defined by the Appalachian Regional Commission [Subregions in Appalachia – Appalachian Regional Commission (n.d.). Retrieved from http://www.arc.gov/research/MapsofAppalachia.asp?MAP_ID=31]. Colorectal cancer calculations are missing data from nine counties (Cumberland, KY; Lee, KY; Leslie, KY; Menifee, KY; Owsley, KY; Robertson, KY; Wolfe, KY; Hancock, TN; Pickett, TN). ^cDemographic information retrieved from Pollard et al. [15], which compiled data from the US Census Bureau, 2011–2015 American Community Survey. Educational attainment is limited to population 25 years and over and gender is limited to civilian population ages 18 and over.

income, percent high school graduates and race/ethnicity, and that the level of coal mining in the county did not significantly improve model fits [1]. More recent studies of all-cause mortality rates in Appalachian counties found higher rates of cardiovascular deaths in coal counties compared to non-coal counties, even after adjustment for socioeconomic factors and obesity [30, 31]. A recent compendium of trends in sociodemographic data suggests Central Appalachians currently have similar health insurance rates compared to the population of the US as a whole, yet still have higher rates of poverty and lower rates of education (Table 1) [15].

A common complication in epidemiological examinations of environmental health effects in Appalachia is the particularly high smoking rate throughout the region [32], which likely accounts for a large portion of the observed disparity in cancers of the lung, head and neck [33]. Even so, regression models adjusting for county-level smoking rates suggest environmental exposures may also contribute to lung cancer disparities in coal mining counties of Appalachia [29]. A recent analysis in West Virginia used a pre/post study design to determine whether environmental exposures associated with mountaintop removal mining, which became prevalent in the 1980s, could have contributed to lung and bronchus cancer deaths in the 2006–2012 period as compared to the 1950–1969 time period [34].

Interestingly, after correcting for smoking rate and latency period, lung and bronchus cancer was significantly higher for residents in counties with the most mountaintop removal mining [smoking corrected odds ratio (OR): 1.39, 95% confidence interval (CI) 1.37, 1.41], but there was not a significant association between coal mining occupation and lung cancer death, though this would be presumed to comprise the most exposed subpopulation.

Although heightened obesity rates found in Appalachia can partially explain disparities in cardiovascular disease (CVD), several studies indicate that, even after accounting for obesity rates and socioeconomic factors, deaths from CVD are positively associated with the amount of coal produced at the county level [35, 36], particularly in counties with mountaintop removal mining [37]. These findings are consistent with a wide and robust body of literature linking fine particulate matter smaller than 2.5 μm (PM_{2.5}) exposure to cardiovascular toxicity, though it is worth noting that the literature is primarily focused on PM_{2.5} and its constituents in urban environments [38].

Potential sources of exposure

Regulatory systems that limit environmental contamination pollutant-by-pollutant and traditional discipline-specific

research initiatives generally have not encouraged holistic cumulative measures of human exposure and outcomes [39]. This review therefore focuses on air and water exposures separately, while recognizing the likely interactions of multiple exposures on health outcomes. Although other sources of exposure (e.g. soil, food) may contribute to cumulative lifetime exposures, this review focuses on water and air, given their frequent mention as potential vectors for human exposure to contaminants in the region [8, 40, 41]. It is interesting to note the seeming discrepancy between the amount of past research focused on ecological health versus human health; for example, a search of ScienceDirect focused on aquatic ecology (“Appalachia” AND “water” AND “ecology”) yields 216 publications, while a search focused on drinking water (“Appalachia” AND “drinking water” AND “human health”) yields 35 publications. Similarly, a ScienceDirect search focused on the effects of air pollution on the nonhuman environment (“Appalachia” AND “air quality” AND “environment”) yields 77 publications, while a search focused on air and human health (“Appalachia” AND “air quality” AND “human health”) returns only 30 publications.

Air quality

Exposure to air pollution is associated with a range of adverse health effects, including premature mortality, lung cancer, chronic obstructive pulmonary disease, CVD, stroke, asthma, damage to the central nervous system and poor birth outcomes [42–47]. In general, Central Appalachia’s trends in air quality mirror those of the broader US, although measurements at existing monitoring sites may not reflect the full spatial variability in pollutant concentrations in this topographically complex region. The U.S. Environmental Protection Agency (EPA) requires monitoring of “criteria” pollutants known to cause adverse health effects such as CVD and respiratory irritation. Figure 2 illustrates trends in $PM_{2.5}$, coarse particulate matter smaller than $10\ \mu\text{m}$ in diameter (PM_{10}), ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO) at monitoring sites in Central Appalachia. Pollutant concentrations at these monitoring sites have been similar in magnitude to the national average and have decreased over time in concert with the passing of stricter regulations, with the exception of ozone at Union, TN, and sulfur dioxide at Wayne, WV. Presently, concentrations of all pollutants at these sites are well below the National Ambient Air Quality Standards, with the exception of ozone; however, ozone levels at many sites in Central Appalachia remain close to the standard.

It is important to recognize that because the trends shown in Figure 2 are limited to the criteria pollutants at monitoring sites, which tend to be situated in more populous areas, they do not fully represent the state of air quality in Central Appalachia or all potential human exposures. There is evidence that the region is a significant outlier relative to the rest of the country in terms of acidic particles. In samples collected at 24 sites across the US in 1988–1991, the most acidic particles occurred in northern, north central and central Appalachia, where emissions of sulfur dioxide (SO_2) were highest; this is unsurprising as SO_2 originates mainly from coal combustion, which is a major regional energy source [48]. Aneja et al. [49] measured residential exposure to PM_{10} at two sites for 2 weeks in 2008. The PM_{10} was largely generated by trucks hauling coal along roads navigating narrow valleys, known locally as “hollows”. The mean PM_{10} concentrations at the two sites were $250\ \mu\text{g m}^{-3}$ and $145\ \mu\text{g m}^{-3}$, 67% higher than and just under the National Ambient Air Quality Standard of $150\ \mu\text{g m}^{-3}$, respectively. Kurth et al. [50] found that particle number concentrations were higher around coal mining sites than around non-mining sites. Some but not all $PM_{2.5}$ and PM_{10} samples collected near surface mining sites were enriched in certain crustal elements (Ga, Al, Ge, Rb, La, Ce) as compared to samples collected near underground mining sites or sites with no mining activity [51].

The most detailed air quality measurements in Appalachia come from two mountaintop research sites in North Carolina (Whitetop and Mt. Mitchell), which are in the south central portion of the region. Motivated by concern about damage to forests and crops [52, 53], studies at these sites have focused mainly on ozone and precipitation acidity, which is caused by emissions of SO_2 and NO_2 . Implementation of the Clean Air Act Amendments in 1995 led to stricter limits on emissions and a substantial decrease in sulfur in cloud water and precipitation [54–56]. Ozone concentrations were found to increase with elevation at Mt. Mitchell and, in contrast to diurnal patterns in urban areas, were highest at nighttime rather than daytime [57–59]. Therefore, people living at higher altitudes could be exposed to higher levels of ozone than predicted by lower-lying monitoring sites. Elemental analysis of particles collected at Whitetop showed that while $PM_{2.5}$ was dominated by sulfur, larger particles also contained metals of crustal origin (e.g. Al, Ca, Fe, Si) [60], indicating windblown dust as a contributor to $PM_{2.5}$.

Most of the research on air quality in Central Appalachia has been driven by concerns over visibility, acid deposition, and damage to vegetation [52, 53, 61–66]. Between 1992 and 2002, the Southern Appalachian Mountains Initiative established a partnership of government, industry,

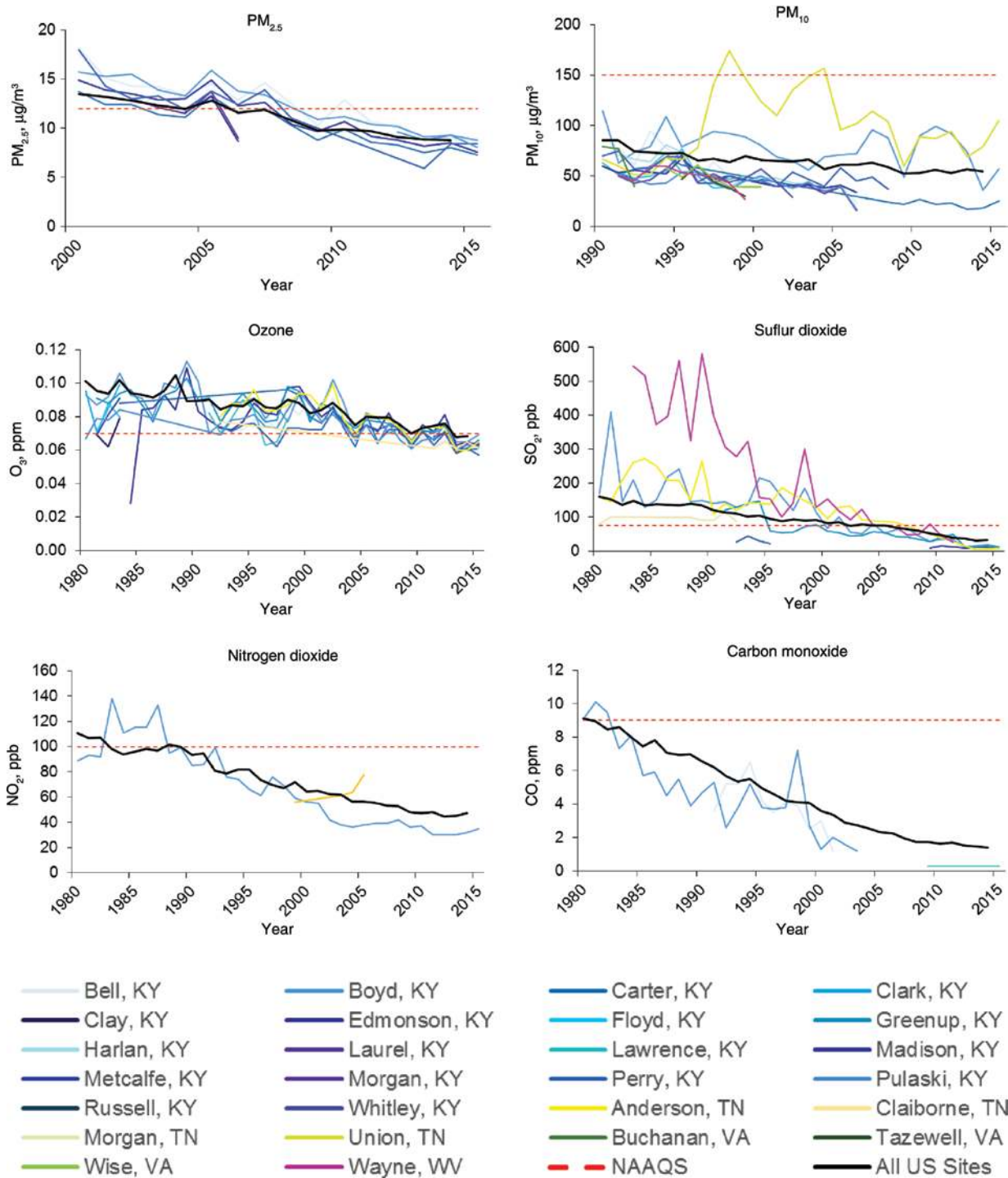


Figure 2: Air quality trends in counties in Central Appalachia compared to the average across all US sites and the National Ambient Air Quality Standard (NAAQS). Metrics are of the form specified by the NAAQS.

academia, and the public whose goal was to improve air quality, particularly visibility and ecosystem impacts, in national parks and wilderness areas in the southeastern US. As part of this initiative, sulfur-containing compounds and organic carbon were found to be the largest

contributors to visibility degradation in the region [67–70]. One outcome of the initiative was new regulations on coal-fired power plants in North Carolina, and in subsequent years, SO₂ emissions decreased by 20.3% per year while PM_{2.5} sulfate concentrations decreased by 8.7% per year

[71]. As a result, the risk of death associated with $PM_{2.5}$ sulfate was estimated to decrease by 63%, preventing 1700 deaths in 2012.

Only recently have studies begun to explicitly address potential links between air pollution exposure and human health in the region. Studies have found that intratracheal instillation in rats of PM_{10} collected near an active mountaintop removal mining site in West Virginia induced mitochondrially-driven apoptosis in heart tissue [72] and microvascular dysfunction [73]. The PM showed potentially carcinogenic effects on human lung cells, while control PM collected in a rural area with no mining activity, 160 km away, did not show these effects [74].

Considerable research is needed to expand the database of measurements and to provide proper controls to study the impact of mining versus other types of resource extraction and activities. Due to the complex topography of the region, there is likely to be high spatial variability in pollutant concentrations [75] that is not captured by the EPA's routine monitoring sites. Except for one study [49], there have been no measurements in hollows, where atmospheric inversions can trap pollutants and lead to localized high personal exposures for residents. It is possible that non-mining activity, such as construction or logging, could also lead to elevated PM concentrations and enrichment of certain species in the PM. The increased emphasis on natural gas extraction in the region may lead to new air quality concerns, as fracking fluids contain organic compounds that can escape into the atmosphere and aerated recycling ponds can be a source of air pollutant emissions [76]. Improving air quality in Central Appalachia may provide not just direct health benefits but also economic benefits, as the region is one of four areas in the US shown to have the greatest potential for "positive amenity values" of improved air quality [77].

Water quality

A survey in 2000 identified water quality as a primary environmental health concern of rural health care practitioners nationally [78]. Although no regionally specific data was presented for Central Appalachia, water contamination is frequently cited as a public health concern by Appalachian residents, as it provides a regular means of direct exposure to environmental contaminants [7, 40, 79, 80]. Regional reliance on private drinking water systems (wells, springs, cisterns), which do not fall under the purview of the Safe Drinking Water Act's monitoring requirements, is significant. The Appalachian Regional

Commission currently estimates that only 75% of the region is served by municipal water systems [81], as compared to 85% nation-wide [82]. These private systems often do not employ treatment prior to consumption, which can leave households uniquely vulnerable to environmental contamination [83].

Despite its frequent mention as an environmental health concern, very little research is available on drinking water quality in Appalachia, and virtually no information regarding other waterborne exposures (e.g. recreational) is available. Available research is generally either linked to studies of coal mining impacts on community health, or, to a lesser extent, household sanitation and wastewater treatment. Much is based on perceptions or anecdotal data of water quality, with no direct measures of health impacts.

The potential that mining activities degrade drinking water sources and cause elevated rates of chronic disease has been recognized for decades. A review of historical environmental and community health concerns in Appalachia published in the late 1970s noted an elevated prevalence of gastrointestinal cancers (stomach, lip, mouth, throat) [6]. Though the author speculated that industrial contamination of drinking water might contribute to this prevalence, he also noted that elevated tobacco use in the region rendered the relative impacts of environmental contamination versus behavioral factors difficult to quantify. Similar observations of elevated rates of chronic diseases, particularly cancer, and speculation of a potential link to waterborne contaminants associated with mining practices is echoed by more recent reviews of community health concerns in Appalachia [8, 40]. However, these studies all rely on broad-scale analysis of secondary data sources (e.g. county-level cancer or vital statistics) and do not provide measures of water consumption (exposure) or contamination (dose) directly, rendering it difficult to identify a causal link.

A focus on water as a significant route of human exposure to contaminants associated with mining practices is not surprising given the substantial recent documentation of aquatic ecology impairments downstream of active or historical mining activity [7, 84]. The exposure of mined overburden to oxygen and weather results in the discharge of metals and nonmetallic ions, generally measured as specific conductance, into Appalachian headwater streams. Elevated concentrations of ions are frequently cited as primarily responsible for losses in the abundance and diversity of aquatic benthic macro-invertebrates, which underlie aquatic food webs. Given the identification of Central Appalachia as a global biodiversity hotspot, the impacts of mining on water quality and hydro-ecology in

the region have gained considerable scientific and public attention [84, 85].

Extrapolating the relative impacts of water quality on non-human versus human animals is inherently very difficult however, particularly in sensitive ecologies; for example, although the Safe Drinking Water Act maximum contaminant level for selenium in human drinking water is 50 ppb, recent studies in Central Appalachia suggest that levels as low as 5 ppb can negatively impact local fish species [86]. Attempts to directly link degradation of invertebrate health directly with human health are difficult and controversial. A recent effort by Hitt and Hendryx [87] found a positive correlation between average stream health scores (WV Stream Condition Indices, or WVSCI) and the incidence of digestive, breast, respiratory and urinary cancer rates at the county level in West Virginia. The authors do not posit exposure pathways or common biological mechanisms that impact human cancers and macroinvertebrate extirpation, stating that “it is intuitive that ecological integrity and human health are intrinsically linked”. It is worth noting that in this study, poverty, smoking and urbanization were examined in parallel via logistic regression and were also linked with elevated cancer rates (i.e. included in the model).

In contrast to the considerable in-stream water quality data available linking coal mining and ecological health, very little data is available on the quality of residents’ drinking water, though several studies focus on community perceptions of water quality. Interviews with over 122 residents of Letcher County, Kentucky, revealed that residents’ concerns regarding the perceived poor aesthetic quality and health risks of their water forced them to change their behavior, e.g. purchasing bottled water, cooking with water from a relative’s home supplied by municipal water or washing clothes at a laundromat [80]. It is important to note that this study targeted residents who had expressed concerns related to their water previously; interviewees were not selected randomly. In addition, the study did not analyze any water samples, and although several residents expressed a belief that local coal mining had contributed to degraded water quality, some residents reported characteristics (e.g. iron staining) that may simply be the result of local geology. A targeted study in Mingo and Wyoming Counties in West Virginia similarly reported that perceptions of poor water quality and issue saliency (i.e. perception of problem seriousness) were the primary factors influencing households to purchase bottled water, even when this purchase represented a nontrivial portion of the family budget [79]. This effort recruited its 276 participants randomly by approaching every 12th home on county roads, but similarly to the

Kentucky study, did not analyze actual water samples for markers of contamination. Interestingly, the West Virginia study found decisions to purchase bottled water appeared similar regardless of water source (private well or spring vs. municipal water); a lack of trust in the public water authority was cited as a common reason to purchase bottled water.

Only three studies reporting actual measures of household drinking water quality at the point of use in Appalachia were identified, all of which were constrained by small sample sizes or limited analytical strategies. Wigginton et al. [88] investigated the relative quantities of metals in household hot water tanks in Martin, Pulaski, and Madison Counties in Kentucky after the 2000 Martin County coal impoundment failure contaminated the county’s surface water supply. Although the authors hypothesized that metals accumulation in the hot water tanks would be significantly higher in Martin County, concentrations were actually highest in Pulaski County homes, particularly for lead. This may be the result of underlying natural water chemistry, although neither pH nor alkalinity, considered primary drivers of corrosion and metal release, were reported. In addition, concentrations of metals at the household point of use, a more likely proxy for resident exposure, were not correlated with hot water tank values. In 2005, students in a service-learning course at Kentucky Community and Technical College collected 179 well water samples from personal and community contacts in Kentucky, West Virginia, Tennessee and Ohio to test for arsenic. Over half of the samples contained detectable arsenic levels, and ten samples (6%) exceeded the Safe Drinking Water Act standard of 10 ppb [89]. A study comparing differences in water quality in samples collected from the point of use of private drinking water supplies participating in a Cooperative Extension program across Virginia found that the number of samples positive for fecal indicator bacteria were highest in samples from wells and springs in the Valley and Ridge geological region of Virginia (where multiple counties designated as Central Appalachian are located); roughly 50% of the 926 samples submitted from this region were positive for total coliform. The number of samples submitted from the Appalachian Plateau geological region was too small to warrant inclusion in the analysis [90].

A significant incidence of bacterial contamination in drinking water wells is not necessarily surprising, given continuing struggles to provide safe drinking water and adequate wastewater treatment in the region. A state-level analysis of the most recently available full 2000 Census on housing indicated that over 7000 homes in West Virginia, over 19,000 homes in Virginia, and almost 15,000 homes

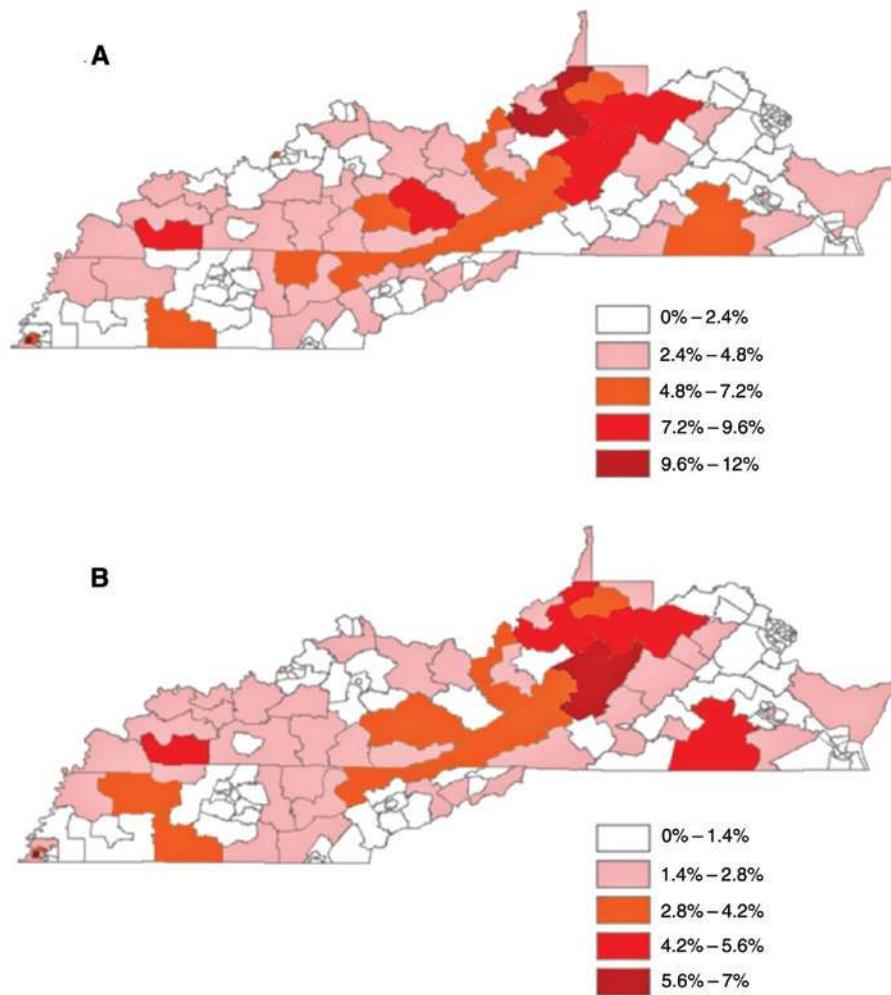


Figure 3: Percentage of occupied homes in Central Appalachian states: (A) without indoor plumbing (drinking water tap); and (B) without an indoor toilet. Data are compiled by United States’ Census Bureau’s Public Use Microdata Areas (PUMAs) using the 5 year 2010–2014 dataset (<https://www.census.gov/programs-surveys/acs/data/pums.html>). PUMAs are geographically defined by the US Census to include populations of 100,000 people. Homes are selected for detailed surveying via statistical methods designed to maximize representation of the entire PUMA population.

in Kentucky did not have indoor plumbing as of 2000 [91]. According to this analysis, West Virginia and Kentucky had the fourth and fifth greatest percentage of their overall population lacking these basic services, with 1.01% and 0.94% of household lacking indoor plumbing. Analysis of the more recent US Census Public Use Microdata System confirms that there are portions of Central Appalachian states where more than 10% of homes do not have indoor drinking water, and more than 7% of homes do not have an indoor toilet (Figure 3).

Not included in summaries of indoor plumbing availability are homes with flush toilets but inadequate wastewater treatment infrastructure. Narrow valleys and thin topsoil layers render traditional septic systems impractical for some locales; consequently, in the absence of

municipal wastewater service or other affordable alternatives, some homes simply “straight pipe” household wastewater to nearby streams, i.e. untreated household wastewater passes directly into adjacent ditches and surface waterways [92, 93]. As straight pipes are technically illegal, this practice is difficult to quantify, although a report on environmental quality in Letcher County, Kentucky, estimated that as many as 3000 straight pipes serve up to 12,000 county residents [94]. Quantifying the number and location of straight pipes, as well as failing septic systems, is essential to understanding the risk to residents; a recent national study identified failing onsite wastewater as the primary risk factor in predicting gastroenteritis outbreaks in homes reliant on private wells [95].

Future research suggestions

The ecological impacts of environmental contaminants and anthropogenic land use in Central Appalachia have been relatively well studied. This is not necessarily surprising, given that the central and southern Appalachians are designated as an ecological biodiversity “hotspot” that hosts nearly 10,000 distinct species [96, 97]. Over the past several decades, recognition of the unique biodiversity of the region has prompted research into the effects of acid rain and air pollution on forests and the link between mineland discharges and the degradation of aquatic macro-invertebrates; these efforts have spurred concurrent regulatory efforts to reduce pollutant discharges and remediate these critical habitats. In contrast, the effects of the region’s natural and human landscape changes on human health remain relatively unclear. Although Appalachia has long been recognized as an American region subject to significant health disparities, the causes of excess morbidity and mortality are poorly understood, limiting the design and implementation of interventions to improve public health. There are several lines of inquiry that warrant further research investigations, including:

Individual, longitudinal measures of exposures for air and water and health outcomes

The majority of past examinations of potential environmental contributions to health disparities in Appalachia have focused solely on the potential impacts of coal mining, generally at the county-level. While compelling in their calls for further research, conclusions from these studies are limited by their ecological study design. Individual-level exposures and their relationships to covariates are not measured in these studies, and the studies fail to account for latency periods between risk factors and health outcomes through the collection of longitudinal measures. Without individual, longitudinal measures of exposures and disease initiation and progression, associations between exposures and outcomes are difficult to identify. Moving forward, researchers must focus on obtaining measurements of individual exposure to specific pollutants in air and water, keeping in mind topographically influenced variability and proximity to resource extraction as well as additional sources of environmental pollution when selecting the sample population. Such measurements could include personal exposure to $PM_{2.5}$ and specific metals and organic compounds in indoor (home) and outdoor air, and microbes,

salts, metals, and organic compounds in drinking water collected at the point of exposure (e.g. the kitchen tap) in homes. In addition, while the presence of coal mining as a significant potential environmental risk cannot be ignored, additional environmental factors and patterns of land-use and land-use change must be examined as likely contributors to elevated regional burdens of disease.

Health effects of natural gas extraction

While coal production in the region has declined over the past decade, natural gas extraction, made more accessible by hydraulic fracturing or “fracking”, has grown sharply. Increases in fracking immediately spurred a host of new concerns about its potential impacts on the environment, especially in terms of groundwater contamination [3, 4, 98]. The associated human health impacts remain at times difficult to quantify [99], but it is worth noting that recent studies have observed increases in asthma [100], sinus headaches and fatigue [101], hospital visits [102], mental distress [103], and adverse birth outcomes [104, 105] near unconventional gas sites. Although the types of pollutants potentially released to the air, water, and soil by fracking operations and the pathways of human exposure likely differ from coal mining operations, regional experience with coal mining impacts must inform the development of monitoring strategies that can reliably inform policy and engage local communities. For example, the current growth in natural gas extraction by hydraulic fracturing presents an immediate opportunity for longitudinal studies of its community health effects that include direct measures of individual exposure. These effects must be distinguished from the impacts of conventional gas wells, which have not previously been explicitly studied.

Health effects of changes in land use

Understanding patterns of land-use, particularly land-use visible or in close proximity to human populations, is critical in understanding not only human health risks, but also community perceptions of risk and well-being. A recent focus group study of Appalachian women found that those who lived closest to new natural gas extraction wells reported greater feelings of powerlessness and attributed increased community illness to the industry’s presence, while those who lived farther away did not believe the wells were responsible for poor health outcomes [106]. These links between awareness of land-use changes and perceived links to health are critical

to recognize in working with Appalachian residents, and community concerns are reflected by the numerous water quality perception studies surrounding coal mining discussed previously. The shift to mountaintop removal mining in recent decades has introduced more extensive and distinctly visible environmental concerns, which likely impacts perceptions of risk, though this has been only lightly examined.

Impacts of land use and land cover change are most clearly revealed through the use of fine-scale satellite imagery and remote sensing techniques. Environmental change in Appalachia has been studied using such techniques, but the focus is typically on impacts on ecosystem health rather than human health [107–109]. There has been little attention focused on human health impacts of changing land use and land cover patterns through time in Central Appalachia, and many of the studies identified in this paper have conducted analyses at a relatively coarse county-scale. In order to truly tease apart the relationship between land cover change and human health impacts, fine-scale data should be employed. Individual-level address-based health outcomes and exposure measures related to air and water quality should be paired with fine-scale satellite imagery using a geographic information system (GIS) to understand links between land cover change and human health, and to reveal the potential for interventions and improvements to health outcomes.

Mental health considerations

There are anecdotal reports of depression and associated issues in communities near mountaintop removal mines. For example, Cordial et al. report that “virtually no research has been undertaken on the psychological effects of” mountaintop removal mining but hypothesize “a high probability of an increased risk of mental health problems for those living near MTR sites” [110]. The Appalachian Regional Commission has found that “persons in Central Appalachia, where coal mining is heaviest, are at greater risk for major depression and severe psychological distress compared with other areas of Appalachia or the nation” [111]. The only available studies of community mental health and well-being are ecologically-based studies focused on the county-level, which, as mentioned previously, do not record individual-level exposures or covariates, rendering causal relationships difficult to determine [112]. The term “solastalgia” is used to describe mental distress following landscape changes, especially when these environmental changes occur in the person’s home environment. Future studies building on the

emerging literature and investigative strategies associated with explorations of solastalgia and other psychoterratic syndromes [113] are encouraged to test the hypothesis that Appalachian communities near extractive industries suffer from mental health effects. It is important to note when designing these studies that changes in the environment that result in emotional distress do not necessarily only comprise dramatic landscape shifts on the scale of mountaintop removal; recent work suggests that fracking, despite its lower visible environmental footprint, is also associated with shifts in individual sense of place, identity and community [103].

Conclusion: building community through participatory research

As research efforts to characterize the impacts of environmental changes in Appalachian communities develop, parallel efforts to educate and involve targeted communities should draw from evidence-based practice on community engagement and community-based participatory research. Successful interventions to reduce environmental health disparities require processes “whereby communities use their voice to define and make health concerns known” [114], as well as community capacity building [115]. This process can redress communities’ sense of disenfranchisement, strengthen opportunities for community voices to influence research priorities, policy and health education, increase community trust in research findings and embolden residents’ perceived self-efficacy in effecting change. For example, Hutson et al. established community research review work groups to engage community leaders in a series of focus groups to disseminate information about cancer disparities and build relationships with healthcare providers [116].

Existing evidence-based models in Appalachia to address social and behavioral factors associated with regional health disparities are evident in the interventions by researchers with the Appalachian Community Cancer Network and others, and can be leveraged for future community engagement to address environmental health disparities, particularly in vulnerable populations such as children and the elderly [14, 117]. For example, implementation of the American Cancer Society’s “Tell a Friend” program in local food pantries in an Appalachia community in Pennsylvania resulted in a 28% increase in breast cancer screenings [118]. Implementation of the “Winning With Wellness” obesity prevention initiative in elementary schools resulted in increases in daily steps and

healthier food selections by students even 4 years later. Building from these successful programs, environmental health modules could be developed and validated for school-based or community organization programs [119]. Ultimately, working with communities will foster interdisciplinary research, bringing together disparate disciplines (e.g. public health, geography, ecology, natural resources management, etc.) to help solve problems identified by impacted Appalachia communities.

Appalachia is frequently described as a region with communities highly tied to the idea of “place” [120–122]. Although current health and economic challenges are significant, residents’ dedication to the mountains may serve as a source of strength and cohesion for addressing environmental health issues. Given the rich history and beauty of Appalachia, there are opportunities for residents of the region to leverage the environment to reinvigorate communities, promote regional health, and preserve and/or reinscribe sense of place for future generations.

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