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Health of Children Living Near Coal Ash

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Abstract

Coal ash, generated from coal combustion, is composed of small particles containing metals and other elements, such as metalloids. Coal ash is stored in open-air impoundments, frequently near communities. The objective of this study was to evaluate the prevalence of health and sleep problems in children living near coal ash and compare these prevalences to children not living near coal ash. In 2013 to 2014, we conducted a cross-sectional survey in a community adjacent to coal ash storage sites and a community not exposed to coal ash. Overall, 111 children who lived near coal ash were in the study; 55.9% (62) were males, 44.1% (49) were females, and the mean age was 10.3 years (SD = 3.9). Descriptive statistics and logistic regression were used to compare the prevalence of health and sleep problems. Attention-deficit hyperactivity disorder ($P = .02$), gastrointestinal problems ($P = .01$), difficulty falling asleep ($P = .007$), frequent night awakenings ($P < .001$), teeth grinding ($P = .03$), and complaint of leg cramps ($P < .001$) were significantly greater in the children living near coal ash. When adjusting for covariates, the odds of allergies excluding asthma, attention-deficit hyperactivity disorder, gastrointestinal problems, difficulty falling asleep, frequent night awakenings, sleep talking, and complaint of leg cramps were greater in children living near coal ash compared to children not living near coal ash (nonexposed). Several components of coal ash, such as heavy metals like lead, mercury, and arsenic, may be associated with health and sleep problems in children. More research is needed to investigate this relationship.

Keywords

coal ash, children's environmental health

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Introduction

Globally, coal's share of the energy market has decreased, yet total consumption of coal is expected to increase 15% by 2040.[1] In 2014, approximately 8000 metric tons of coal was produced among the major coal producing countries, with the largest production occurring in China.[2] Approximately 65.5% of primary coal produced is used globally for electricity and commercial heat.[2]

Coal combustion, a process used to generate electricity, creates waste by-products known as coal combustion residuals, 60% of which is coal ash.[3,4] Coal ash contains radioactive elements and varying concentrations of metals including arsenic, cadmium, lead, and mercury.[5-7] Approximately 80% of coal ash is fly ash, which is composed of glassy spherules with a respirable range in size between 1.98 and 5.64 µm.[4,8] As particle size decreases and surface area increases, pollutant concentrations in coal ash increase. Spencer and Drake found that the concentration of metals in fly ash can be 2 times greater than the concentration found in the coal.[9]

According to the American Coal Ash Association, in 2014 coal-fired plants in the United States generated approximately 130 million tons of coal combustion residuals.[10] The US Environmental Protection Agency (EPA) estimates the coal ash is stored in over 310 active landfills and an estimated 735 active surface impoundments across 47 states.[11] The age of the storage sites vary considerably, but the EPA reports 75% are more than 25 years old and 10% are more than 50 years old; therefore, many do not have adequate protections in place to reduce environmental contamination.[12] In 2010, the EPA reported that among states with coal ash storage facilities, 36% do not have minimum liner requirements for landfills and 67% do not have liner requirements for

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ash ponds.[11] In addition, activities related to the maintenance of these coal-combustion facilities, including the hauling, dumping, and storing of coal ash, allow particles to escape into the ambient air as fugitive dust emissions.[13]

In 2014, the US EPA revised environmental regulations to classify coal ash as a special waste, allowing coal ash to be recycled in manufacturing products while establishing minimum national criteria for combustion waste storage facilities.[14] These national criteria, including liner requirements for impoundments, ground water monitoring, and reporting on fugitive dust emissions, were established to reduce risk from improper management of coal ash storage units.[14] The EPA has stated "that without fugitive dust controls, there could be exceedances of the National Ambient Air Quality Standards for fine particulate matter in the air at residences near *coal ash* landfills."[11]

In addition to exposure from inhalation of fugitive dust, people may be exposed to coal ash from drinking water, if the community relies on well water, as well as through dermal contact with contaminated soils and dust. Metals available in coal ash can leach from the ash particles into the soil and water in areas surrounding coal ash storage facilities.[3,4,15] The EPA has reported that some contaminants from fly ash leachate could be elevated and above the maximum concentration limit or the drinking water equivalent level for metal contaminants.[11]

In the United States, the EPA estimates that 6 million people, including 1.5 million children, are exposed to coal ash.[11] Children have an increased risk of exposure to fly ash. Children have higher rates of respiration relative to adults, increased hand-to-mouth behavior, and a tendency to play near the ground, which increases exposure to ambient particulate matter.[16,17] The effect of chronic coal ash inhalation on children has not been well studied; however, studies evaluating the biological effects of particulate matter of similar structure and heavy metal concentration raise concerns applicable to coal ash particle exposure.[18-20] Experimental research has demonstrated that fine and ultrafine particulate matter can pass directly through the nasal olfactory pathway into the circulatory system to the brain.[18,19] In addition, research has shown when air pollution is cleared from the lungs it can enter the gut and exit the body via the gastrointestinal tract.[20] Chronic exposure to air pollution and particulate matter has been found to cause chronic inflammation and elevated levels of cytokines throughout the body and brain.[18,19] In addition, some of the metals in fly ash are neurotoxins,[21-24] and exposure to neurotoxic heavy metals during rapid growth in the early stages of life can disrupt developmental processes and result in neurological dysfunction.[17,24]

To date there are no studies assessing the impact of coal ash on the health and sleep of children living near coal ash storage sites. Therefore, the primary objective of this study is to evaluate the prevalence of health conditions and sleep problems in children living near coal ash storage and compare to children who do not live near a coal ash storage facility.

Methods

The community-based cross-sectional study involved 4 neighborhoods adjacent to coal ash storage. In addition, a comparison population with similar demographic and socioeconomic characteristics was chosen 60 miles away from the storage facility in a rural setting. The children living in the rural setting did not live near power plants and coal ash storage sites. Institutional review board approval (12.0258) was obtained from the University of Louisville.

Description of the Coal Combustion Electric Plant

The power generating plant, located in the state of Kentucky in the United States, opened in the 1950s and occupies 510 acres. It burned 1.3 million tons of coal each year. The plant has one landfill and one slurry pond for the storage of coal ash, but the electric company has identified 9 potential sources for fugitive dust and odor emissions. The landfill, which opened in 1982, stores a mix of coal ash products on 163 acres. The main ash pond, which opened in 1972, stores fly ash and bottom ash. It is 40 acres in size with a dam height of 12 feet. In 2011, 2012, and 2013, the plant was fined for numerous violations associated with fugitive dust and odors from the landfill. There are homes located across the street and within 150 feet from the plant and coal ash storage pond.

Study Population

In the community living near coal ash and the comparison population, parents or legal guardians, 18 years or older, completed a questionnaire about the health and sleep of all children residing in their home. For this analysis, the study population is the 111 children, ages 4 to 17, about which parent-reported health and sleep information was obtained. Children were considered to be exposed to coal ash (n = 61) if they lived near coal ash storage. Overall, 55.9% (62) are males, 44.1% (49) are females, and the mean age is 10.3 years (SD = 3.9). The nonexposed comparison group (n = 50) is defined as the children living in the rural setting not near coal ash storage. Both populations are multigenerational and nontransient. Most of the children had lived in the respective areas, near coal ash or in the rural comparison area, for a majority of their lives (median percent of life lived in area = 84.4%; range = 16.7% to 100%).

To be included in this study, children who were considered exposed had to be younger than 18 years of age and live in 1 of 4 neighborhoods near the coal burning power plant. Children who were considered nonexposed were less than 18 years of age and lived at least 60 miles from coal burning power plants and coal ash storage. Children were excluded if they did not meet the inclusion criteria.

Survey Methods

In the communities located adjacent to the coal ash storage facility, flyers and door-to-door methods were used to recruit participants. Recruitment of participants in the nonexposed comparison group occurred in the waiting room of a primary health care clinic that provides a range of health services for many residents in the county. Incentives such as water bottles, hats, screwdrivers, and coloring books were provided for parents and children.

Survey Questionnaire

Since there are no previously validated questionnaires for evaluating health conditions in populations of children exposed to coal ash, one had to be developed for the purpose of the study. The questionnaire was developed based on results from 5 focus groups with community members living near the coal ash storage facilities. Detailed methods for the focus groups have been published.[25] Common themes that arose from the focus groups were used to structure the questionnaire about children's health and sleep. The children's health section contained a large table with a list of health conditions and instructed parents or guardians to "circle Yes if your child has the health condition." Health conditions reported on the questionnaire and used in this analysis include asthma, allergies, learning difficulties, attention-deficit hyperactivity disorder (ADHD), developmental delay, emotional behavioral disorders, and gastrointestinal or stomach problems. The children's sleep section contained 19 questions pertaining to general sleep characteristics, bedtime routine, sleep problems, and daily activities. Current sleep problems reported on the questionnaire were difficulty falling asleep, frequent night awakenings, teeth grinding, repetitive movements during sleep (leg jerking, head rolling, lip smacking, hand flapping, or twitching), sleep walking, sleep talking, and complaining of leg cramps. Repetitive movements were reported as yes/no, while all other responses were formatted as a Likert-type scale with the following response options: Never, Rarely, Sometimes, Frequently, and Always.

Information about participant demographics, length of time living in either community (exposed or comparison), and parent or guardian tobacco use was also collected by questionnaire. A child was considered to be exposed to secondhand smoke (SHS) if the parent or guardian classified themselves as a "current smoker," indicated that somebody smokes in the home, or reported that somebody smokes while the child is present.

Data Analysis

SAS 9.4 (Cary, NC) was used for statistical analysis. Descriptive techniques were used to characterize health conditions and sleep problems in the exposed and comparison groups. *P* values were calculated using χ^2 or Fisher's exact test for categorical variables and Wilcoxon rank-sum test for continuous variables. The percent of life living in each community (comparison or exposed) was calculated by dividing the amount of time (years) lived in the community by the age of the child. Logistic regression was used to evaluate the association between exposure group and health or sleep outcomes. Crude and adjusted odds ratios with 95% confidence intervals are reported. The adjusted models included age, gender, and SHS exposure as covariates. Logistic regression was not used to evaluate the association between developmental delay, learning difficulties, emotional/behavioral disorders, or sleep walking and exposure group because of the low prevalence (less than 5) in the comparison group.

Results

Participant Demographics

In the exposed group (n = 61), 48% (29) were males and 52% (32) were females. The median age was 11 years (min = 4, Q1 = 8, Q3 = 14, max = 17). In the comparison group (n = 50), 66% (33) were males and 34% (17) were females. The median age was 10 years (min = 4, Q1 = 6, Q3 = 12, max = 17). There was no significant difference in gender or age between the 2 groups (P = .06 and P = .11, respectively). In the exposed group, the median percent of life lived near coal ash storage was 62.5% (range = 16.7% to 100%). While the median percent of life lived in the comparison area was 100% (range = 41.7% to 100%). Children in the comparison group lived in the rural setting for a greater percentage of their lives compared to percent of life the exposed children lived near

Table 1. Health Conditions in Children.

	Comparison (n = 50)	Exposed (n = 61)	Total (N = 111)	*P* Value
Asthma	18% (9)	26% (16)	23% (25)	.30
Allergies	40% (20)	74% (45)	59% (65)	<.001*
Learning difficulties	6% (3)	26% (16)	17% (19)	.005*[a]
ADHD	16% (8)	36% (22)	27% (30)	.02*[a]
Developmental delay	6% (3)	8% (5)	7% (8)	.73[a]
Emotional/behavioral disorders	4% (2)	38% (23)	23% (25)	<.001*[a]
GI/stomach problems	10% (5)	31% (19)	22% (24)	.01*[a]
Mean number of health conditions reported per child	1.0 ± 1.1	2.4 ± 1.7	1.8 ± 1.6	<.001*

Abbreviations: ADHD, attention-deficit hyperactivity disorder; GI, gastrointestinal.
[a]*P* values for Fisher's exact test due to low cell counts.
*Statistically significant (*P* < .05 level) compared to nonexposed children.

Table 2. Odds Ratios (95% Confidence Intervals) for Health Outcomes in Children Living Near Coal Ash Compared to Nonexposed.

	Unadjusted	Adjusted[a]
Asthma	1.62 [0.6, 4.1]	2.52 [0.8, 7.6]
Allergies	4.22 [1.9, 9.4]	3.96 [1.6, 10]
ADHD	2.96 [1.2, 7.4]	3.61 [1.2, 10.7]
GI problems	4.07 [1.4, 11.9]	5.74 [1.7, 19.6]

Abbreviations: ADHD, attention-deficit hyperactivity disorder; GI, gastrointestinal; SHS, secondhand smoke.
[a]Adjusted: SHS, age, and gender.

coal ash (*P* < .0001). More children in the exposed group reported SHS exposure compared to the comparison group (36% [22] and 16% [8], respectively; *P* = .02).

Health Conditions

Table 1 contains the prevalence of health conditions. Health conditions that were significantly different between the exposed group and nonexposed comparison group included allergies (74% exposed vs 40% nonexposed, *P* < .001), learning difficulties (26% exposed vs 6% nonexposed, *P* = .005), ADHD (36% exposed vs 16% nonexposed, *P* = .02), emotional/behavioral disorders (38% exposed vs 4% nonexposed, *P* < .001), and gastrointestinal or stomach problems (31% exposed vs 10% nonexposed, *P* = .01). Overall, the parents of children exposed to coal ash reported significantly more health conditions per child than the parents of children in the comparison group (2.4 vs 1.0; *P* =<.001).

Odds ratios and confidence intervals from logistic regression models with health outcomes as the dependent variable and exposure group as the independent variable are reported in Table 2. In the unadjusted models, children living near coal ash were significantly more likely to have allergies (odds ratio [OR] = 4.22; 95% confidence interval [CI] = [1.9, 9.4]), ADHD (OR = 2.96; 95% CI = [1.2, 7.4]), and gastrointestinal problems (OR = 4.07; 95% CI = [1.4, 11.9]) compared to children in the comparison group. While adjusting for SHS exposure, age, and gender in logistic regression models, children living near coal ash had significantly greater odds of allergies (adjusted odds ratio [AOR] = 3.96; 95% CI = [1.6, 10]), ADHD (AOR = 3.61; 95% CI = [1.2, 10.7]), and gastrointestinal problems (AOR = 5.74; 95% CI = [1.7, 19.6]) compared to children in the comparison group.

Sleep Problems

There was no significant difference between the exposed and comparison groups in the average hours of sleep per night (mean = 8.20, SD = 1.34, and mean = 8.38, SD = 0.90, respectively; *P* = .10). In addition, both the exposed and comparison groups reported having a regular bedtime routine (80% and 82%, respectively; *P* = .82). Children in the exposed group were significantly more likely to eat a large meal or snack (47% compared to 22% of the comparison group; *P* = .008) and/or use medications to help them sleep than children not exposed to coal ash (32% compared to 2% of the comparison group; *P* < .001).

Table 3 reports the prevalence of sleep problems. The prevalence of difficulty falling asleep (64% exposed vs 38% nonexposed, *P* = .007), frequent night awakenings (69% exposed vs 32% nonexposed, *P* < .001), teeth grinding (51% exposed vs 30% nonexposed, *P* = .03), and complaining of leg cramps while resting (57% exposed vs 24% nonexposed, *P* < .001) was significantly greater in children exposed to coal ash compared to nonexposed children. Overall, children exposed to coal ash

Table 3. Sleep Disruptive Behaviors[a].

	Comparison (n = 50)	Exposed (n = 61)	Total (n = 111)	*P* Value
Difficulty falling asleep	38% (19)	64% (39)	52% (58)	.007*
Frequent night awakenings	32% (16)	69% (42)	52% (58)	<.001*
Teeth grinding	30% (15)	51% (31)	41% (46)	.03*
Repetitive movements	40% (20)	52.2% (32)	47% (52)	.19
Sleep walking	6% (3)	15% (9)	11% (12)	.22[a]
Sleep talking	30% (15)	46% (28)	39% (43)	.09
Complaining of leg cramps while sleeping	24% (12)	57% (35)	42% (47)	<.001*
Mean total number of sleep disruptive behaviors reported (per child)	2.6 ± 2.4	4.92 ± 3.1	3.9 ± 3.0	<.001*

[a]Prevalence data include blank responses in the denominator.
[a]*P* value for Fisher's exact test due to low cell counts.
*Statistically significant (*P* < .05 level) compared to nonexposed children.

Table 4. Odds Ratios (95% Confidence Intervals) for Sleep Problems in Children Living Near Coal Ash Compared to Nonexposed.

	Unadjusted	Adjusted[a]
Difficulty falling asleep	2.89 [1.3, 6.3]	3.26 [1.4, 7.6]
Frequent night awakenings	4.70 [2.1, 10.5]	8.64 [2.9, 25.5]
Teeth grinding	2.41 [1.1, 5.3]	2.47 [1.0, 6.2]
Repetitive movements	1.66 [0.8, 3.5]	2.05 [0.8, 5.0]
Sleep talking	1.98 [0.9, 4.3]	3.33 [1.3, 8.7]
Complaining of leg cramps while sleeping	4.26 [1.9, 9.7]	3.96 [1.6, 10.1]

Abbreviation: SHS, secondhand smoke.
[a]Adjusted: SHS, age, and gender.

reported significantly more sleep disruptive behaviors than nonexposed children (4.92 vs 2.6, $P < .001$).

Results from logistic regression models with sleep problems as the dependent variable and exposure group as an independent variable are reported in Table 4. In the unadjusted models, children living near coal ash were significantly more likely to report difficulty falling asleep (OR = 2.89; 95% CI = [1.3, 6.3]), frequent night awakenings (OR = 4.70; 95%CI = [2.1, 10.5]), teeth grinding (OR = 2.41; 95% CI = [1.1, 5.3]), and complaining of leg cramps while sleeping (OR = 4.26; 965% CI = [1.9, 9.7]) compared to children in the comparison group. While adjusting for SHS exposure, age, and gender, results from logistic regression models suggest that children living near coal ash had significantly greater odds of difficulty falling asleep (AOR = 3.26; 95% CI = [1.4, 25.5]), frequent night awakenings (AOR = 8.64; 95% CI = [2.9, 25.5]), teeth grinding (AOR = 2.47; 95% CI = [1.0, 6.2]), sleep talking (AOR = 3.33; 95% CI = [1.3, 8.7]), and complaining of leg cramps while sleeping (AOR = 3.96; 95% CI = [1.6, 10.1]) compared to children in the comparison group.

Discussion

This study is the first to assess health conditions and sleep problems in children living near coal ash storage, and to compare the findings to a population of children not exposed to coal ash. Our results show significantly more children living near coal ash storage sites located beside the power plant in Kentucky have allergies, ADHD, and gastrointestinal problems compared to children in the comparison group. In addition, significantly more children living near coal ash have difficulty falling asleep, frequent night awakenings, teeth grinding, sleep talking, and complain of leg cramps while sleep compared to the comparison group.

There are no studies evaluating the health effects of coal ash exposure in children; however, the association between exposure to air pollution and adverse health outcomes has been documented in previous experimental and epidemiologic studies.[26-28] Exposure to air pollution has been found to impair lung function and increase wheezing in children.[26-28] Orazzo et al found exposure to various air pollutants was significantly associated with an increase in emergency room visits for gastrointestinal problems and wheezing.[29] Experimental research suggests exposure to particulate matter is able to alter the microbiome of the gut and long-term exposure can exacerbate colitis.[30]

Exposure to coal ash particles could affect both the respiratory and mental health of children. Borcherding et al conducted experimental studies that demonstrated the potential for coal ash particles to promote growth of pathogenic bacteria capable of causing respiratory infections.[31] In addition, ADHD, autism, behavioral problems, and decreased cognitive function have been associated with exposure to some of the metals found in coal ash, including arsenic, lead, mercury, manganese, and cadmium.[21-23,32-34] Children's exposure to metals and particulate matter, both prenatal and postnatal, can disrupt normal brain development leading to functional impairments.[35]

Recent studies have also found a significant association between elevated levels of particulate matter in air pollution and disorders of sleep initiation and maintenance in children, as well as an increased prevalence of habitual snoring.[36,37] Children with sleep problems can develop chronic illnesses and life-long problems. Sleep may be vital in the regulation of emotions and metabolism, as well as critical to memory, brain development, and learning.[38] Furthermore, inadequate sleep may predispose children to obesity, diabetes, and other chronic health conditions, while adequate sleep may improve function of the immune system and reduce risk of infection.[39]

There are several strengths and limitations that need to be considered. One strength of this study is that it is community based. Themes developed in community focus groups were used to establish general questionnaire topics.[23] Survey of the nonexposed children with similar sociodemographics provided comparison information while controlling for certain economic and cultural factors that may affect health and sleep.

Since this study was a cross-sectional study, we were unable to determine how long a child had a health condition. The purpose of this cross-sectional study was to assess current prevalence of health conditions in children; therefore, we did not ask about length of illness. One limitation that may exist is recall bias, by parents or guardians not accurately reporting health conditions and sleep problems of children in their household. To reduce recall bias, the questionnaire focused on current health and current sleep behaviors. Another limitation may be selection bias in the exposed group. Participants who were more concerned about exposure to coal ash, or those who had children with more health conditions, may have been more likely to participate in the survey. A third limitation of this study is that no environmental measures were collected to confirm the presence of coal ash in the homes of children. One major difference between the 2 groups is the urban setting of the exposed group and rural setting of the comparison group. The composition of particulate matter in these 2 settings is likely different beyond the presence, or absence, of coal ash particles. Other sources of pollution not considered in this study may also negatively affect sleep and health, in both populations.

Despite these limitations, this study is able to characterize health conditions and sleep problems in children living near a coal ash storage facility and utilizes a comparison group to identify areas for future more in-depth investigations. Much more research is needed to understand the effect of coal ash on health and sleep. Utilizing quantifiable measures of particulate matter will control for differences in particulate matter composition between children living near coal ash (exposed) and children not living near coal ash (nonexposed). Furthermore, more in-depth surveys of health history and psychological assessments will better document children's health conditions.

Conclusions

In this study, living near coal ash was found to be significantly associated with increased odds of adverse health outcomes and sleep problems for children. It is important to further assess the impact of coal ash exposure on the health and sleep of children living near coal ash storage facilities because exposure to particulate matter and heavy metals has been found to affect multiple organ systems and impair cognitive function.[19,32,36,40,41] Findings from this study can help guide larger studies assessing coal ash exposure and well-being of children living near coal ash storage.

Author Contributions

CGS: Contributed to conception and design; contributed to acquisition, analysis, and interpretation; drafted manuscript; critically revised manuscript; gave final approval; agrees to be accountable for all aspects of work ensuring integrity and accuracy.
KMZ: Contributed to conception and design; contributed to acquisition, analysis, and interpretation; critically revised manuscript; gave final approval; agrees to be accountable for all aspects of work ensuring integrity and accuracy.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

1. International Energy Agency. World energy outlook special report 2016: energy and air pollution. https://www.iea.org/publications/freepublications/publication/weo-2016-special-report-energy-and-air-pollution.html. Published 2016. Accessed September 11, 2016.
2. International Energy Agency. Key coal trends, excerpt from: Coal information. https://www.iea.org/publications/freepublications/publication/KeyCoalTrends.pdf. Published 2016. Accessed September 11, 2016.
3. Flues M, Sato IM, Scapin MA, Cotrim MEB, Camargo IMC. Toxic elements mobility in coal and ashes of

Figueira coal power plant, Brazil. *Fuel*. 2013;103:430-436. doi:10.1016/j.fuel.2012.09.045.

4. Jones KB, Ruppert LF, Swanson SM. Leaching of elements from bottom ash, economizer fly ash, and fly ash from two coal-fired power plants. *Int J Coal Geol*. 2012;94:337-348. doi:10.1016/j.coal.2011.10.007.
5. Bednar AJ, Averett DE, Seiter JM, et al. Characterization of metals released from coal fly ash during dredging at the Kingston ash recovery project. *Chemosphere*. 2013;92:1563-1570. doi:10.1016/j.chemosphere.2013.04.034.
6. Flues M, Moraes V, Mazzilli BP. The influence of a coal-fired power plant operation on radionuclide concentrations in soil. *J Environ Radioact*. 2002;63:285-294.
7. Hatori Y, Matsuyama S, Ishii K, et al. Pixe analysis of individual particles in coal fly ash. *Int J PIXE*. 2010;20(1):57-62. doi:10.1142/s0129083510001975.
8. Brown P, Jones T, BéruBé K. The internal microstructure and fibrous mineralogy of fly ash from coal-burning power stations. *Environ Pollut*. 2011;159:3324-3333. doi:10.1016/j.envpol.2011.08.041.
9. Spencer LL, Drake LD. Hydrogeology of an alkaline fly ash landfill in eastern Iowa. *Ground Water*. 1987;25:519-526.
10. American Coal Ash Association. 2014 Coal Combustion Product (CCP) & Use Survey report. https://www.acaa-usa.org/Portals/9/Files/PDFs/2014ReportFinal.pdf. Published July 2016. Accessed September 11, 2016.
11. Environmental Protection Agency. Hazardous and solid waste management system; identification and listing of special wastes; disposal of coal combustion residuals from electric utilities; proposed rule (Codified at 40 CFR Parts 257, 261, 264 et al.). *Fed Reg*. 2010;75(118):35128-35264.
12. Luther L. H.R. 2273 and S. 3512: Analysis of proposals to create a coal combustion residuals permit program under RCRA. http://www.crs.gov. Published December 10, 2012. Accessed May 10, 2015.
13. Mueller S, Mallard JW, Mao Q, Shaw SL. Fugitive particulate emission factors for dry fly ash disposal. *J Air Waste Manag Assoc*. 2013;63:806-818.
14. Environmental Protection Agency. Hazardous and solid waste management system; disposal of coal combustion residuals from electric utilities (Codified at 40 CFR Parts 257 and 261). *Fed Reg*. 2015;80(74):21302-21501.
15. Patra KC, Rautray TR, Tripathy BB, Nayak P. Elemental analysis of coal and coal ash by PIXE technique. *Appl Radiat Isot*. 2012;70:612-616. doi:10.1016/j.apradiso.2011.12.013.
16. Pope AC III, Dockery DW. Acute health effects of PM10 pollution on symptomatic and asymptomatic children. *Am Rev Respir Dis*. 1992;145:1123-1128.
17. Landrigan PJ, Kimmel CA, Correa A, Eskenazi B. Children's health and the environment: public health issues and challenges for risk assessment. *Environ Health Perspect*. 2003;112:257-265. doi:10.1289/ehp.6115.
18. Block ML, Calderon-Garciduenas L. Air pollution: mechanisms of neuroinflammation and CNS disease. *Trends Neurosci*. 2009;32:506-516. doi:10.1016/j.tins.2009.05.009.
19. Calderon-Garciduenas L, Franco-Lira M, Torres-Jardon R, et al. Pediatric respiratory and systemic effects of chronic air pollution exposure: nose, lung, heart, and brain pathology. *Toxicol Pathol*. 2007;35:154-162. doi:10.1080/01926230601059985.
20. Moller W, Haussinger K, Winkler-Heil R, et al. Mucociliary and long-term particle clearance in the airways of healthy nonsmoker subjects. *J Appl Physiol (1985)*. 2004;97:2200-2206. doi:10.1152/japplphysiol.00970.2003.
21. Kim S, Arora M, Fernandez C, Landero J, Caruso J, Chen A. Lead, mercury, and cadmium exposure and attention deficit hyperactivity disorder in children. *Environ Res*. 2013;126:105-110. doi:10.1016/j.envres.2013.08.008.
22. Froehlich TE, Anixt JS, Loe IM, Chirdkiatgumchai V, Kuan L, Gilman RC. Update on environmental risk factors for attention-deficit/hyperactivity disorder. *Curr Psychiatry Rep*. 2011;13:333-344. doi:10.1007/s11920-011-0221-3.
23. Bouchard M, Laforest F, Vandelac L, Bellinger D, Mergler D. Hair manganese and hyperactive behaviors: pilot study of school-age children exposed through tap water. *Environ Health Perspect*. 2006;115:122-127. doi:10.1289/ehp.9504.
24. Rodriguez-Barranco M, Lacasana M, Aguilar-Garduno C, et al. Association of arsenic, cadmium and manganese exposure with neurodevelopment and behavioural disorders in children: a systematic review and meta-analysis. *Sci Total Environ*. 2013;454-455:562-577. doi:10.1016/j.scitotenv.2013.03.047.
25. Zierold KM, Sears CG. Community views about the health and exposure of children living near a coal ash storage site. *J Community Health*. 2015;40:357-363. doi:10.1007/s10900-014-9943-6.
26. Gao Y, Chen EYY, Li LP, He QQ, Wong TW. Chronic effects of ambient air pollution on lung function among Chinese children. *Arch Dis Child*. 2013;98:128-135. doi:10.1136/archdischild2011-301541.
27. Jung KH, Hsu SI, Yan B, et al. Childhood exposure to fine particulate matter and black carbon and the development of new wheeze between ages 5 and 7 in an urban prospective cohort. *Environ Int*. 2012;45:44-50. doi:10.1016/j.envint.2012.03.012.
28. Li S, Williams G, Jalaludin B, Baker P. Panel studies of air pollution on children's lung function and respiratory symptoms: a literature review. *J Asthma*. 2012;49:895-910. doi:10.3109/02770903.2012.724129.
29. Orazzo F, Nespoli L, Ito K, et al. Air pollution, aeroallergens, and emergency room visits for acute respiratory diseases and gastroenteric disorders among young children in six Italian cities. *Environ Health Perspect*. 2009;117:1780-1785. doi:10.1289/ehp.0900599.
30. Kish L, Hotte N, Kaplan GG, et al. Environmental particulate matter induces murine intestinal inflammatory responses and alters the gut microbiome. *PLoS One*. 2013;8:e62220. doi:10.1371/journal.pone.0062220.
31. Borcherding JA, Chen H, Caraballo JC, et al. Coal fly ash impairs airway antimicrobial peptide and increases bacterial growth. *PLoS One*. 2013;8:e57673. doi:10.1371/journal.pone.0057673.t001.

32. Nigg JT, Nikolas M, Knottnerus GM, Cavanagh K, Friderici K. Confirmation and extension of association of blood lead with attention-deficit/hyperactivity disorder (ADHD) and ADHD symptom domains at population-typical exposure levels. *J Child Psychol Psychiatry*. 2010;51:58-65. doi:10.1111/j.1469-7610.2009.02135.x.
33. Rodriguez-Barranco M, Gil F, Hernandez AF, et al. Postnatal arsenic exposure and attention impairment in school children. *Cortex*. 2016;74:370-382. doi:10.1016/j.cortex.2014.12.018.
34. Vrijheid M, Casas M, Gascon M, Valvi D, Nieuwenhuijsen M. Environmental pollutants and child health-a review of recent concerns. *Int J Hyg Environ Health*. 2016;219:331-342. doi:10.1016/j.ijheh.2016.05.001.
35. Grandjean P, Landrigan PJ. Neurobehavioural effects of developmental toxicity. *Lancet Neurol*. 2014;13:330-338. doi:10.1016/S1474-4422(13)70278-3.
36. Abou-Khadra MK. Association between PM10 exposure and sleep of Egyptian school children. *Sleep Breath*. 2013;17:653-657. doi:10.1007/s11325-012-0738-7.
37. Kheirandish-Gozal L, Ghalebandi M, Salehi M, Salarifar MH, Gozal D. Neighbourhood air quality and snoring among school-aged children. *Eur Respir J*. 2014;43:824-832. doi:10.1183/09031936.00113113.
38. Perry GS, Patil SP, Presley-Cantrell LR. Raising awareness of sleep as a healthy behavior. *Prev Chronic Dis*. 2013;10:E133. doi:10.5888/pcd10.130081.
39. Gerber L. Sleep deprivation in children: a growing public health concern. *Nursing*. 2014;44:50-54. doi:10.1097/01.NURSE.0000441881.87748.90.
40. Lanphear BP, Auinger P, Froehlich T, Kahn RS, Braun J. Exposures to environmental toxicants and attention deficit hyperactivity disorder in US children. *Environ Health Perspect*. 2006;114:1904-1909. doi:10.1289/ehp.9478.
41. Rojas-Castaneda JC, Vigueras-Villasenor RM, Rojas P, et al. Alterations induced by chronic lead exposure on the cells of circadian pacemaker of developing rats. *Int J Exp Pathol*. 2011;92:243-250. doi:10.1111/j.1365-2613.2011.00761.x.