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Trends in Respirable Coal Mine Dust Concentration (mg/m3) based on Coal Miners' Occupational Designation: An Analysis of the MSHA Coal Dust Samples Data Set (2000-2022)

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Trends in Respirable Coal Mine Dust Concentration (mg/m^3) based on Coal Miners' Occupational Designation:
An Analysis of the MSHA Coal Dust Samples Data Set (2000-2022)

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Public Health in the
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By

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Lexington, Kentucky

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ABSTRACT OF THESIS

Trends in Respirable Coal Mine Dust Concentration (mg/m^3) based on Coal Miners' Occupational Designation:
An Analysis of the MSHA Coal Dust Samples Set (2000-2022)

Rates of Coal Workers' Pneumoconiosis (CWP) have recently increased in prevalence over the past 20 years. Recent regulation (Phase III) by the Mining Safety and Health Administration to lower the coal dust standard to 1.5 mg/m3 has been mandated to assist in reducing the burden of CWP. Occupations in the coal mining industry have different exposures to coal dust depending on their occupational responsibilities. This study examined the respirable coal dust trends for underground and surface mining occupations from 2000 to 2022. The ultimate goal is to see how respirable coal dust exposures have changed in multiple occupations over this period and ensure mines meet the MSHA Phase III standard.

KEYWORDS: Coal Mining, Surface Mine, Underground Mine, Coal Dust, Occupations.

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04/08/2023
Date

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

Coal workers' pneumoconiosis (CWP) is an occupational lung disease characterized by the inhalation of coal dust, causing permanent scarring to the bronchioles and alveolar ducts (Liu et al., 2009). CWP has been a persistent health problem in underground and surface coal mining operations since the late 1940s (Nemery, 2009). Categories of CWP can range from simple to complicated depending on the miner's level of exposure to coal dust and the extent of damage to the lungs causing various health effects (Almberg et al., 2018; Perret et al., 2017). Progressive Massive Fibrosis (PMF) is the most advanced stage of CWP, resulting in the most severe health effects (Almberg et al., 2018). The health effects of CWP can range from shortness of breath to premature death in the most severe cases (Crowe, 2019). These health effects have been associated with the number of years per life lost (YPLL) due to CWP, which has been increasing in coal miners over the past 30 years to 12.9 YPLL (Mazurek, Wood, Blackley, & Weissman, 2018).

The prevalence of CWP for underground and surface coal mine workers in the United States has been on an upward trend. A 2018 study conducted on the prevalence of CWP over a 47-year period (1970-2017) showed that for coal miners who had worked more than 25 years, the prevalence of CWP was 10%, while among those working less than 25 years, the prevalence of CWP exceeds 5% (Blackley, Halldin, & Laney, 2018). A 2012 Morbidity and Mortality Weekly Report (MMWR) presented an analysis conducted on 2,257 surface mine workers who had less than one year of mine experience; this study showed that 2.0% had evidence of CWP and 0.5% had PMF (CDC, 2012). Compared to the prevalence of CWP in the early to mid-1990s, when the condition was deemed "near-eradication," CWP cases have been increasing even with the current exposure regulations and controls in place (Hall, Blackley, Halldin, & Laney, 2019).

Previous studies have shown a linear relationship between the amount of coal dust exposure and the number of CWP cases in the United States through the National Study of Coal Worker's Pneumoconiosis data and retrospective cohort studies (M. Attfield & Morring, 1992; M. D. Attfield & Seixas, 1995). In coal miners that were exposed to 2 mg/m^3 respirable coal dust (Mine Safety and Health Administration respirable dust standard until 2014) for 40 years, up to 12% were expected to have at least Category 2 CWP, and up to 6.7% were expected to develop PMF (M. Attfield & Morring, 1992). In comparison, of 1,1422 blue-collar workers who were not exposed to respirable coal dust, less than 1% showed evidence of pneumoconiosis (Castellan, Sanderson, & Petersen, 1985).

The regulations regarding coal mine dust exposure have undergone numerous changes throughout time. Significant changes involving coal dust exposure across the

United States began with the Coal Mine Health and Safety Act (CMHSA) of 1969. This act mandated dust-monitoring programs to analyze the amount of dust coal workers were being exposed to and set a respirable coal dust standard of 3.0 mg/m^3 (Breslin, 2010; Petsonk, Rose, & Cohen, 2013). This mandate was one of the first federal regulations on coal dust exposure in the United States, and regulations to further decrease the dust standard were slated to be implemented soon after (Breslin, 2010). Within three years of the 3.0 mg/m^3 standard, the Mine Safety and Health Administration (MSHA) decreased the coal dust standard to 2.0 mg/m^3 (Breslin, 2010). In 2014, the Mine Safety and Health Administration reduced the coal mine dust exposure further to 1.5 milligrams per cubic meter of air through the Phase III Standard but gave mines two years to meet the standard (National Academies of Sciences & Medicine, 2018).

The coal dust exposures that coal miners face have changed due to differences in mine type, coal mining techniques, and coal mining occupations. Mine types can create differences in dust exposure due to the enclosed nature of underground mines and the open dust exposure of surface mines (Brent C Doney et al., 2019; Brent C. Doney et al., 2020). Concerning mining techniques, surface mines use open pit mining with explosives and other methods, while underground mines use methods like continuous mining machines. These methods produce different coal dust exposure levels, as evidenced by recent studies conducted analyzing the geometric mean of coal dust concentration, which were 0.17 mg/m^3 for surface mines and 0.55 mg/m^3 for underground mines (Brent C Doney et al., 2019; Brent C. Doney et al., 2020). In addition to the differences in mining techniques, different mining occupations have differing dust exposure levels. Mining occupations provide different roles depending on their job description, and additionally, the machinery they operate differs. For this reason, the coal dust exposures of various occupations differ by the proximity of machinery, proximity to coal removal operations, and proximity to transport operations. Previous studies have highlighted the differences in respirable coal mine dust exposure across time (Crowe, 2019; Brent C Doney et al., 2019; Brent C. Doney et al., 2020).

Though multiple studies have analyzed the association between exposure to respirable coal dust and CWP in underground and surface mining operations, there has been a gap in research pertaining to how dust exposures have changed in specific occupations over time. These studies have analyzed mining type or mining occupations through geometric means generalized into one value for a span of time, but no previous study has been found analyzing how coal dust exposures in mining occupations vary across an extended time period (Crowe, 2019; Brent C Doney et al., 2019; Brent C. Doney et al., 2020). For this reason, this capstone investigates how coal dust exposures in various mining occupations have changed over a 22-year period (2000-2022) and how respirable coal dust concentrations differ between mine types (underground and surface) and mining methods (continuous, conventional, hand load, longwall, and scoop). Showing how exposures have changed over time will provide insight into whether coal mines are in compliance with recent regulations. It is important that all mines comply with these regulations to reduce the exposure workers face that elevates their risk of CWP. Examination of the coal dust exposures of different occupations and mine types could provide an explanation for the increase in CWP cases nationwide as well.

Methods

The database used for this analysis was the Mine Safety and Health Administration's (MSHA) Coal Dust Samples Data Set (CDSDS) (MSHA, 2022). The CDSDS contains data from January 3, 2000, until November 4, 2022. The database was compiled of respirable coal dust samples from underground, surface, and facility coal mining facilities collected by MSHA coal mine inspectors and coal mine operators during annual inspections. The coal dust samples were collected using gravimetric sampling, coded as CMDPSU in the dataset.

Gravimetric sampling by MSHA is conducted by using a sampling pump (airflow at 2 L/min) with a cyclone attached that assists in separating respirable dust samples from other dust samples (MSHA, 2020). Occupations that have previously had the highest dust concentration exposures were prioritized for sampling, and they were sampled for a full-term shift, as determined by the worker's schedule. This could be anywhere from 8 to 12 hours in total. The respirable dust samples were collected on filter cassettes, which were provided with a unique identification number and sealed once sampling was completed for analysis. Samples were then analyzed at the Mt. Hope, West Virginia MSHA laboratory for dust concentration (mg/m3) by comparing the weight of the pre and post-sample filter (MSHA, 2020).

All active mines in the U.S. are eligible to be inspected by MSHA to ensure coal dust compliance, and a total of 1,048,576 samples were included in the unedited dataset. MSHA requires that underground mines be inspected four times a year, while surface mines are inspected two times a year. These inspections occur randomly; however, inspections can occur more frequently for coal mines that have had previous violations or if a complaint is recorded. Complaints could be made by workers who feel that conditions are unsafe or anyone else who feels that a coal mine is in violation of the MSHA regulations. The variables included in the unedited dataset included cassette number, inspector/operator sample, sample date, cassette initial weight, cassette final weight, concentration, sample type, mine ID, mine type, mining method, and occupation.

The CDSDS was cleaned by removing invalid, contaminated, misclassified, and blank samples. The definitions regarding these designations are as follows: invalid samples were samples that were damaged and could not be analyzed (MSHA, 2022). Contaminated samples were those that had a loss or addition of analyte by mistake (MSHA, 2022). Misclassified samples had incorrect information associated with a sample, such as incorrect mine ID numbers or sampling methods (MSHA, 2022). Lastly, blank samples were control samples sent to the MSHA lab to ensure quality control and lack of contamination (MSHA, 2022). These entries were removed for their lack of information and to decrease the misclassification bias present in the data. This data cleaning resulted in 235,337 samples. Then the data was cleaned further by removing facility mining samples from the dataset, as the primary focus of this analysis is underground and surface mining operations. Removal of the facility mine samples produced 211,123 samples.

A new category was created to group the sampling data based on occupational groups. A new occupations category was created to group the 51 occupations listed to get a total of 16 categories. Occupational groupings were based on discussions of similar exposure groups and occupational job descriptions with experts in the field (Table 1). One occupational category (Stall Driver) was removed due to its lack of relevance in modern mining and small sample size (8 entries). Only designated occupational and non-designated occupational samples were used to analyze coal dust concentration in the mines, as the primary focus is dust exposure in mining occupations. This cleaning removed area, control, and work area samples. This coding was conducted based on analyses completed by previous studies on occupational dust (Crowe, 2019; Brent C Doney et al., 2019; Brent C. Doney et al., 2020).

After data cleaning, the edited data produced 209,581 unique samples for analysis. The final variables included in the dataset were: cassette number, sample date, sample year, cassette initial weight, cassette final weight, concentration, sample type, mine id, mine type, mining method, and occupation. Final concentrations of coal dust in the dataset that were coded as a zero were replaced with the lowest detection value (0.001 mg/m^3) divided by 2 to get a value of 0.0005 mg/m^3. This limit of detection value (LOD) was used to calculate log-transformed values such as geometric mean. A total of 219 samples were re-coded to a LOD of 0.0005 mg/m^3.

Data analysis was performed using two different statistical programs. The CDSDS dataset was first imported into SPSS Statistics from the original MSHA text file. SPSS Statistics was then used to calculate descriptive statistics of coal dust concentration (count, mean, minimum, maximum, standard deviation). These values were stratified based on the year of the sample, occupation, mining method, and mine type (Table 1). Dust concentrations were log-transformed to calculate the geometric means. SPSS was also used to conduct a One-Way Analysis of Variance Tests for the stratified categories.

Due to SPSS not being able to calculate geometric standard deviation and geometric standard error, Microsoft Excel was used to calculate these two metrics for coal dust concentrations. Additionally, Microsoft Excel was used to conduct linear regression trend analysis tests between year and concentration of dust for multiple variables (mine type, mining method, and occupation). The purpose of trend analysis is to allow multiple categories to be analyzed on the same graphic showing geometric means for coal dust concentrations on the y-axis and years on the x-axis. Six different trend analysis graphics were generated for the variables mining occupation (4), mining type (1), and mining method (1). The standard for respirable coal dust differs depending on the organizational regulations. The Occupational Health and Safety Administration has a time-weighted average (TWA) for respirable coal dust at 2.4 mg/m^3. In comparison, the National Institute of Occupational Safety and Health (NIOSH) has a TWA of 1 mg/m^3 (NIOSH, 2019). This analysis used the recently enacted MSHA Phase III standard of 1.5 mg/m3 as the comparison standard (National Academies of Sciences & Medicine, 2018). A significance threshold of ≤0.05 was used for analysis.

Results

Overall Respirable Coal Dust Trends

The characteristics of the MSHA Coal Mine Data Set stratified by mine type, mining method, and occupational category are given in Table 1. The overall geometric mean of coal dust concentrations for all samples in the CDSDS are given in Figure 1. Coal mine dust concentrations have been decreasing (β =-0.0077) over time with an R^2 value of 0.825.

Mine Type Respirable Coal Dust Trends

Most samples were from underground mines (195,223), comprising 93.1% of the total samples, while surface mine samples (14,358) comprised the other 6.9%. The samples concentration within the surface, as well as the underground mines, were statistically different and significant based on the results of a One-Way Analysis of Variance (ANOVA), producing an F-value of 727.9 and a p-value of $\leq$ 0.05. Surface mine geometric mean concentration of dust (0.655 mg/m3) was 30.5% higher than that of underground mines (0.502 mg/m3). Figure 2 represents the trend analysis of mine type and the geometric mean of coal dust concentration based on the year of the sample. Surface mines had the highest slope decrease (-0.0156x) over the 22-year period compared to underground mines (-0.0072x); however, the R^2 value was higher for underground mines (0.845) compared to surface mines (0.496). Comparing the first and last year of sampling for each mine type, surface mines had an 86.7% decrease in geometric mean for dust concentration, and underground mines had a 34.5% decrease. Table 2 depicts all of the β and R^2 values for each of the stratified categories below.

Mining Method Respirable Coal Dust Trends

Five different mining methods were represented in the dataset. Continuous mining had the most samples at 186,688 coal dust samples (89.1% of the total samples), while the mining method with the least number of samples was hand loading (0.7% of the total samples). One-way ANOVA with Tukey Honestly Significant Difference Test (HSD) of all five mining methods showed statistically significant differences between samples with a significance of $\leq$ 0.05 and an F value of 1475. The longwall mining method had the highest geometric mean dust concentration level (0.894 mg/m^3), while the hand load mining method had the lowest. The trend analysis results for 22 years showed that conventional mining with a cutting machine had the largest trend of decrease at -0.0186x, while the scoop method had a slight increasing trend of 0.00019x. The other three mining methods had varying degrees of decreasing trend lines, as shown in Figure 3.

Occupational Categories Respirable Coal Dust Trends

Regarding occupational categories, the three categories with the highest number of samples were shuttle car, continuous miner, and roof bolter. The occupations with the highest geometric mean dust concentration were longwall (0.950 mg/m^3), continuous miner (0.684 mg/m^3), and cutting machine (0.655 mg/m^3). Results of the One-Way ANOVA showed that occupational samples were statistically and significantly different.

Figures 4, 5, 6, and 7 show the geometric coal dust concentration for each of the 16 occupational groups that were analyzed based on year. These trend analyses show that 3 out of the 16 occupations (18.8%) had positive linear trends (auger, rockman, and supply man). The other 13 occupational groups had varying degrees of negative linear trends, with those in the cutting machine category having the largest negative linear trend of -0.0251x. The figures also show that coal dust concentrations fluctuate in periods of high and low concentrations.

Samples that Exceeded the MSHA Phase III Standard

The number of samples that exceeded the 1.5 mg/m^3 MSHA Phase III Standard throughout the entire dataset was 17,385. Table 3 depicts the number of samples that exceeded the Phase III standard based on the previously mentioned sub-categories of mine size, mining method, and occupational group and the percentage of the count for that sub-category. Based on Table 3, longwall, for both mining method and occupational category, had the highest number of exceedance samples (2853 and 2479, respectively) and the highest percentage of exceedance (19.8% and 22.4%, respectively). Surface mines (11.3%) had higher exceedance numbers compared to underground (8.1%). The sub-categories with the lowest percentage of exceedance were hand load (2.1%) and maintenance (1.7%).

Discussion

This study analyzed the MSHA Coal Dust Samples Data Set from 2000 to 2022 to discover the trends of coal mine dust concentrations based on factors of mine type, mining method, and trends in time for mining occupations. The results of the analysis showed that both decreasing and increasing trends in coal mine dust concentrations were present over the 22-year period for mine type, mining method, and mining occupation.

Overall Respirable Coal Dust Samples

The analysis of all 209,581 dust samples present in the data set showed that the geometric dust concentrations have been on a slight downward trend (-0.0077mg/m^3 per year) for all years analyzed. Interestingly, the geometric coal mine dust concentrations were all well-below the MSHA standard of 2.0 mg/m^3, which was in effect before 2016, and all the concentrations were below the Phase III MSHA 1.5 mg/m^3 dust standard as well (National Academies of Sciences & Medicine, 2018). These results are consistent with previous studies as they have found a similar decreasing trend of coal mine dust concentrations for similar periods (Crowe, 2019; Brent C Doney et al., 2019; Brent C. Doney et al., 2020).

Mine Type Respirable Coal Dust Samples

An unexpected result during the analysis of the underground and surface coal mine dust samples was that the geometric mean of the surface coal mine dust samples (0.655 mg/m^3) was higher than that of the underground mine dust samples (0.502 mg/m^3). This contradicts what was found in the 2019 and 2020 Doney et al. studies, which found that underground coal mines had a higher geometric coal mine dust concentration (0.55 mg/m^3) compared to surface mines (0.17 mg/m^3) (Brent C Doney et al., 2019; Brent C. Doney et al., 2020). The smaller sample size for surface mine samples could be an explanation for this difference. With the smaller sample size, higher coal dust concentrations would cause a higher overall geometric mean concentration. The trend analysis performed on underground and surface mines depicted surface mines having a decreasing trend of -0.0156x, while underground mines had a decreasing trend of -0.0072x. This is evidence that even though surface mines had a higher geometric mean concentration, the geometric mean dust concentration has been decreasing more over time than in underground mines. This shows that while the differing mine types show various levels of decreasing trend, overall coal mine dust concentrations are decreasing over time.

Mining Method Respirable Coal Dust Samples

Regarding the mining method, longwall mining had the highest geometric coal dust concentration (0.871 mg/m^3), while the hand load mining method had the lowest coal mine dust concentration (0.131 mg/m^3). These concentrations are consistent with what is expected because longwall mining involves the use of a piece of equipment called a shearer that mines the coal. The longwall process generates large quantities of dust, which would explain why this method has the highest geometric dust concentrations. For hand load mining, miners use a pickaxe to undercut a coal seam, then drill the seam, blast the seam with explosives, and load the coal by hand (Dix, 1988). One factor as to why this method of mining produces less dust is the lack of machinery that is involved, unlike longwall and continuous mining methods. The trend analysis produced an interesting finding in that the scoop mining method had an increasing trend of 0.0019x, while all the other methods (continuous, hand load, conventional with cutting machine, and longwall) had decreasing trends varying from (-0.005x to -0.0186x). Comparing the geometric coal mine dust concentration for all mining methods over the 22-period to the MSHA Phase III dust standard of 1.5 mg/m^3, the geometric mean concentrations were under the Phase III standard.

Occupational Categories Respirable Coal Dust Samples

The highest coal dust concentration geometric mean for the category mining occupation was longwallers (0.950 mg/m^3), as was also seen in the mining methods category. Laborers had the lowest geometric coal mine dust concentration at 0.232 mg/m^3. The differences that are observed in coal mine dust concentration for each of the sixteen occupations could be based on a number of different factors. The factors that may influence the coal mine dust collected during the sampling process include a worker's proximity to coal mining operations that produce dust, the quality of ventilation that is used to reduce dust exposures, and advancements in machinery to reduce dust exposures (ex: dry vacuum system on roof bolting machinery) (Crowe, 2019; Reed, Shahan, Ross, Blackwell, & Peters, 2020). The geometric coal dust concentrations are consistent with previous studies that have analyzed dust concentration based on occupation (Brent C Doney et al., 2019; Brent C. Doney et al., 2020; Shahan, Seaman, Beck, Colinet, & Mischler, 2017). The trend analysis for the sixteen occupations showed that the majority of occupations (13 out of 16, 81%) had decreasing trends of coal mine dust concentration.

The three occupations that had increasing trends of dust concentration were augers (0.0067x), rock man (0.0033x), and supply man (0.011x). While the decreasing trends of dust in these occupations are important, the increasing trends of coal dust for these three occupations previously mentioned show improvements can be made. Comparing the occupational dust samples to the MSHA Phase III standard, all occupations' geometric coal mine dust concentrations were below the 1.5 mg/m^3 standard.

Respirable Coal Dust Exceedance Samples

The coal mine dust concentrations that had exceeded the Phase III standard in the data set were 17,385 samples (8.3%). Surface mines (11.3%), longwall mining (19.8%), and longwallers (22.4%) had the highest exceedance fractions for each of the sub-categories (mine type, mining method, and mining method). These sub-categories match those that had the highest geometric dust concentrations. These exceedance fractions are important because almost one-fifth of those in the longwall mining method and occupation. These large numbers of samples indicate that improvements can, in multiple aspects, reduce the coal mine dust exposure to under the 1.5 mg/m3 MSHA Phase III standard (National Academies of Sciences & Medicine, 2018).

Limitations

The limitations present in this study included a large number of invalid samples in the MSHA Coal Dust Samples Data Set (MSHA, 2022). These invalid samples removed over half of the total number that could be analyzed. Another limitation in this analysis was the small number of samples for some occupations like rockman. With few samples, the trend analysis had gaps in data for some years, and this resulted in the geometric mean varying widely. A third limitation was possible misclassification bias that could exist from grouping the mining occupations together. This occupational grouping could cause the calculated geometric coal mine dust concentrations to be higher or lower than the actual value.

Conclusion

In conclusion, the majority of geometric coal mine dust concentrations over time have been decreasing; however, the amounts have been small. Improvements could be made in decreasing the number of samples that exceed the MSHA Phase III standard. Focusing on the occupations whose samples have exceeded the Phase III standard by making ventilation, administrative, or engineering controls to further reduce the amount of coal dust produced or reduce the exposure of workers would be beneficial. This would allow workers to be exposed to less dust and possibly reduce the number of CWP cases. In addition, further research in comparing CWP cases based on these coal mine dust concentrations and the impact the MSHA Phase III standard will have on long-term (25 years or more) miners would be beneficial to ensure the Phase III standard is effective or to reduce the standard further.

Table 1:Mean Coal Dust Concentration (mg/m^3) Based on Mine Type, Mining Method, and Occupation from the MSHA Coal Dust Data Set 2000-2022

Category	N	Mean	Std. Dev	Max	Geo Mean	Geo St. Error
Mine Type						
Underground	195223	.690	.635	72.08	.502	.005
Surface	14358	.838	.632	12.30	.655	.019
Mining Method						
Continuous	186688	.675	.611	72.08	.489	.005
Conventional	2524	.796	.697	7.01	.552	.046
Hand Load	1500	.267	.453	6.50	.131	.060
Longwall	13069	1.08	.794	14.49	.871	.020
Scoop	5800	.727	.703	13.31	.494	.031
Occupations						
Auger	476	.687	.459	2.87	.524	.107
Cont. Miner	43686	.896	.730	12.30	.684	.011
Cutting Machine	1500	1.02	.985	7.98	.655	.060
Driller	1731	.637	.567	6.21	.444	.056
Explosives	332	.821	.705	6.17	.599	.128
Laborer	1518	.388	.431	4.68	.232	.060
Loading Ops.	31326	.591	.559	38.11	.427	.013
Longwall	11091	1.16	.817	14.49	.950	.022
Maintenance	8046	.410	.370	7.30	.306	.026
Rockman	17	.831	.824	3.48	.526	.588
Roof Bolter	39179	.692	.547	13.31	.532	.012
Section Foreman	2853	.593	.487	5.96	.443	.044
Shuttle Car	60461	.600	.579	72.08	.447	.009
Supply Man	2445	.481	.471	6.82	.337	.047
Utility Man	4345	.590	.506	5.91	.441	.035
Ventilation	575	.648	.478	4.03	.516	.097

Abbreviations: Cont.- Continuous, Ops. - Operations, Geo Mean- Geometric Mean, Geo St. Error- Geometric Standard Error

**Minimum values were not included in the table as only four occupations (Auger .0100, Explosives .0020, Rockman .0720, and Ventilation .0310) had minimum values other than .0005*

***Geometric Standard Deviations were not included in the table as only one occupation (Rockman 2.35) had a value other than 2.33.*

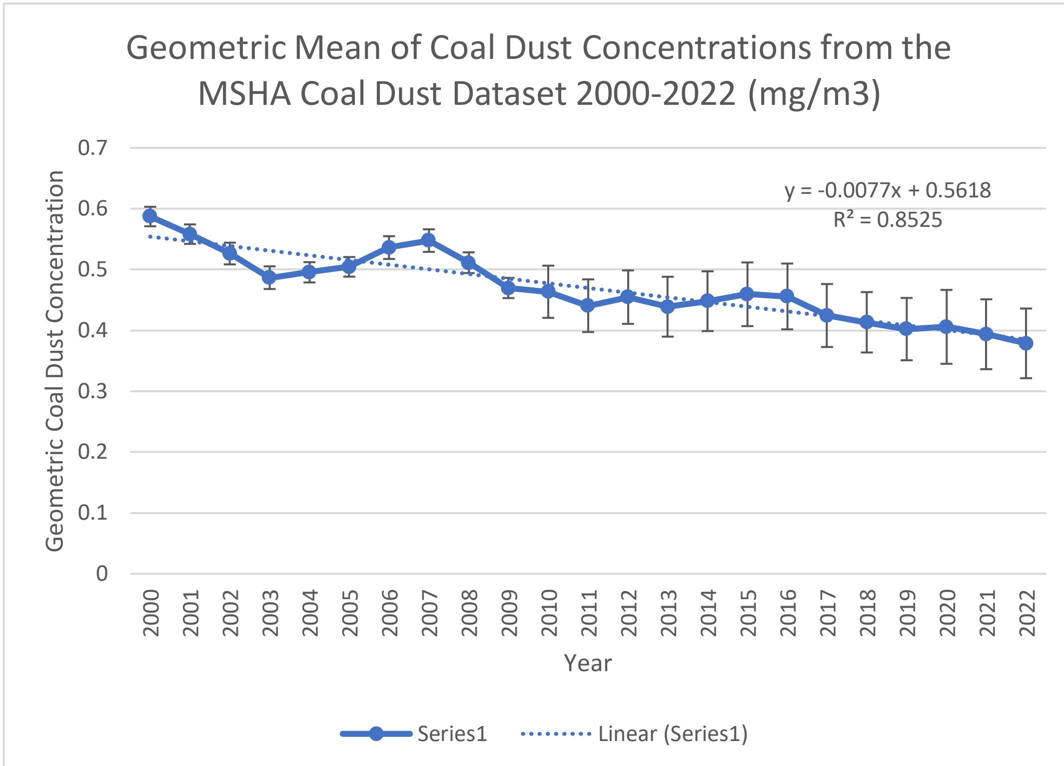

Figure 1: Overall Geometric Mean Concentration of Coal Dust, 2000-2022

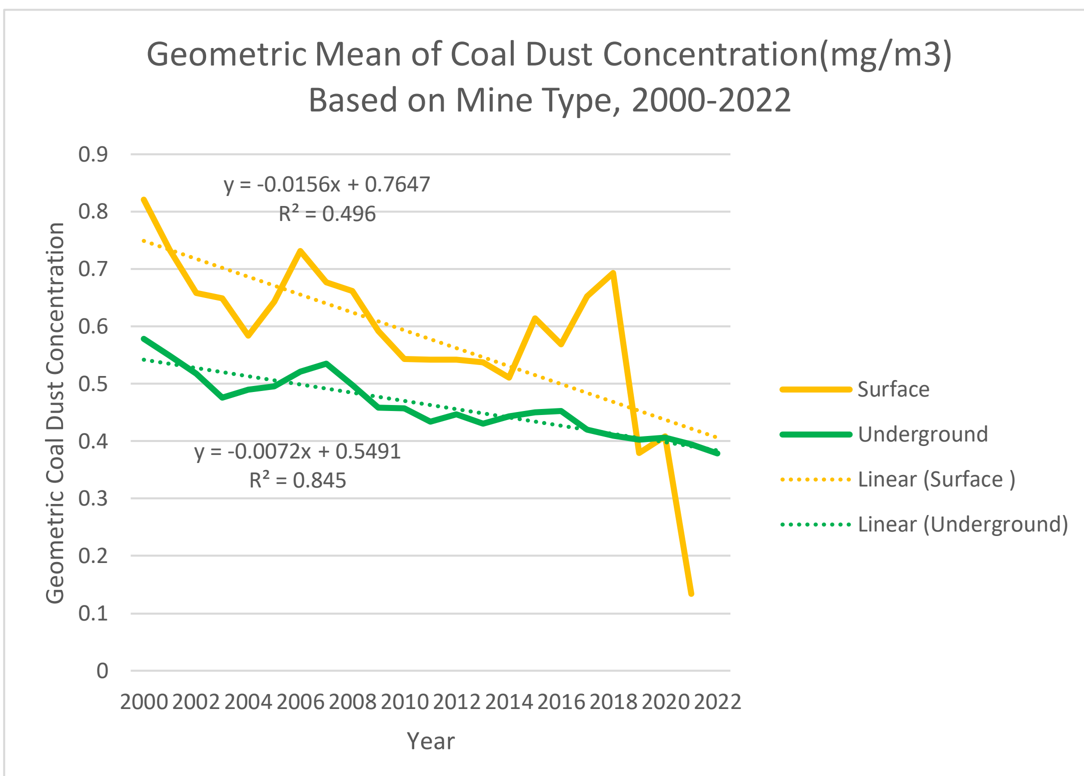

Figure 2: Geometric Coal Dust Concentration Based on Mine Type, 2000-2022

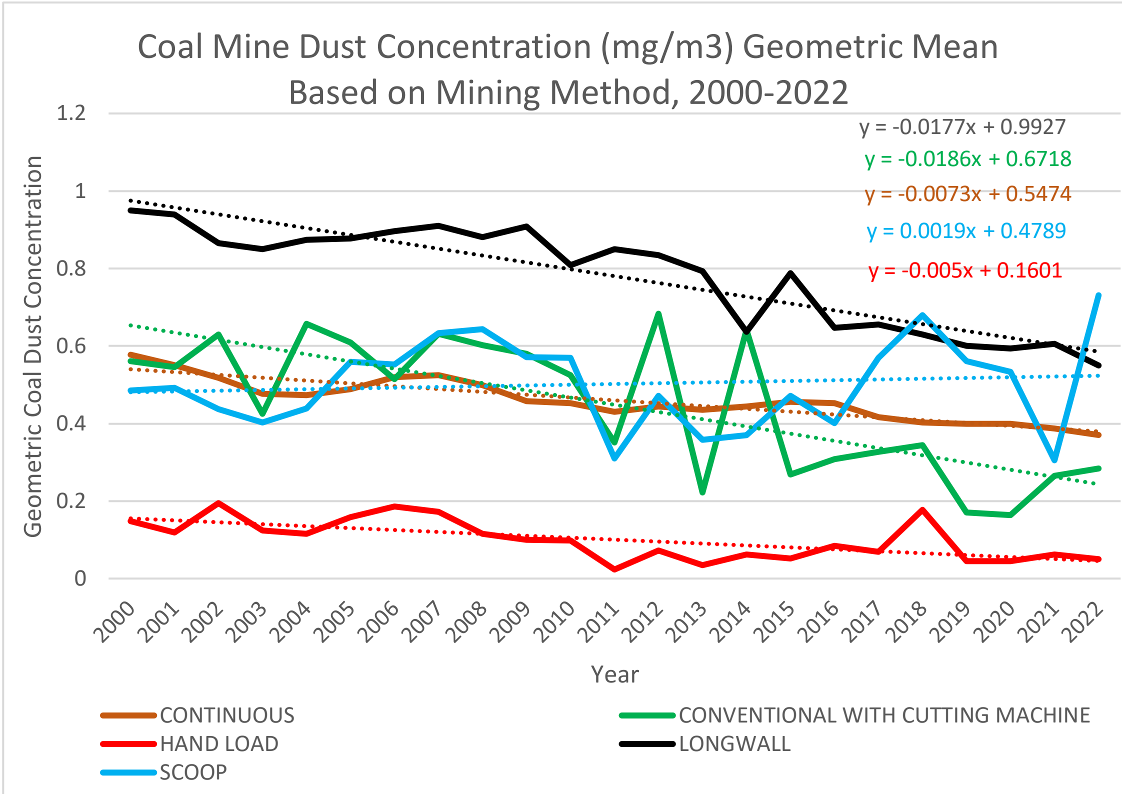

Figure 3: Geometric Coal Dust Concentration Based on Mining Method, 2000-2022

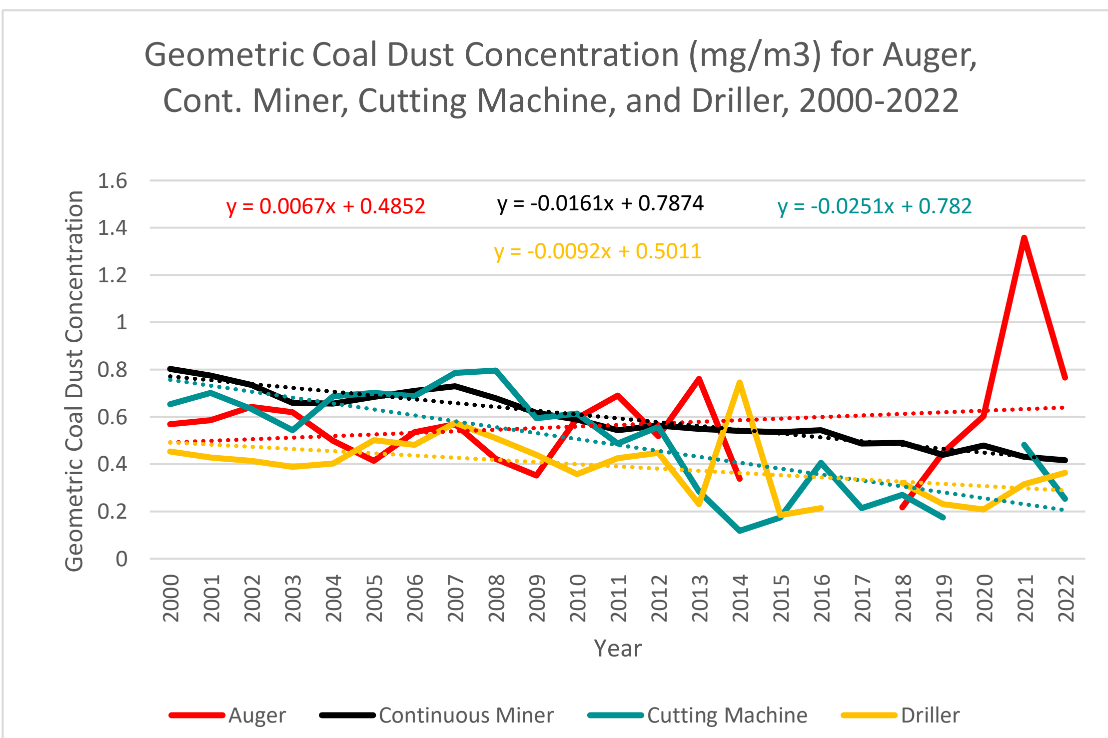

Figure 4:Geometric Coal Dust Concentration for Auger, Cont. Miner, Cutting Machine, and Driller, 2000-2022

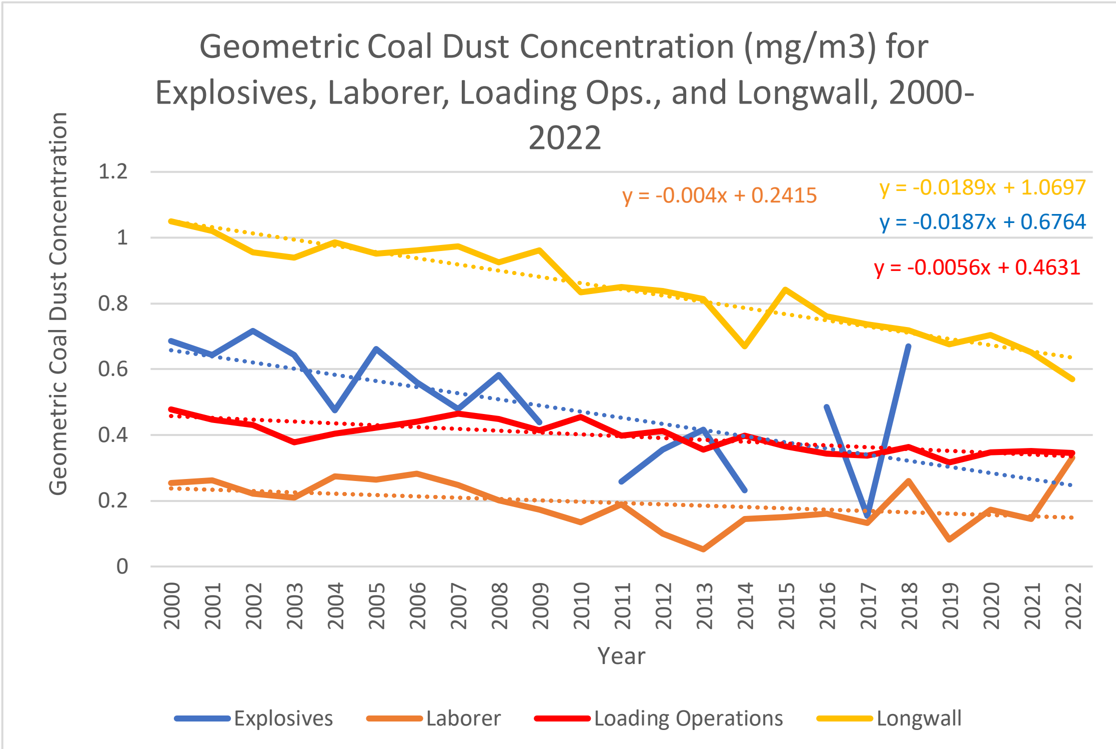

Figure 5: Geometric Coal Dust Concentration for Explosives, Laborer, Loading Ops., and Longwall, 2000-2022

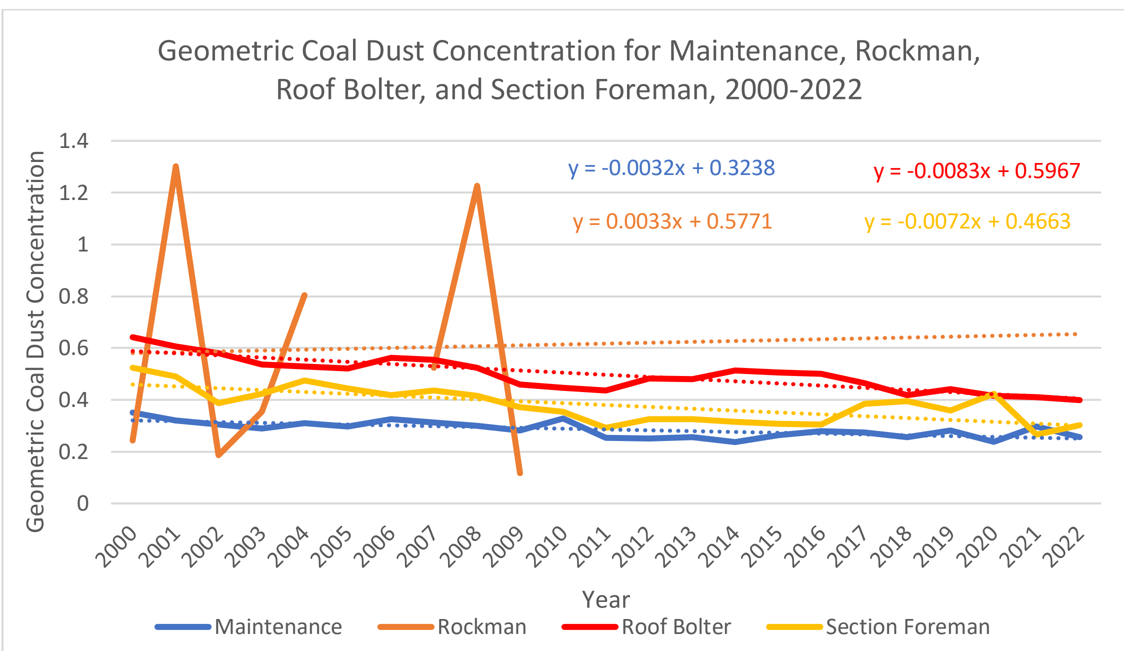

Figure 6: Geometric Coal Dust Concentration for Maintenance, Rockman, Roof Bolter, and Section Foreman, 2000-2022

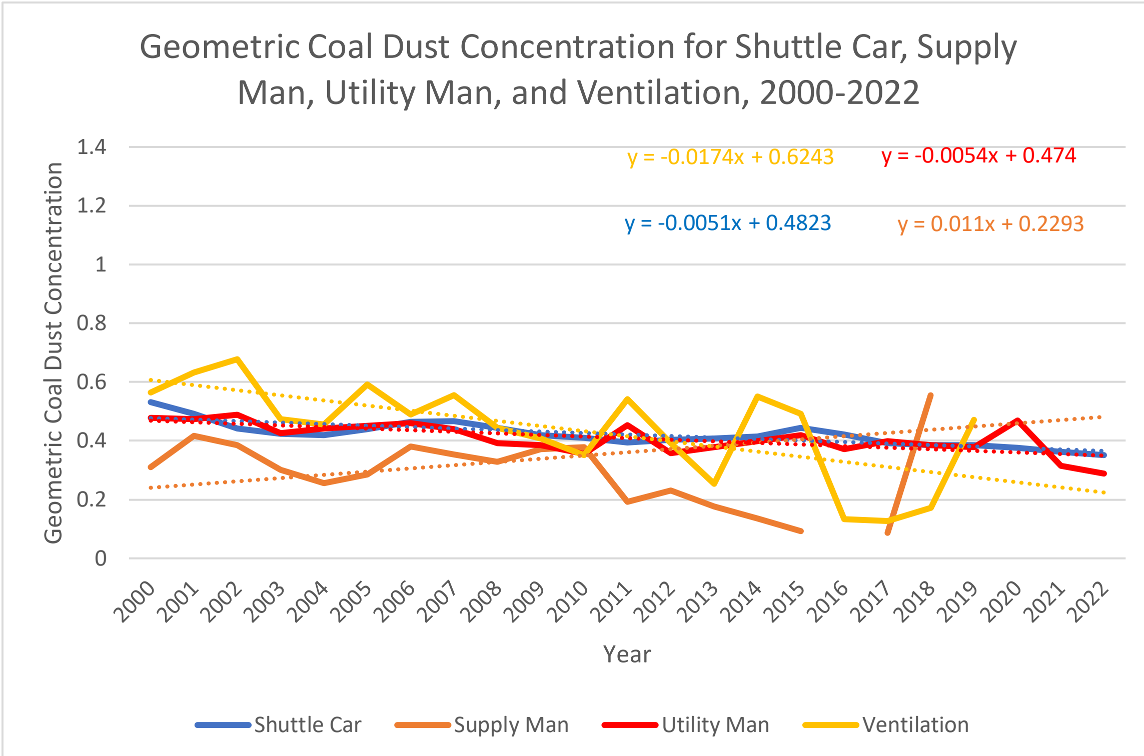

Figure 7: Geometric Coal Dust Concentration for Shuttle Car, Supply Man, Utility Man, and Ventilation, 2000-2022

Table 2: Trend Beta and R^2 Values for Mine Type, Mining Method, and Occupation from the MSHA Coal Dust Data Set, 2000-2022

Category	N	β Values	R^2 Values
Mine Type			
Underground	195223	-0.0072	0.845
Surface	14358	-0.0156	0.496
Mining Method			
Continuous	186688	-0.0073	0.838
Conventional	2524	-0.0186	0.533
Hand Load	1500	-0.0050	0.420
Longwall	13069	-0.0177	0.838
Scoop	5800	0.0019	0.013
Occupations			
Auger	476	0.0067	0.040
Cont. Miner	43686	-0.0161	0.922
Cutting Machine	1500	-0.0251	0.585
Driller	1731	-0.0092	0.220
Explosives	332	-0.0187	0.393
Laborer	1518	-0.0040	0.147
Loading Ops.	31326	-0.0056	0.651
Longwall	11091	-0.0189	0.893
Maintenance	8046.	-0.0032	0.478
Rockman	17	0.0033	0.001
Roof Bolter	39179	-0.0083	0.747
Section Foreman	2853	-0.0072	0.499
Shuttle Car	60461	-0.0051	0.680
Supply Man	2445	0.0110	0.070
Utility Man	4345	-0.0054	0.481
Ventilation	575	-0.0174	0.482

Table 3:Dust Samples Exceeding MSHA Phase III Based on Mine Type, Mining Method, and Occupation from the MSHA Coal Dust Data Set, 2000-2022

Category	N	N Exceedance	% Exceedance
Mine Type			
Underground	195223	15758	8.1
Surface	14358	1627	11.3
Mining Method			
Continuous	186688	13920	7.5
Conventional	2524	300	11.9
Hand Load	1500	31	2.1
Longwall	13069	2583	19.8
Scoop	5800	551	9.5
Occupations			
Auger	476	27	5.7
Cont. Miner	43686	6124	14.0
Cutting Machine	1500	306	20.4
Driller	1731	112	6.5
Explosives	332	42	12.7
Laborer	1518	49	3.2
Loading Ops.	31326	1611	5.1
Longwall	11091	2479	22.4
Maintenance	8046	139	1.7
Rockman	17	1	5.9
Roof Bolter	39179	2776	7.1
Section Foreman	2853	144	5.0
Shuttle Car	60461	3249	5.4
Supply Man	2445	80	3.3
Utility Man	4345	214	4.9
Ventilation	575	32	5.6

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