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Short communication

Characterization of particulate matter (PM_{10}) related to surface coal mining operations in Appalachia

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ABSTRACT

This study investigates the environmental exposure of residents of a community in southwest Virginia to respirable concentrations of dust (PM-10 i.e. PM_{10}) generated by trucks hauling coal from surface coal mining operations. The study site is representative of communities in southwest Virginia and other parts of Appalachia that are located in narrow hollows where homes are placed directly along roads that experience heavy coal truck traffic.

Preliminary air sampling (Particulate Matter i.e. PM_{10}) was conducted for a period of approximately two weeks during early August 2008 in the unincorporated community of Roda, Virginia, at two locations (about a mile apart along Roda Road (Route 685) in Wise County, Virginia). For the purposes of this study (a combination of logistics, resource, and characterization of PM) we sited the PM samplers near the road to ascertain the micro exposure from the road. The results revealed high levels of PM_{10} (the mean adjusted 24-h concentration at the Campbell Site = 250.2 $\mu g\,m^{-3}$ ($\pm$135.0 $\mu g\,m^{-3}$); and at the Willis Site = 144.8 $\pm$ 60.0 $\mu g\,m^{-3}$). The U.S. 24-h national ambient air quality standard for PM_{10} is 150 $\mu g\,m^{-3}$. Elemental analysis for samples (blank-corrected) collected on Quartz filter paper (on one randomly selected day) at both the sites revealed the presence of antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium. Electron micrographs reveal the morphology and habit (shapes and aggregates) of the particulate matter collected.

1. Introduction

Surface coal mining has increased globally during the past 30 years. The use of coal is expected to increase by 60% over the next 20 years (http://www.worldcoal.org). This increase in coal usage raises a number of environmental challenges. Many of the environmental impacts of surface coal mining, particularly mountaintop removal mining in Appalachia, are well documented (Palmer et al., 2010; Gilbert, 2010). These impacts include loss of biodiverse native hardwood forests, burial of ecologically valuable headwater streams by valley fills, reduced soil infiltration capacity and increased runoff, and increased levels of acidity, electrical conductivity, total dissolved solids, and heavy metals in water bodies located downstream from mining operations. Less well known are the impacts to communities in Appalachia from air pollution caused by coal mining, and particularly by trucks that haul coal and other materials through residential areas (Aneja, 2009).

The central Appalachian region, including parts of Kentucky, Tennessee, Virginia, and West Virginia, is generally recognized to be one of most economically distressed regions in the United States (Appalachian Regional Commission, 2010). Within this region, the areas with the highest levels of poverty correspond to the areas with the greatest coal mining intensity (Hendryx, 2008). Central Appalachia also suffers from an excess of premature deaths (Halverson et al., 2004). Even adjusting for factors common to Appalachia such as poverty, smoking, and poor education, high age-adjusted mortality rates directly correlate with proximity to mining operations, with mortality rates increasing with increased coal production (Hendryx, 2008). The elevated adjusted mortality experienced in coal mining areas occurs in both males and females, suggesting that the cause is not occupational exposure but rather chronic exposure to air and water pollution caused by coal mining and related activities (Hendryx and Ahern, 2009). Human health impacts may come from water or exposure to airborne toxins and dust.

As described above, the impacts of surface coal mining on wetlands and water quality are well documented (Gilbert, 2010). Less well documented is the air pollution associated with surface

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coal mining. Surface mines generate air pollution, primarily particulate matter, through blasting, wind erosion of exposed areas, and handling of coal at the mines, during transportation, and at processing plants. Because surface mining laws require a buffer between active mining operations and populated areas, the impacts of air pollution from blasting and wind erosion may not always be acutely experienced. Other forms of mining-related air pollution are harder for local residents to avoid.

After coal is removed from the ground, it is typically transported off-site via large trucks that travel on public roads. These coal trucks frequently travel through communities located in steeply sided valleys, or hollows, where homes are situated very close to the narrow roads. Some communities experience up to hundreds of truck trips a day. Coal trucks emit dust directly from their tires, bodies, and beds. They also track dirt and other materials from unpaved roads onto paved roads where the material dries and is re-entrained by the passage of subsequent vehicles.

The mountainous terrain of Appalachia both concentrates the air pollution associated with coal mining, and forces residents to place their homes in close proximity to roads and other sources of dust. Accordingly, typical methods of measuring regional air impacts – which involve placing monitors away from roads, among other precautions – may not accurately represent the actual exposure of residents of these communities. The objective of this study was to measure the exposure of residents of one community to respirable dust, and to correlate that exposure to dust sources including coal trucks.

2. Material and methods

During August 2008, two (2) PM_{10} air samplers were employed during a twelve day measurement period in the community of Roda in southwest Virginia where residents reported high truck traffic and significant dust problems (Fig. 1). PM_{10} samplers were located along a narrow, public road (Roda Road (Route 685) in Wise County, Virginia) that branches off of a state highway (Virginia State Route 78) and terminates approximately four miles later at the entrances to several coal mines. One sampler was located in the front yard of a residence located very close to the entrance to the coal mines ("Site Campbell") (36°57′35″N, 82°49′57″W, elevation 1942 feet MSL), and the second PM_{10} sampler was located in the front yard of a residence located approximately one mile further down the road, closer to the state highway ("Site Willis") (36°57′8″N, 82°49′14″W, elevation 1862 feet MSL). In both cases, the samplers were located

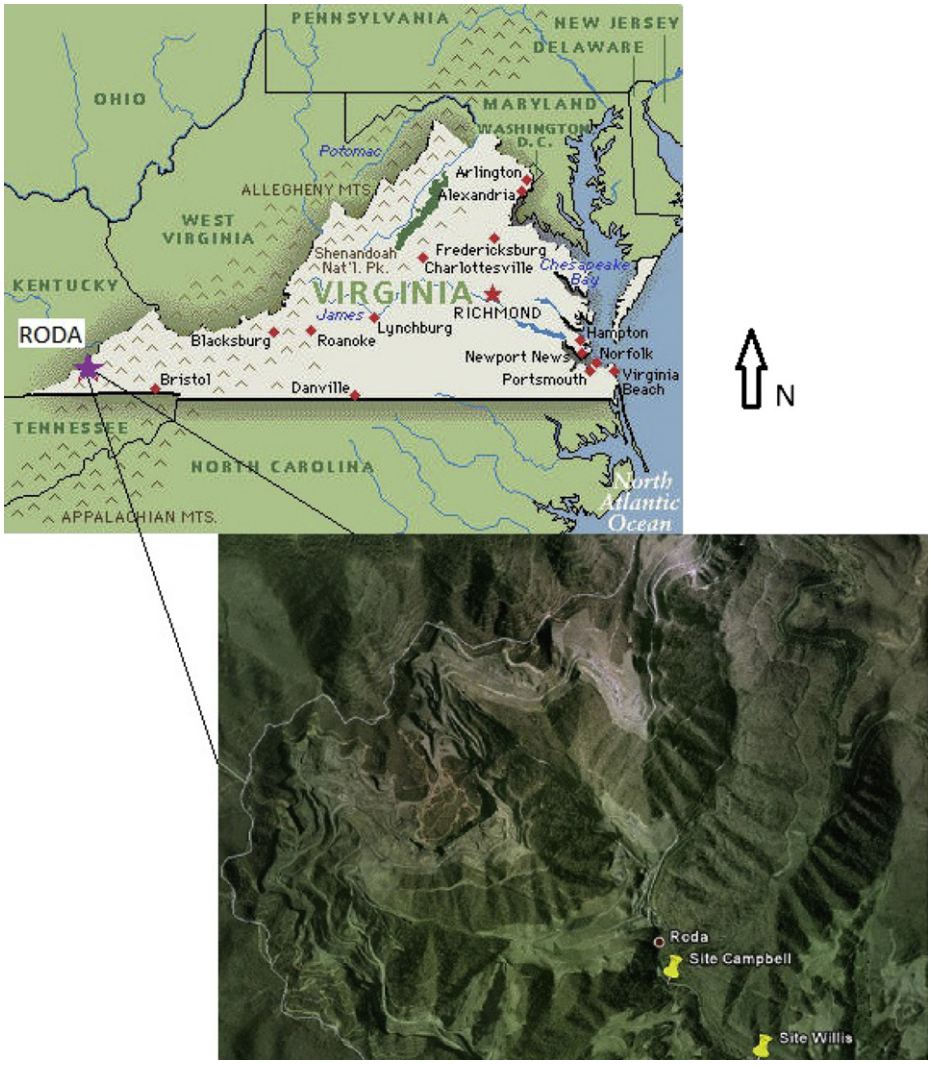

Fig. 1. Location of measurement sites in Roda, Virginia. Satellite image provides PM_{10} sampler locations (Site Campbell and Site Willis) along a narrow, public road (Roda Road (Route 685) in Roda, Wise County, Virginia) that branches off of a state highway (Virginia State Route 78) and terminates approximately four miles later at the entrances to several coal mines.

between the road and the front of the home, and within six (6) feet of the front of the home. The inlet height for both the samplers was ~5.5 feet. The topography around each monitoring site relative to the roadway was flat. These sampling locations were selected to represent micro to middle scale environments that are representative of the exposure of local residents. Because our goal was to record actual exposure levels experienced by local residents (special experiment) and not to evaluate regional air quality, we did not follow all of the United States Environmental Protection Agency (U.S. EPA) citing criteria for ambient air quality monitoring.

The PM_{10} samplers used were U.S. EPA reference method Andersen/GMW Model GUV-16H High Volume air samplers equipped with size selective inlets to collect ambient particulate matter with an effective aerodynamic size of less than ten microns. The samplers were calibrated in the laboratory immediately prior to the field deployment, and then calibrated and operated every day in accordance with the manufacturer's specifications and U.S. EPA methodology (US EPA, 1983, http://www.tisch-env.com/index8.asp). On-site calibrations included volumetric flow verification through the samplers via comparison of the calibrated orifice results to the volumetric flow controller tables. The samplers were operated continuously for twelve days, resulting in twelve 24-h samples from each location. Most of the particulate matter samples were collected onto 8-inch × 10-inch fiberglass filters, but on the same randomly determined day an 8-inch × 10-inch quartz fiber filter was used at each location. The quartz filters were equilibrated in an environmentally conditioned weighing room at ~70 °F and ~50% RH. The actual temperatures and humidities are in the research records at ERG. Binder-less Quartz filters were used directly from the manufacturer (Whatman) after equilibration and pre-weighing. Filters were handled with nitrile gloves and placed in glassene envelopes for shipping. Moreover, two blank quartz filter samples were also used (one for each site); and the blank corrections applied to the exposed quartz filters. The blank results are representative of a field sample because the blank samples were transported, prepared, digested and analyzed in the same way as the field sample. Analysis procedures for ambient quartz filters followed the Technical Assistance Document guidance for the National Air Toxics Trends Stations Program (http://www.epa.gov/ttnamti1/files/ambient/airtox/nattsTADRevision2_508Compliant.pdf).

Following the conclusion of sampling, the fiberglass filters were analyzed to determine mass, while the quartz filters were analyzed for mass and for the presence of a select group of metals. Filter tare weights were recorded prior to filter media shipment and use. Weight of the filter with the collected sample was measured following 24-h equilibration under environmentally controlled balance room conditions. The sample mass was determined by subtracting the original filter tare weight from the sample plus filter tare weight. Where the actual sampling exposure time for a filter was less than or greater than 24-h, we calculated the 24-h equivalent mass for the sample. A selection of the filters was subjected to scanning electron microscopy to confirm that the particles were consistent with the ten micron standard. The blank quartz filters were also analyzed for the presence of metals and used for blank correction for metal concentrations in the samples. A comprehensive US EPA based QA/QC protocol was in place for the entire experiment (Aneja, 2009).

A 4-inch × 1-inch portion of each of the two quartz filters was removed and the sample extracted in a 4% nitric acid solution via sonification for a total of 90 min, followed by the addition of 15 mL of water and sonification for an additional 90 min. The acid extractable fraction of each quartz filter portion was then analyzed by inductively coupled plasma mass spectrograph. This inorganic analysis followed the requirements in U.S. EPA compendium method IO-3.5. The US EPA IO-3.5 methods can be found at: http://www.epa.gov/ttnamti1/inorg.html.

3. Results

At the Campbell Site, our air sampling revealed adjusted 24-h concentrations of PM_{10} that ranged from 31.9 $\mu g\,m^{-3}$ to 469.7 $\mu g\,m^{-3}$ for the twelve sampling days. The mean adjusted 24-h concentration at the Campbell Site was 250.2 $\mu g\,m^{-3}$ ($\pm$135.0 $\mu g\,m^{-3}$). At the Willis Site, the adjusted 24-h concentrations of PM_{10} ranged from 19.2 $\mu g\,m^{-3}$ to 218.5 $\mu g\,m^{-3}$ for the twelve sampling days. The mean adjusted 24-h concentration at the Campbell Site was 138.5 $\mu g\,m^{-3}$ ($\pm$62.9 $\mu g\,m^{-3}$). The U.S. EPA National Ambient Air Quality Standard for 24-h concentrations of PM_{10} is 150 $\mu g\,m^{-3}$. Ten out of twelve samples taken at the Campbell site exceeded this limit, with one sample more than three times the national standard. Six out of twelve samples taken at the Willis site exceeded the national standard (Fig. 2). Moreover, a selection of the filters (collected at both sites on August 13, 2010) was subjected to scanning electron microscopy to confirm that the particles were consistent with the ten micron standard, and therefore that the samplers were measuring only respirable particles and that the results accurately represented the environmental exposure of the Roda community. The scanning electron microscopy further showed the morphology and habit (shapes and aggregates) of the particles, suggesting that particles that appeared at lower resolution to exceed ten microns in diameter had been subject to a growth mechanism owing to impaction and agglomeration on the filter media (Fig. 3).

Particulate matter is typically composed of a complex mixture of chemicals that is strongly dependent on source characteristics. Inorganic analysis of the two samples – one from each site – revealed the presence of antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium (Table 1). All of these metals present in the Roda samples are known to be present in coal (Finkelman, 1995).

4. Discussion and conclusions

Elevated levels of particulate matter have been associated with significant negative effects on human health. Significant and measurable reductions in life expectancy in the United States have been correlated to exposure to fine particulate matter (Pope et al., 2009). Exposure to PM_{10} is significantly correlated with all-cause, cardiovascular, and respiratory mortality (Zanobetti and Schwartz, 2009). In recognition of these health risks, the U.S. EPA has established health-based standards that provide maximum

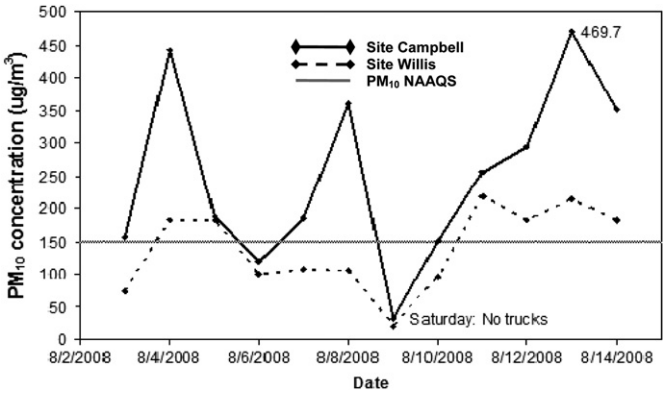

Fig. 2. Measurements of PM_{10} 24-h concentration at the two locations (Site Campbell and Site Willis) in Roda, Virginia, during August 2008.

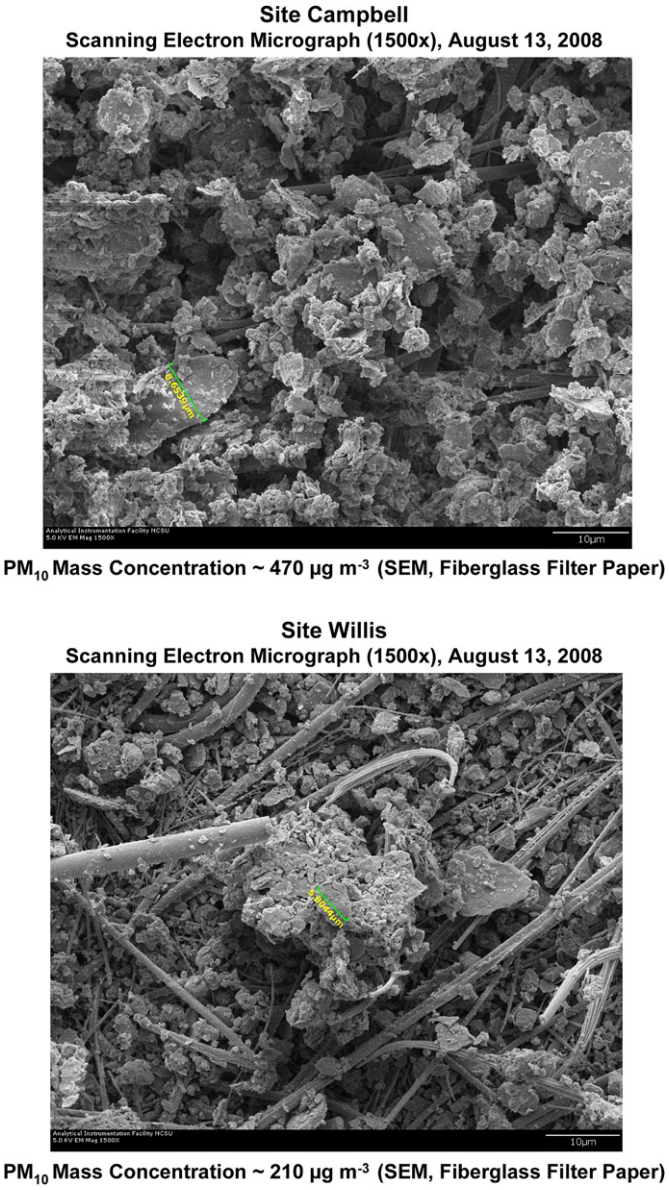

Fig. 3. Images from scanning electron microscopy.

ambient concentrations for particulate matter, including a standard of 150 $\mu g\,m^{-3}$ for 24-h concentrations for PM_{10}. U.S. EPA's recent draft policy assessment for particulate matter standards suggests a new 24-h PM_{10} standard in the range of 65–85 $\mu g\,m^{-3}$ for 24-h concentrations (U.S. EPA, 2010). Exposure to particulate matter that includes coal dust is particularly hazardous (Hendryx et al., 2008). The risks associated with coal dust exposure among mine workers are well studied. Recognizing the risk to the general public from exposure to particulate matter containing coal dust, the Wisconsin Department of Health and Family Services has proposed a risk-based ambient air concentration of 20 $\mu g\,m^{-3}$ for coal dust (WDHFS Letter, 2003).

The results of our recent air monitoring in Roda, Virginia, reveal that this community contends with exposure to particulate matter containing coal dust at levels far above what is considered safe. The extent of the community's exposure is not entirely understood at this time, as the study was limited to twelve consecutive days in August of one year, and particulate matter concentrations may vary seasonally. However, that multiple exceedances of the PM_{10} standards were documented within the limited sampling period strongly suggests that particulate matter exposure is a chronic problem for the Roda community, at least for portions of the year. In addition, there was insufficient data available from this study to assess the relative weight of the various factors (e.g. volume of truck traffic, weather conditions, additional sources of PM_{10}) that may have contributed to the variability of particulate matter concentrations recorded at each site. However, the near absence of detectable particulate matter on the one day when trucks were not running, combined with the consistent relative decrease in particulate matter levels between the site closest to the mine exit (Site Campbell) and the site approximately one mile further from the mine exit (Site Willis) (Fig. 2), strongly suggests that trucks carrying materials from the mines are a major contributor to the recorded particulate matter concentrations at this location.

Table 1
Inorganic analysis of particulate matter (PM_{10}) collected on quartz filters.

Analyte	PM_{10} mass concentration collected on the quartz filter paper ($ng\,m^{-3}$)	Time of exposure (h)	Normalized 24 h-Mass concentration ($ng\,m^{-3}$)[a]
Site Campbell – sample collected August 7, 2008			
Antimony	1.83	23.67	1.856
Arsenic	0.958	23.67	0.971
Beryllium	0.067	23.67	0.068
Cadmium	0.263	23.67	0.267
Chromium	2.74	23.67	2.778
Cobalt	0.915	23.67	0.928
Lead	3.9	23.67	3.954
Manganese	34.1	23.67	34.575
Mercury	0.14	23.67	0.142
Nickel	3.04	23.67	3.082
Selenium	0.613	23.67	0.623
PM_{10} mass	183,432	23.67	185,990
Site Willis – sample collected August 7, 2008			
Antimony	1.810	23.5	1.849
Arsenic	0.720	23.5	0.735
Beryllium	0.041	23.5	0.042
Cadmium	0.090	23.5	0.092
Chromium	3.600	23.5	3.166
Cobalt	0.697	23.5	0.991
Lead	3.320	23.5	3.391
Manganese	19.400	23.5	19.813
Mercury	0.972	23.5	0.993
Nickel	14.300	23.5	14.604
Selenium	0.568	23.5	0.592
PM_{10} mass	96,853	23.5	98,914

Volumetric flow rate of ambient air through the quartz filter paper: 40 $ft^3\,min^{-1}$.
[a] PM_{10} mass collected on the filter normalized to 24 h exposure.

Because this community is similarly situated to other communities in Appalachia where surface coal mining is common, it is very likely that these other communities contend with similar chronic exposure to particulate matter. However, additional study is required to confirm this hypothesis. Should further study demonstrate similar patterns of particulate matter exposure in other communities that experience high coal truck traffic, new regulations may be required to address the primary sources of this particulate matter.

Under the terms of the Clean Air Act, the U.S. EPA sets National Ambient Air Quality Standards (NAAQS) for a selection of air pollutants. Each state is then required to prepare and apply a State Implementation Plan (SIP) that describes how the state will attain and maintain those standards for each pollutant. The EPA has promulgated several NAAQS for particulate matter, including for PM_{10}. Many states, in turn, have adopted plans or control measures to limit emissions of particulate matter or fugitive dust. These SIPs for particulate matter or dust, however, are largely inadequate to address the problem of dust emitted by coal operations, including in particular the dust emitted by coal haul trucks.

Table 2
The particulate matter values from different regions of the world in or near an opencast coal mine.

Regions		$PM_{2.5}$ ($\mu g\,m^{-3}$)	PM_{10} ($\mu g\,m^{-3}$)	SPM or RPM ($\mu g\,m^{-3}$)
North East England (Pless-Mulloli et al., 2000)	Average	–	22.1	
Czech Republic (Hykysova and Brejcha, 2009)	Heating period	–	37	
	Non heating period	–	26	
	Transition period	–	33	
	Annual mean	–	33.5	
Turkey (Onder and Yigit, 2009)	Drilling	–	3080	
	Coal handling plant	–	1840	
	Stock yard	–	1670	
	Overburden loading	–	1350	
	Coal loading	–	1300	
Zonguldak City, Turkey (Tecer et al., 2008)	Winter	34.17	63.59	
	Spring	29.84	59.16	
	Summer	25.03	41.83	
	Autumn	23.03	39.66	
Jharia, India (Ghose and Majee, 2002)	Average (6 stations)	–	–	1473.66 (SPM); 197.79 (RPM)
Dhanbad, India (Dubey and Pal, 2012)	Average (31 stations)	–	194 ± 32 Range: (59–339)	
Present study	Campbell Site	–	250.2 ± 135.0 Range: (31.9–469.7)	
	Willis Site	–	144.8 ± 60.0 Range: (19.2–218.5)	

SPM is the suspended particulate matter and RPM is the respirable particulate matter.

In many states, the SIPs for particulate matter or fugitive dust require only that emitters employ "reasonable precautions" to prevent particulate matter from becoming airborne (Alaska SIP). A smaller subset of states provide examples of such reasonable precautions, but these examples fail to include those actions most likely to prevent the release of dust from trucks or from material tracked out onto roads (Virginia SIP). As a result, state and federal regulators are limited in their ability to enforce the standards, and emitters are not informed about actions they should take to reduce their dust emissions.

States, therefore, should consider revising their SIPs for particulate matter or fugitive dust to require that emitters take at least the following reasonable precautions: cover all loads transported by truck or railcar; promptly remove spilled or tracked materials from paved roads; wash all wheels, undercarriages, and other parts of every vehicle that hauls coal or other materials before or immediately after the vehicle leaves a dusty, dirty, or muddy surface; clean the empty bed and/or any other part of a vehicle that had recent contact with material capable of emitting dust; and install and use rumble strips, speed bumps, or other devices designed to reduce vehicle speed and to dislodge mud and other materials from tires and vehicle bodies before vehicles enter public roads.

We recently conducted monitoring in Roda, Virginia, a community that experiences heavy coal truck traffic and that is similarly situated to other communities in the steep hollows of Appalachia. Our monitoring revealed levels of respirable particulate matter (PM_{10}) up to three times the federal standard. The measured PM values are in the same range as the particulate matter values near an opencast coal mine in India, and significantly higher than particulate matter values near opencast coal mines in England and the Czech Republic (Table 2). The respirable particulate matter levels measured in Roda, therefore, are more closely aligned with those levels experienced in a newly industrialized nation than with the lower levels experienced in other developed nations. Without clear regulations and effective enforcement, communities like Roda will continue to contend with dangerous levels of particulate matter in dust generated by coal trucks.

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