Identification of Toxic Agents and Potential Exposure Routes to Appalachian Coal Mining Communities

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ABSTRACT

Recently there has been increased concern about the health of Appalachian communities in the vicinity of coal mining operations. An important consideration in community health is the physical health of its residents. Several studies have reported that coal mining communities have a higher incidence of disease, including; asthma, birth defects, black lung, cardiovascular disease, cardiopulmonary disease, hypertension, kidney disease, lung disease, and cancer as well as mortality, than non-coal mining communities.

The objectives of this study were to conduct an extensive literature search in order to (1) identify environmental agents linked to asthma, birth defects, cardiovascular disease, hypertension, kidney disease, lung disease, and cancer, (2) identify toxic agents and potential exposure pathways associated with coal mining and (3) assemble the literature into an associations matrix that allows for the presence and absence of overlaps between health effect and toxic agents linked with coal mining to be identified.

The health effects literature search was performed using the Medline: ProQuest database. Search terms included "environmental health," "air pollution," and "tap water," in conjunction with the specific health effect/disease being targeted in the search. The search results were limited to review articles in English. All of the articles found were published in 2001 or later, with the majority published between 2008 and 2011. The potential sources literature search was performed using Science Citation Index, Web of Science, and PubMed databases. Search terms included "coal mining contaminants," "coal mining toxic agents," "coal mining dust," and "coal mining and ground water." The search results were limited to articles that identified toxic agents that coal mining communities may have had elevated exposure to because of an increased concentration of toxic agents at the coal mining site, an increased transmission of agents due to coal mining activities, or a combination of the two.

The health effects literature search resulted in 108 papers which identified over 200 toxic agents associated with asthma, birth defects, cardiovascular disease, hypertension, kidney disease, lung disease, and cancer. The number of toxic agents was reduced to 23 when screened by literature references linking the toxic agents to coal mining. The resulting associations matrix allows for

potential exposure routes of plausible toxic agents to be identified. Given the toxic agents identified, the primary routes of exposure are ingestion and inhalation for soil/dust and ingestion for water. Fugitive dust in Appalachian coal mining communities is the major exposure pathway of concern for surface coal mining operations. Further research is needed to quantify the amount of dust leaving coal mining operations and determine the total content and bioavailable fractions (via ingestion and inhalation) of dust constituents, in order to determine if exposure to coal mining communities is sufficiently elevated to cause adverse health effects.

INTRODUCTION

Recently there has been increased concern about the health of Appalachian communities in the vicinity of coal mining operations. An important consideration in community health is the physical health of its residents. Several studies have reported that coal mining communities have a higher incidence of disease, including; asthma, birth defects, black lung, cardiovascular disease, cardiopulmonary disease, hypertension, kidney disease, lung disease, and cancer as well as mortality, than non-coal mining communities (Ahern et al. 2011; Hendryx 2009; Hendryx and Ahern 2008; Hendryx et al. 2007; Hendryx et al. 2010; Hendryx et al. 2008; Hendryx et al. 2011; Hendryx and Zullig 2009). In addition to environmental exposures, several factors have been identified as associated with chronic disease including lack of physical activity, poor nutrition, obesity, excessive alcohol consumption, smoking, awareness of health status (i.e., blood pressure, cholesterol, etc.), and access to health care (Centers for Disease Control and Prevention 2012). However, previous studies conclude that the increased incidence of disease is due to coal mining activity with few if any toxic agents identified.

When the source of a toxic agent is not in the immediate vicinity of a person or population, pathways of exposure must be established. Environmental pathways of exposure can be complex, with the extent of exposure determined by exposure factors such as amount, frequency, and duration. The modes in which toxic agents enter the body are limited to inhalation, ingestion, and dermal absorption (US EPA 2011). Depending on its chemical properties, the toxic agents that enter the body will have specific sites where the agent will inflict damage on the body tissues.

The toxic effects of many environmental agents have been extensively studied. As a result, literature linking environmental chemicals to specific diseases can be used to identify agents associated with diseases reported to be elevated in coal mining communities. The objectives of this study were to conduct an extensive literature search in order to (1) identify environmental agents linked to asthma, birth defects, cardiovascular disease, hypertension, kidney disease, lung disease, and cancer, (2) identify toxic agents and potential exposure pathways associated with coal mining and (3) assemble the literature into an associations matrix that allows for the presence and absence of overlaps between health effect and toxic agents linked with coal mining to be identified.

METHODS

Literature reviews targeting (1) health effects and (2) potential sources of toxic agents carried in soil/dust and water as a result of coal mining activities were performed. The health effect literature search was performed to identify environmental factors associated with specific diseases reported in the literature of Appalachian coal mining (Ahern et al. 2011; Hendryx 2009; Hendryx and Ahern 2008; Hendryx et al. 2007; Hendryx et al. 2010; Hendryx et al. 2008; Hendryx et al. 2011; Hendryx and Zullig 2009). The health effects literature search was performed using the Medline: ProQuest database. Search terms included "environmental health," "air pollution," "tap water," in conjunction with the specific the health effect/disease being targeted in the search. The search results were limited to review articles in English. All of the articles found were published in 2001 or later, with the majority published between 2008 and 2011. The potential sources literature search was performed using Science Citation Index, Web of Science, and PubMed databases.

Search terms included "coal mining contaminants," "coal mining toxic agents," "coal mining dust," and "coal mining and ground water." The search results were limited to articles that identified toxic agents that coal mining communities may have had elevated exposure to because of an increased concentration of toxic agents at the coal mining site, an increased transmission of agents due to coal mining activities, or a combination of the two.

HEALTH EFFECTS LITERATURE SEARCH RESULTS

Asthma

Search results for asthma yielded nine papers, with results summarized in Table 1 (Breysse et al. 2010; Cecchi et al. 2010; De Luca et al. 2010; Dozor 2010; Holgate et al. 2010; Sly 2011; Stapleton et al. 2011; Tzivian 2011; Weinmayr et al. 2010).

Birth Defects and Low Birth Weight

Search results for birth defects and low birth weight yielded five papers with results summarized in Table 2 (Wang and Pinkerton 2007; Wigle et al. 2008; Wigle et al. 2007; Wu 2010; Vrijheid et al. 2011).

Cancer

Search results for cancer yielded 35 papers with results summarized in Table 3 (Brody 2010; Carpenter 2010; Chameides 2010; Field 2010; Fucic et al. 2010; Gamble 2010; Gibb et al. 2011; Guha et al. 2010; Hajdu 2011; Hansen and Lassen 2011; Hendryx et al. 2010; Hendryx et al. 2008; Hendryx et al. 2011; Hosgood et al. 2011; IARC 2011; Kligerman and White 2011; Kunzli

Table 1. Literature search results for toxic agents associated with asthma

Active Smoking	Diesel exhaust
Environmental tobacco smoke	Indoor air pollution
Ambient air toxicants	Traffic exhaust
• Particulate matter undefined	Insecticides
• Particulate matter—$PM_{2.5}$	• DDT/DDE
• Particulate matter—$PM_{2.5-10}$	• Organophosphate insecticides
• Particulate matter—PM_{10}	• Other or unspecified insecticides
• Particulate matter—Ultrafine particles	Maternal use of paracetamol (an analgesic)
• Ozone	Personal care products
• Nitrogen dioxide	Exposure to biologically active allergens
• Sulfur dioxide	Airborne mouse allergen
Air pollution episodes	Climate change × pollen
Chemical domestic products for cleaning	Respiratory viruses

Table 2. Literature search results for toxic agents associated with birth defects and low birth weight

Active Smoking	PCBs
Environmental tobacco smoke	Phthalates
Ambient air toxicants	TCDD
• Particulate matter undefined	Pesticides
• Carbon monoxide	Solvents
• Ozone	• Chlorinated solvents
• Nitrogen dioxide	• Glycol ethers
• Sulfur dioxide	• Unspecified solvents

(table continues)

Table 2. Literature search results for toxic agents associated with birth defects and low birth weight (continued)

Arsenic	Drinking water nitrate, nitrite (NO_2 + NO_3)
Cadmium	Aeroallergens
Lead	Power-frequency magnetic fields
Mercury	Proximity to hazardous waste disposal sites
Methyl mercury	Radiofrequency radiation
Mixed metals	Solid waste
Chlorination disinfection by-products	Sunlight (UV radiation)
Dioxin	

Table 3. Literature search results for toxic agents associated with cancer

Active Smoking	Acrylonitrile
Environmental tobacco smoke	Benzene
Ambient air toxicants	Benzidine
• Particulate matter—$PM_{2.5}$	Bisphenol A
• Particulate matter—PM_{10}	Brominated flame retardants
• Particulate matter—Ultrafine particles	Carbon tetrachloride
Air pollution episodes	Dioxin
Coke oven emissions	Ethylene oxide
Cooking fumes from high temperature oils	Formaldehyde
Diesel exhaust	Hydrazine
Household coal combustion	Napthalene
Household biomass burning	PCBs
Metal dust	Perchloroethylene
Nanoparticles	Persistent organic pollutants
Night shift work	Polycyclic aromatic hydrocarbons
Non-ferrous metal dust and fumes	Vinyl chloride
Occupation as a painter	Pesticides
Traffic emissions	Solvents
Socioeconomic risk factors	Nutraceuticals
Education	Water disinfection by-products
Occupational class	Human papillomavirus
Housing characteristics	Human immunodeficiency virus
Deprivation index	Chlamydia pneumonia
Arsenic	Prior lung disease
Beryllium	Electricity (extremely low frequency)
Cadmium	Electromagnetic fields
Chromium	Ionizing radiation
Cobalt	Microwave radiation
Nickel	Non-ionizing radiation
Silica	Radionuclides
Asbestos	Radon
Bitumen	Sunlight (UV radiation)
1,3 butadiene	Wireless devices (radiofrequency)

and Tager 2005; Kutting and Drexler 2010; Linet and Inskip 2010; Lubin 2010; Mates et al. 2010; McErlean and Ginsberg 2011; Merletti et al. 2011; Mossman et al. 2011; Nielsen and Wolkoff 2010; Samet 2010; Samet 2011; Samet et al. 2009; Soto and Sonnenschein 2010; Stefanovic and Polenakovic 2009; Suk 2010; Sung et al. 2011; Vena 2010; Weichenthal et al. 2010; Wigle et al. 2008; Wigle et al. 2007).

Cardiovascular Disease

Search results for cardiovascular disease yielded 30 papers with results summarized in Table 4 (Bernal-Pacheco and Roman 2007; Bhatnagar 2006; Brook 2007; Brook et al. 2010; Cole and Freeman 2009; Delfino et al. 2005; Fang et al. 2010; Faught et al. 2009; Galimanis et al. 2009; Gill et al. 2011; Hassing et al. 2009; Hendryx and Ahern 2008; Hendryx and Zullig 2009;

Table 4. Literature search results for toxic agents associated with cardiovascular disease

Active Smoking	Chromium
• Carbon monoxide	Copper
• Vapor phase components	Iron
• Particulate phase 'tar'	Lead
• Nicotine	Mercury
Environmental tobacco smoke	Nickel
Ambient air toxicants	Selenium
• Particulate matter undefined	Sulfur
• Particulate matter—$PM_{2.5}$	Vanadium
• Particulate matter—$PM_{2.5-10}$	Zinc
• Particulate matter—PM_{10}	Silica
• Particulate matter—Ultrafine particles	Quartz
• Carbon monoxide	Inorganic dust
• Ozone	Sand
• Ozone × allergen level	Cotton
• Nitrogen dioxide	Aldehydes
• Sulfur dioxide	Dioxin
• Sulfates	Endotoxin
Asphalt fumes	PCBs
Black Carbon	Polyaromatic hydrocarbons
Diesel exhaust	Semiquinones
Distance to major road	Styrene
In vehicle $PM_{2.5}$	Volatile organic substances
Metal	Pesticides
Metal fumes	• Chlorinated pesticides
Occupational and Indoor pollutants	• Unspecified pesticides
Organic carbon species	Solvents
Respirable PM	• Chlorinated solvents
Traffic emissions	• Glycol ethers
Welding and soldering fumes	• Unspecified solvents
Welding fume $PM_{2.5}$	Maternal drugs
Heavy metals and elements	Maternal toxins
Arsenic	Maternal infection
Cadmium	Radiation

Table 5. Literature search results for toxic agents associated with hypertension

Active Smoking	Particulate matter undefined
• Carbon monoxide	Arsenic
• Vapor phase components	Cadmium
• Particulate phase 'tar'	Lead
• Nicotine	Mercury
Ambient air toxicants	PCBs

Table 6. Literature search results for toxic agents associated with kidney disease

Aluminum	Chlorinates
Arsenic	Chloroform
Beryllium	Dinitrotoluene
Bismuth	Ethylene glycol
Cadmium	Halogenated alkenes
Chromium	Hydrocarbon-induced nephrotoxicity
Germanium	Methylene chloride
Gold	Napthenes
Lead	Organic chemicals and solvents
Mercury	Toluene
Silicon	Trichloroethylene
Uranium	Volatile hydrocarbons
Aliphatic aromatics	Polycyclic aromatic hydrocarbons in water
Aristolochic acid	Aromatic amines in water
Arsine gas	Viruses
Bipyridyl herbicides	Ochratoxin A
Carbon tetrachloride	Mycotoxins

Hoffmann et al. 2009; Houston 2007; Houston 2011; Humblet et al. 2008; Mastin 2005; Navas-Acien et al. 2007; O'Toole et al. 2008; Peters 2005; Sauvant and Pepin 2002; Soto and Sonnenschein 2010; Su et al. 2011; Sun et al. 2010; Vardavas and Panagiotakos 2009; Vaziri 2008; Vermylen et al. 2005; Virdis et al. 2010; Zanobetti et al. 2011).

Hypertension

Search results for hypertension yielded nine papers with results summarized in Table 5 (Virdis et al. 2010; Sun et al. 2010; Brook 2007; Delfino et al. 2005; Chen et al. 2007; Houston 2007; Gallagher and Meliker 2010; Vaziri 2008; Houston 2011; Everett et al. 2011).

Kidney Disease

Search results for cancer yielded 15 papers with results summarized in Table 6 (IPCS 1991; Cannata-Andia and Fernandez-Martin 2002; Soderland 2010; Voice et al. 2006; Gallagher and Meliker 2010; Bandara et al. 2010; Edwards and Prozialeck 2009; Prozialeck and Edwards 2010; Ekong et al. 2006; Evans and Elinder 2011; Vicente-Vicente et al. 2010; Brautbar 2004; Stefanovic and Polenakovic 2009; Rankin 2004; Bruning 2002).

Lung Disease

Search results for lung disease yielded four papers with results summarized in Table 7 (Kunzli and Tager 2005; Soto-Martinez and Sly 2010; Peden and Bush 2011; Po et al. 2011).

COAL MINING AS A POTENTIAL SOURCE OF TOXIC AGENTS

Soil and Dust

The potential source literature search yielded twelve papers that indicate potential increased

exposure to toxic agents carried in soil and or dust brought to the surface by coal mining activities and are summarized in Table 8. Studies indicated an increase in ambient air toxicants in the form of undefined particulate matter (Ghose 2007; Trivedi et al. 2010; Ghose and Majee 2007; Chaulya 2004), particulate matter less than 10 µm in diameter (PM_{10}) (Trivedi et al. 2010; Ghose and Majee 2007; Chaulya 2004; Dubey et al. 2011; Mukherjee et al. 2005), carbon monoxide (Ghose 2007), nitrogen dioxide (Ghose 2007; Ghose and Majee 2007; Dubey et al. 2011), and sulfur dioxide (Ghose 2007; Ghose and Majee 2007; Dubey et al. 2011). Elevated levels of elemental toxicants that have been reported to be associated with coal mining include: arsenic (As) (Black and Craw 2001; Šebestová et al. 1996; De and Mitra 2004), Beryllium (Be) (Šebestová et al. 1996), cadmium (Cd) (Dubey et al. 2011; Das and Chakrapani 2011), chloride (Cl) (Ghose and Majee 2007), chromium (Cr) (Dubey et al. 2011; De and Mitra 2004), copper (Cu) (Dubey et al. 2011; Šebestová et al. 1996; De and Mitra 2004; Das and Chakrapani 2011), iron (Fe) (Dubey et al. 2011; Brook et al. 2010), lead (Pb) (Dubey et al. 2011; De and Mitra 2004), manganese (Mn) (Brook et al. 2010; Dubey et al. 2011), nickel (Ni) (Dubey et al. 2011; Das and Chakrapani 2011; De and Mitra 2004), zinc (Zn) (Dubey et al. 2011; Šebestová et al. 1996; De and Mitra 2004; Das and Chakrapani 2011), and silica (Dubey et al. 2011; Onder and Yigit 2009). In addition, organic toxicants in the form of aldehydes (Ghose and Majee 2007; Ghose 2007), benzene (Ghose and Majee 2007), and polyaromatic hydrocarbons (PAH) (Ghose and Majee 2007) have also been identified.

Table 7. Literature search results for toxic agents associated with lung disease

Ambient air toxicants
• Particulate matter undefined
• Carbon monoxide
• Ozone
• Ozone × allergen level
• Nitrogen dioxide
• Sulfur dioxide
• Biomass smoke

Ground Water

Surface water was not considered due to the infrequency in which surface water is consumed directly and therefore not a significant exposure pathway. However, ground water is a potential drinking water source for many Appalachian residents and therefore the ingestion of water from wells is a major exposure pathway of concern. The potential source literature search yielded four papers that indicate potential increased exposure to toxic agents released in ground water as a result coal mining activities and are summarized in Table 9. The studies indicate increased groundwater concentrations of organic carbon (McAuley and Kozar 2006), aluminum (Al) (McAuley and

Table 8. Literature search results for toxic agents potentially associated with soil/dust due to coal mining

Ambient air toxicants	Copper
• Particulate matter undefined	Iron
• Particulate matter—PM_{10}	Lead
• Carbon monoxide	Manganese
• Nitrogen dioxide	Nickel
• Sulfur dioxide	Zinc
Arsenic	Silica
Beryllium	Aldehydes
Cadmium	Benzene
Chloride	Polyaromatic hydrocarbons
Chromium	

Table 9. Literature search results for toxic agents potentially associated with ground water due to coal mining

Organic carbon species	Iron
Aluminum	Lead
Ammonia	Manganese
Arsenic	Nickel
Calcium	Potassium
Chromium	Sulfur
Cobalt	Zinc
Copper	Quartz

Kozar 2006), ammonia (McAuley and Kozar 2006), As (Wigginton et al. 2008; Gupta 1999), calcium (Ca) (McAuley and Kozar 2006), cobalt (Co) (De and Mitra 2004), chromium (Cr) (McAuley and Kozar 2006), copper (Cu) (Gupta 1999), iron (Fe) (Wigginton et al. 2008; McAuley and Kozar 2006), potassium (K) (McAuley and Kozar 2006), manganese (Mn) (McAuley and Kozar 2006; Wigginton et al. 2008; Gupta 1999), nickel (Ni) (McAuley and Kozar 2006), lead (Pb) (Wigginton et al. 2008), quartz (McAuley and Kozar 2006), sulfur (S) (McAuley and Kozar 2006), and zinc (Zn) (Wigginton et al. 2008; De and Mitra 2004).

ASSOCIATIONS MATRIX RESULTS

The results of the two literature searches were combined into a single associations matrix, which allowed for overlaps in toxic agent induced health effects and potential sources of toxic agents from coal to be observed. The full associations matrix that lists each overlap with citations separately is too large for publication in this manuscript. A summary of only the overlaps between single associations and toxic agents are presented in Table 10. Of particular importance are the agents associated with cancer. The International Agency for Research on Cancer (IARC 2011) has categorized agents into five groups: (1) carcinogenic to humans, (2A) probably carcinogenic to humans, (2B) possibly carcinogenic to humans, (3) not classifiable as to its carcinogenicity to humans, and (4) probably not carcinogenic to humans. Of the agents identified with potential links to coal mining, arsenic, beryllium, cadmium, chromium (VI), silica, and benzene are categorized as group 1, and cobalt and nickel as group 2B.

DISCUSSION

The associations matrix summarizes important information that ties only plausible toxic agents to previously cited health effects of concern. Increases in particulate matter and ambient air toxicants are due primarily to open cast surface coal mining (Trivedi et al. 2010; Ghose and Majee 2007). Activities that generate fugitive dust (dust that moves off site) include dust created from wind erosion of disturbed land and stockpiles, drilling, and blasting. Some studies indicate that up to 80% of total dust was attributed to transportation, including loading/unloading of coal and overburden and dust generated from unpaved haul roads (Ghose 2007). However, the exact source or mining practice that may contribute to these increases can vary from mining site to mining site (Ghose 2007).

Elevations in specific toxicants arise from multiple sources and practices. The sources of carbon monoxide, nitrogen dioxide, sulfur dioxide, aldehydes, benzene, and other PAHs in coal mining areas are due to such things as mine fire, burning of coal, blasting, and movement of vehicles (Ghose 2007; Ghose and Majee 2007). Elevation of As in soil/dust is a primarily a result of As co-occurrence with pyrite. Pyrite (FeS_2) is an iron sulfide mineral common in coal deposits and may be a source of As enrichment that is released into the environment in coal removal processes. Concentration of As in pyrite has been documented to be up to 25,525 mg/kg in eastern Kentucky coal fields and up to 3,900 mg/kg in West Virginia coal fields (Diehl et al. 2012).

While enrichment of Cd, Cr, Cu, Fe, Pb, Ni, Zn, and silica in coal mining compared to non-coal mining soil/dust have been reported (De and Mitra 2004; Šebestová et al. 1996; Das and Chakrapani 2011; Onder and Yigit 2009), most of the soil/dust concentrations fall well below the 95th percentile of U.S soils (Smith et al. 2005). Rather than drastic enrichment of soil/dust concentrations of Cd, Cr, Cu, Fe, Pb, Ni, Zn, and silica due to coal mining, evidence suggests primarily crustal origins, and elevated exposure is due in large part to increased amounts of dust generated by coal mining as discussed previously (Dubey et al. 2011).

Table 10. Associations matrix of health effects and toxic agents in ground water (W) and soil/dust (S) potentially due to coal mining

Associations/Causes	Asthma	Birth Defects	Cardiovascular Disease	Hypertension	Kidney Disease	Lung Disease	Cancer
Ambient air toxicants							
• Particulate matter undefined	S	S	S	S		S	
• Particulate matter—PM_{10}	S		S				S
• Carbon monoxide		S	S			S	
• Nitrogen dioxide	S	S	S			S	
• Sulfur dioxide	S	S	S			S	
Organic carbon species			W				
Aluminum					W		
Arsenic		S,W	S,W	S,W	S,W		S,W
Beryllium					S		S
Cadmium		S	S	S	S		S
Chromium			S,W		S,W		S,W
Cobalt							W
Copper			S,W				
Iron			S,W				
Lead		S,W	S,W	S,W	S,W		
Nickel			S,W				S,W
Sulfur			W				
Zinc			S,W				
Silica			S				S
Quartz			W				
Aldehydes			S				
Benzene							S
Polyaromatic hydrocarbons			S				

Potential enrichment of ground water with Al, As, Cr, Co, Cu, Fe, Pb, Ni, Zn, silica, and quartz may be attributed to acid mine drainage that leaches these constituents from soil. Coal mining exposes pyrite to atmospheric conditions and allows it to react with oxygen, resulting in hydrolysis of water molecules and the release of acidic protons (Black and Craw 2001). In northern and central Appalachian coal mining regions, mine-drainage constituents may become elevated compared to levels in un-mined areas because of exposure of acidic mine drainage to naturally occurring calcareous materials. The result is neutral pH ground water with elevated levels of Al, Ca, Fe, Zn, and silica (McAuley and Kozar 2006); which have been identified as agents of concern in the associations matrix (Table 10). Elevated As levels, above the US EPA drinking water standard (10 μg/L) have been detected in ground water samples collected from the Appalachian region. Wigginton et al. (2008) reported elevated levels of As, Fe, Mn, and Pb in some wells in Big Sandy Region of Kentucky and West Virginia. However, the authors concluded that linking the elavated levels to coal mining was not possible due to naturally higher concentrations occuring in Big Sandy Region rock.

While the associations matrix indicates an indirect link between health effects and coal mining source using literature not limited to Appalachia and health effects, there are two studies which support these results with direct biological measures. A study by Johnson et al. (2011), using toenails collected from colorectal cancer patients as a biomarker, documented potentially elevated exposure to As, Cr, and Ni in Appalachian Kentucky coal mining counties over a non-mining reference county. The study also found that lung cancer incidence, mortality rates, and colorectal mortality rates are higher in Appalachian coal mining counties than non-coal mining counties in Kentucky. However, further research is needed in order to determine the source of As, Cr, and Ni and establish an exposure pathway that links the source to individuals with evidence of increased exposure. In a study by Knuckles et al. (2012), rats' lungs were exposed to dust collected one mile from an active mountain top mining site. The exposure resulted in microvascular dysfunction, which may contribute to cardiovascular disease. However, there was no evidence provided that can confirm that the dust collected for the exposure study can be sourced to the coal mine. Characterization of potential source material from the coal mining site sufficient to confirm that coal mining is the source is necessary in order to link coal mining to the study conclusions.

CONCLUSION

This study provides a broad look at possible toxic agents that could be implicated in health effects reported to be elevated in Appalachian coal mining communities. The list of toxic agents was significantly narrowed when screened by literature references linking the toxic agents to coal mining. The resulting associations matrix allows for potential exposure routes of plausible toxic agents to be identified. Given the toxic agents identified, the primary routes of exposure are ingestion and inhalation for soil/dust and ingestion for water.

Fugitive dust in Appalachian coal mining communities is the major exposure pathway of concern for surface coal mining operations. In addition to the potential for adverse health effects associated with particulate matter, constituents in the dust may also need to be considered. In particular, As, Cd, and Pb are associated with many of the health effects reported to be elevated in coal mining communities. Ingestion of potentially toxic constituents in ground water may also be a concern, but the variability in regional hydrology and natural geology make it difficult to establish a link between elevated levels of potentially toxic agents and coal mining in Appalachia.

While this study provides potential associations between adverse health effects and toxic agents, it is impossible to establish a causal linkage without site specific exposure characterization in the Appalachian region. Further research is needed to quantify the amount of dust leaving coal mining operations and determine the total content and bioavailable fractions (via ingestion and inhalation) of dust constituents, in order to determine if exposure to coal mining communities is sufficiently elevated to cause adverse health effects.

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