Diesel particulate matter exposure in South African platinum mines: an overview

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ABSTRACT: Personal diesel particulate matter (DPM) sampling was conducted on nearly 300 mine workers in the diesel and non-diesel sections of three platinum mines in South Africa. Respiratory health questionnaires were administered to all of these workers. The workplace exposure to DPM did not differ significantly between the three mines. Within each shaft there were significant differences, indicating that other factors influence exposure to DPM. More than half of the workers had elemental carbon (EC) exposures above 0.160 mg/m^3. The main determinants of worker exposure were found to be the task performed by the mine employee and the location from the main DPM source. Other determinants were inconclusive and detailed observations are required. Approximately 13% of the study participants reported having at least one respiratory symptom that has been associated with DPM exposure in the literature. Associations between DPM exposure and several respiratory symptoms as well as headaches, although significant when unadjusted for potential confounders, were not significant when the data were adjusted for smoking and duration of employment. Due to the relatively low prevalence of symptoms in some of the exposure categories these results need to be confirmed using a larger study population

1 INTRODUCTION

A variety of diesel-powered equipment is routinely used in underground mines. The emissions from the diesel engines can accumulate in the mines and cause a substantial risk of mine employees being exposed to exhaust emissions. In June 2012 diesel exhaust emissions (DEE) were classified as a Group 1 human carcinogen by the International Agency on Cancer (IARC, 2012).

South Africa does not have an occupational exposure limit (OEL) for DPM, partly due to a lack of information on health outcomes of exposed employees. As DPM is not a regulated pollutant in South Africa, the Department of Minerals and Resources (DMR) does not have information on DPM exposure of mine employees. However, certain mining groups have either established in-house DPM limits or have adopted the USA Mine Safety and Health Administration (MSHA) limits against which to compare DPM exposure (i.e. 0.16 mg/m^3 total carbon).

A Diesel Particulate Matter (DPM) study was conducted for the Platmine Collaborative Research Programme (Platmine) in 2011. The aim of this study was to determine trends in mine employee exposure to DPM based on historical data (Pretorius, 2012). As DPM is not a regulated pollutant, exposure information available for this study was limited. The recommendation following the study was that a DPM baseline study should be conducted across the platinum mining industry in order to determine mine employee exposure. In 2012 the Centre for Mining Innovation (CMI) of the Council for Scientific and Industrial Research (CSIR) in South Africa led this baseline study.

This baseline study provided a unique opportunity to measure the exposure of and evaluate health outcomes (symptoms) in the same employees in a South African mining environment. By collecting data on a control group (with no DPM exposure) and across several occupations and exposure categories, the association between reported symptoms and exposure could be studied. This type of study had not been undertaken previously in South Africa.

This paper presents results from the baseline exposure measurement study conducted in three platinum mines in South Africa and discusses the related health outcomes in these employees. Exposure models for predicting exposure levels of employees in South African platinum mines were developed and are discussed here.

2 OBJECTIVES

The objectives of the exposure modelling and health outcomes study were:

- To determine the current exposure to DPM of workers in three Platmine mines;
- To identify determinants of DPM exposure in these mine workers;
- To determine the prevalence of health symptoms associated with DPM exposure in these mine workers; and
- To determine the association of health symptoms related to DPM exposure with measured levels of DPM in these mine workers.

Because of the relatively small number of mine workers included in this study and the cross-sectional design of the study, the focus was on acute, rather than chronic, health effects. The objective was not to link DPM to the risk of developing lung cancer. Lung cancer is a disease with a long latency period and large-scale longitudinal studies are needed to determine this risk.

3 METHODOLOGY

3.1 *Population description*

During the period 24 July 2012 to 20 September 2012, the CSIR collected 225 valid personal exposure measurements for 225 individual Platmine employees. The survey was conducted on 14 days at three mines, in six different shafts. Logistical constraints prevented repeat exposure measurements being collected. Two of the six shafts in which exposure data were collected were non-diesel shafts. In a "non-diesel shaft" the vehicles and equipment are powered by electricity, for example; whereas, in a "diesel shaft", the engines are powered by diesel fuel.

3.2 *Sampling Strategy*

The sampling strategy included personal DPM exposure sampling, the administering of a health questionnaire to the same study participants, and the collection of environmental data and contextual information on the workplace of these participants. The aim was to sample 100 mine employees from each of the three mines: approximately 80 employees who were exposed to diesel emissions (exposed group) and approximately 20 employees who were not exposed to diesel emissions (control group).

It was a requirement of the Human Research Ethics Committee (HREC) of the University of the Witwatersrand (WITS) that the health questionnaire be administered in the home language of the subject. The dominant languages spoken at each of the three subject mines were identified prior to the selection of the study team as Tswana, Sotho, Zulu and English. Some of the team members could speak more than one African language, which was useful in cases where study subjects were not fluent in any of the four dominant languages.

The chosen diesel and non-diesel sections were fully operational and assessments were conducted in such a way as to limit work disruption as far as possible. The assessments were conducted during the shifts where diesel engines were the most in use.

Because of the comprehensive nature of the personal sampling, the study subjects were selected from the same workplace. Five or more volunteers at a time were asked to participate in the study and, where possible, subjects were selected based on high, medium and low expected occupational DPM exposure. The aim was to include all the diesel engine operators, individuals who worked in close proximity to the diesel source, and employees that roved the mechanised section.

3.3 *Health Assessment*

The aims and procedures of the study were communicated to the mine employees through the health and safety structures of each mine. Ethics clearance was obtained from the WITS HREC (Clearance certificate no. M120665). The health questionnaire was developed by the WITS School of Public Health (SPH) with assistance from Nederlandse Organisatie Voor Toegepast-Natuurwetenschappelijk Onderzoek (TNO). A standard epidemiological questionnaire was adapted for relevance to DPM and the South African mining industry. The purpose of the questionnaire was to establish the prevalence of symptoms related to DPM exposure, as identified in the scientific literature. The research team was trained to administer the health questionnaire in the different African languages and to use gestures, pictures or props to explain a question where necessary. The training was conducted by staff members at the National Institute for Occupational Health (NIOH), who have vast experience in the administering of health-related questionnaires in South Africa.

On the day of sampling, the study subjects were informed again about the nature of the study. They were assured of the confidentiality of their answers, and were told that their participation was voluntary and that they would be contacted directly if the findings from the study indicated any serious health concerns. Each subject signed a consent form before the questionnaires were administered or any personal exposure measurements were taken. The questionnaires were administered at the start of the shift and the subjects were released to continue with their normal duties for the remainder of the shift.

3.4 *Exposure Assessment*

Exposure measurements were taken using a three-piece cassette loaded with a 37 mm tissue quartz filter with a respirable, size-selective cyclone attached. Sampling was done at a pump flow rate of 2.2 L/min (specified by cyclone supplier) for the duration of the mine employee's shift.

After the health questionnaires had been completed and the subjects returned to their workplaces, the research team collected the environmental data and contextual information on the study subjects by going to their respective workplaces. Sampling times were recorded and subject-specific information was collected about jobs, locations in the mines, main tasks performed, and the periods of time that a diesel source was present. General information was also collected on mine characteristics, such as the number of vehicles operating underground and ventilation rates on the day of sampling.

Laboratory analyses for elemental carbon (EC), organic carbon (OC) and total carbon (TC) were conducted on each sampled filter according to the NIOSH 5040 method, using the thermal optical carbon analyser from Sunset Laboratories. Filter data were discarded if the filters were lost or damaged, if the post calibration of the sampling pump exceeded ± 5%, if the sampling information was incomplete, or if the sampling pump failed during the shift.

At the end of the sampling period, the exposure measurements and sampling information were provided to each mine for their records. Information on the employees that were sampled, their occupations, work areas, the sampling duration, flow rates used and the EC, OC and TC exposure concentrations were also provided.

3.5 *Statistical Analyses*

TNO developed a Microsoft® Access database where all the exposure and health questionnaire information was collated. After the measurement days, the data were entered into the database and checked by the sampling team. The database was sent to TNO, where it was checked and inconsistencies were discussed with the sampling team. Statistical analyses on the DPM measurements were performed by TNO, using SAS statistical software (v 9.1). Descriptive statistics were generated at job- and task-level. Determinant analyses were performed using mixed effects models and by performing univariate analysis. Models were discussed with the sampling team before any final decisions were made regarding the best statistical exposure model. The level of detail of the model (e.g. the number of determinants taken into account) depended on the detail of the gathered contextual data, the amount of exposure data available for modelling, and the observed contrast in exposure levels in the study population. The analysis focused on elemental carbon (EC), which is the marker for DPM emitted by the diesel engines. For samples with exposure levels of below the limit of detection (LOD); i.e. 0.011 mg, half of the LOD value was used to estimate the exposure concentration (Hornung and Reed, 1990).

Health symptoms selected for analysis were based on those identified from the literature as being associated with exposure to DPM. Additional symptoms possibly associated with DPM exposure were identified based on significant associations found when applying Pearson's Chi-square and, where appropriate, the Fisher's exact tests.

All analyses of health symptoms were performed in STATA Inc. version 12. Participants were categorised into "low" and "high" exposure groups, based on their exposure measurements, using a cut-off of 0.16 mg/m^3 EC; i.e. all participants exposed to lower than 0.16 mg/m^3 EC were placed in the low exposure group and all those with exposure levels that were equal to or higher than 0.16 mg/m^3 EC were placed in the high exposure group. In the absence of a DPM limit, it is common practice for the South African mines to use the MSHA limit of 0.16 mg/m^3 TC when assessing exposure to DPM in general and to compare EC with this MSHA limit for TC. Logistic regression analysis was performed to determine the association between health symptoms and DPM exposure, using exposure as a binary variable (where workers were classified as having high or low exposure). Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated.

Potential confounders that were taken into account in the analyses were smoking and duration of employment.

4 LIMITATIONS OF THE STUDY

Many of the employees that were sampled were in a hurry to complete the questionnaire in order to get back to work because of production pressures. These employees answered "No" to many of the health questions and said that there was nothing wrong with their health. The scope of the study did not include the evaluation of the subjects' medical files to validate their answers.

In some cases, the sampling team could not gather environmental data or contextual information at the workplace of a subject due to unsafe conditions. This information was then gathered as close as possible to the workplace and as comprehensively as possible under the circumstances.

Two of the parameters that were difficult to quantify consistently for all the mines were the duration of exposure to the diesel source and the location of the study subject in relation to the intake air. For this reason, these parameters could not be conclusively identified as determinants of exposure.

The sampling inadvertently took place during the worst strike season in the history of the platinum mining industry of South Africa (Hartford, 2012). At some mines, the sampling was disrupted and the team had to return at a later stage to continue data collection. One non-diesel section (i.e. control group) was not sampled at all because the fieldwork was postponed several times due to the strike actions. However, sufficient data were collected for the other non-diesel sections, and it was decided to continue with the data analysis without the third non-diesel section.

5 RESULTS

In total, 225 personal exposure measurements were recorded for workers in three mines (50 measurements were discarded according to the criteria in section 3.4).

5.1 *Descriptive statistics of the study population*

Table 1 summarises the overall exposure for all the mines (diesel and non-diesel).

Table 1. Overall exposure levels (mg/m^3) of elemental carbon (EC) for all the mines

Number of workers	N	225
Number below limit of detection (% in brackets)	N < LOD (%)	49 (21.8)
Average Mean	AM	0.2
Geometric Mean	GM	0.09
Geometric Standard Deviation	GSD	4.46
Minimum	MIN	0.005
Maximum	MAX	1.14

The relatively large geometric standard deviation (GSD) of 4.46 indicates substantial variation in exposure levels among the individuals monitored. However, this was mostly provoked by the inclusion of the non-diesel shafts.

Table 2 is a breakdown of the exposure levels for the different mines and shafts. At Mine A, two diesel shafts were sampled.

All the personal exposure measurements conducted for employees in the non-diesel shafts had EC exposure levels of below the limit of detection (0.011 mg/m^3) of the laboratory test method. This finding is expected since EC is used as surrogate for DPM exposure from diesel engines (Rogers and Davies, 2005). This finding confirms that no diesel emission sources were present in these shafts.

Table 2. Exposure levels (mg/m^3) of elemental carbon (EC) at different sampling locations

Location	N	N < LOD	AM	MIN	MAX
Mine A1	18	1 (5.6)	0.25	0.006	0.68
Mine A2	40	5 (12.5)	0.10	0.007	0.38
Mine A3*	12	12 (100)	0.009	0.005	0.01
Mine B1	68	5 (8.8)	0.34	0.006	1.14
Mine B2*	22	22 (100)	0.008	0.007	0.01
Mine C1	65	4 (6.2)	0.19	0.005	0.41

*non-diesel shafts

5.2 *Exposure levels per job title*

The job titles (i.e. type of work) were grouped into general team members, maintenance and support, and diesel engine operators. However, the exposures measured should be related to the work actually performed. Descriptive statistics are presented in Table 3 for the 190 employees from the diesel shafts, according to the main task performed.

Table 3. Descriptive statistics for EC exposure (mg/m^3) per performed main task

Task Performed	N	Exposure < LOD n (%)	AM	GM	MIN	MAX
Operating	55	3 (5.5)	0.34	0.23	0.007	1.14
General	76	3 (3.9)	0.23	0.16	0.005	0.66
Maintaining	59	8 (13.6)	0.14	0.08	0.006	0.40

The operators of diesel-powered engines were, on average, the highest exposed group. In contrast, maintenance and support employees were, on average, a factor of three times less exposed than the operators.

5.3 *Exposure modelling*

The sampling team collected information about factors that could potentially affect exposure levels and these factors were used to explore the modelling of exposure levels. Mixed-effect regression models were used to investigate the potential effects of these determinants on the measured exposure levels and were introduced into the statistical model as a fixed effect in order to investigate their influence on exposure levels.

Mixed-effect regression models without the inclusion of fixed effects showed that average exposure levels did not differ significantly over the three mines but did differ significantly across the different shafts (p=0.06). However, after excluding the two non-diesel shafts, no significant differences in exposure levels among the shafts were found. In contrast, the analyses showed that the average exposure levels for EC varied significantly (p=0.04) across measuring days and study subjects.

Further analyses were performed to describe and explain the differences in EC exposure levels between employees in the diesel shafts:

- Measurement day was included as a random effect in the mixed regression model;
- Job title and main task performed (both divided into three groups) were included as a fixed effect;
- The shift (day/night) in which the study subject worked was also introduced as a fixed effect;
- Ventilation to which workers were exposed was based on their location in the mine in relation to fresh, intake air (face, workshop, diverse);
- The air movement measurements were introduced into the mixed models; and
- Time spent near a diesel source.

Job title, task performed and location were found to have a significant effect on the exposure levels. The estimated time spent near a diesel engine did not have a significant effect on exposure levels but this could be because it was difficult to quantify this factor consistently for all the mines.

The location had a significant influence on the exposure levels due to the varying ventilation in those areas. But the actual measured ventilation was not found to significantly influence exposure. This might have been due to the measuring method used which measured air movement and which might not be the optimal way of representing ventilation (i.e. air replacement).

The three significant determinants, (job title, task performed and location) were included in a multivariate (mixed-effect) model. Job title and task no longer independently influenced exposure levels in this model as these determinants were highly correlated. The model with location and task as fixed effects explained slightly more variability in exposure levels than the model with location and job title. The results of the model with task and location included as fixed effects are presented in Table 4.

Table 4. Results of the mixed effect regression model with measurement day as random effect, log transformed exposure levels as dependent variable and task and location as fixed effects

Determinants	Mixed-effect model without fixed effects		Mixed-effect model with fixed effects	
	β	P-value	β	P-value
Between shaft/days	0.30	0.04*	0.07	0.14
Within shaft/days	1.10	<0.0001*	0.91	< 0.001*
Intercept**	-2.03	<0.0001*	-3.85	< 0.001*
Main Task:				
Operating			0.43	0.02
Maintaining			-0.12	0.51
General			0	.
Location:				
Diverse			1.72	< 0.001*
Face			2.14	< 0.001*
Workshop			0	.

*Statistically significant

**Exponent (intercept) gives the GM exposure level for job title (e.g. general) and location (e.g. workshop).

Mine employees that operate a diesel engine and those located at the face had the highest exposures. These two determinants (job title and location) explained 30% of the variability in exposure levels. The multivariate model explained 77% of the variation among measurement days at different shafts. After taking location in the mine and task performed into account, exposure levels did not vary significantly among employees at different shafts and during different working days. However, the models explained only 17% of the exposure found within one measurement day. This indicates that among employees at the same location performing the same task substantial variation in exposure levels exists. Other factors such as ventilation and the time spent near a diesel source may account for some of this variability. However, this could not be determined with the information gathered for this study.

Figure 1 presents the measured exposure levels to EC for employees grouped in one of the measured combinations of location and task.

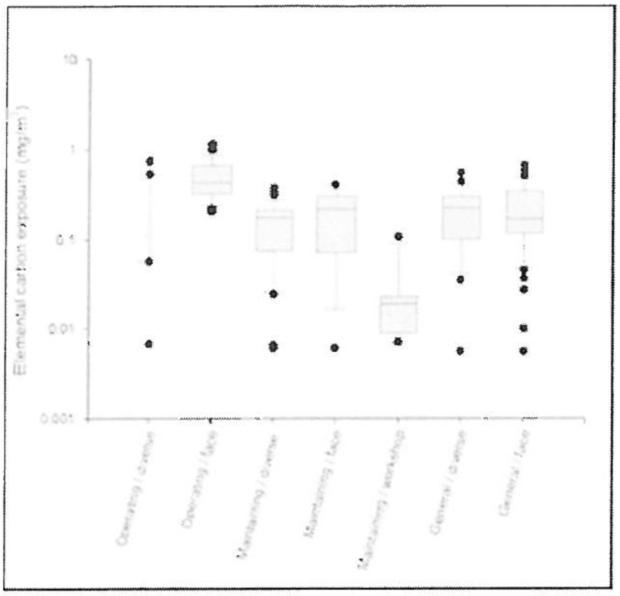

Figure 1. Exposure levels grouped per task and location in the mine.

Figure 1 clearly indicates that the employees in the workshops were less exposed to EC than the other employees in the mine. Operating diesel-powered vehicles resulted in the highest exposures, particular near the face. The exposure levels of the employees in the non-diesel shafts are not included in the figure. The exposure of these employees to EC was below the limit of detection in all cases.

Currently, no OEL has been set for DPM in South Africa but it is common practice to use 0.16 mg/m^3 (the MSHA limit for TC) when assessing exposure to EC. This study showed that 58% of the collected EC exposure measurements exceeded 0.16 mg/m^3. The EC exposure measurements of almost all the operators at the face exceeded 0.16 mg/m^3. In South Africa, the Chamber of Mines has recommended a phased approach for implementing an exposure limit for DPM. The approach will start with an exposure limit of 0.350 mg/m^3 TC, which was valid until the end of December 2013. The measurements conducted during this survey show that 18% of study subjects had EC exposure levels higher than 0.35 mg/m^3. Table 5 presents the percentage of measurements that were higher than the two limit values discussed above.

Table 5. Percentage of measurements in which the EC level exceeded the MSHA exposure limit for TC

Description	N	% > 0.16 mg/m^3	% > 0.35 mg/m^3
Total	190	58	18
Driving / diverse	31	52	13
Driving /face	24	100	58
Maintaining / diverse	35	0	3
Maintaining / face	13	8	8
Maintaining / workshop	11	0	0
Mining / diverse	25	64	16
Mining / face	51	55	20

5.4 *Health Outcomes*

In total, 275 questionnaires were collected from employees. Approximately 96% of the study participants were male. As many as 13% of platinum mine employees reported one or more respiratory symptoms associated with exposure to DPM; up to 21% reported other non-respiratory symptoms that have been associated with DPM exposure (Table 6).

Table 6. Reported health symptoms in study participants

Symptom	N	n	%
Respiratory symptoms:			
Wheeze	275	29	10.6
Cough	272	32	11.8
Trouble breathing	261	11	4.2
Phlegm	254	32	12.6
Shortness of breath	273	16	5.9
Wheeze at work	252	25	9.9
Non-respiratory symptoms:			
Headaches	268	44	16.4
Light-headedness	268	55	20.5
Nausea	268	18	6.7

Although symptoms of chronic obstructive pulmonary disease (COPD) were elicited in the questionnaire, only one person was defined as having COPD. Five workers were defined as having asthma and six as having chronic bronchitis. The combination of symptoms used can be found in Table 7. These numbers were equally distributed across the two exposure groups, and were too small to be included in further analyses.

Table 7. Combination of symptoms that were used for COPD, asthma and chronic bronchitis

No.*	Question	Symptom
11.1a	Do you have trouble breathing continuously so that your breathing is never quite right?	COPD
1.2.1	Have you been short of breath when the wheezing noise was present?	Asthma
1.2.2	Have you had this wheezing or whistling when you did not have a cold or flu?	Asthma
2	Have you been woken up with a feeling of tightness in your chest at any time in the last 12 months?	Asthma
8.1	Do you cough like this on most days/nights for as much as three or more months in each of the last two years?	Chronic bronchitis
10.1	Do you bring up phlegm like this on most days/ nights for as much as three or more months in each of the last two years?	Chronic bronchitis

*Health symptom questionnaire number

Table 8. Reported health symptoms in platinum employees, stratified by EC exposure level

Symptoms	Exposed to EC < 0.16 mg/m^3 N = 117 %	Exposed to EC ≥ 0.16 mg/m^3 N = 108 %	Odds Ratio	95% CI
Respiratory symptoms:				
Wheeze	7.8	10.3	1.35	0.53-3.40
Cough*	6.1	14.3	2.55	0.98-6.59
Trouble breathing	0.9	3.0	3.44	0.35-34.0
Phlegm*	6.5	17.3	4.52	1.41-14.5
Shortness of breath	4.3	4.7	1.09	0.31-3.9
Wheeze at work*	5.6	15.5	3.11	1.14-8.5
Non-respiratory symptoms:				
Headaches*	9.7	19.0	2.18	0.98-4.9
Light-headedness	16.8	21.9	1.39	0.70-2.7
Nausea	5.3	8.6	1.67	0.57-4.9

*Statistically significant

All respiratory symptoms were reported more often among workers with exposures above the MSHA exposure limit (Table 8), indicating that respiratory symptoms may be associated with DPM exposure in this population. Statistical significance was reached for "cough", "phlegm" and "wheeze at work". For the non-respiratory symptoms, the proportion of mine workers who reported having headaches was higher in the high exposed than the low exposed group. The unadjusted ORs were also all elevated among the higher exposed group, indicating that these symptoms might be associated with DPM exposure.

Almost 20% of the mine employees smoked. The distribution of the proportions of participants in the different categories of duration of employment was similar in both the low and high exposed groups.

The association between symptoms and exposure did not appear to be confounded by smoking (i.e. smoking could not explain the higher prevalence of symptoms in the group with exposure above 0.16 mg/m3 EC) as, when the data were adjusted for smoking, phlegm, wheeze at work and headaches were still significantly associated with high EC exposure (Table 10). However, when the data were also adjusted for duration of employment, the ORs were slightly lower and did not reach statistical significance. This indicates that the symptoms may be associated with cumulative exposure to DPM, which is a combination of duration of employment and historic exposure levels, rather than the current levels measured during the survey.

Table 9. Characteristics of study participants with regard to other variables potentially associated with health symptoms (n = 275)

Variable	Exposed to EC < 16 mg/m^3 N = 117 n (%)	Exposed to EC ≥ 16 mg/m^3 N = 108 n (%)
Smoking status:		
Current smoker	24 (20.5)	20 (18.5)
Ever smoker	28 (23.9)	30 (27.8)
Duration of employment (current mine):		
≤ 5 years	53 (45.3)	53 (49.1)
6 – 10 years	23 (19.7)	19 (17.6)
>10 years	15 (12.8)	13 (12.0)
Duration of employment (all mines):		
≤ 5 years	36 (30.8)	44 (40.7)
6 – 10 years	30 (25.6)	21 (19.4)
>10 years	25 (21.30)	20 (18.5)

Table 10. Reported health symptoms in platinum mine employees, unadjusted and adjusted for smoking*, and for smoking plus duration of employment**,by EC exposure category

Symptoms	Adjusted for smoking		Adjusted for smoking and duration of employment	
	Odds Ratio	95% CI	Odds Ratio	95% CI
Respiratory symptoms:				
Wheeze	1.30	0.51-3.4	1.07	0.38-2.97
Cough	2.50	0.96-6.48	2.29	0.81-6.44
Trouble breathing	3.26	0.33-32.1	2.79	0.28-27.8
Phlegm	2.95	1.16-7.50	2.39	0.85-6.69
Shortness of breath	0.98	0.27-3.60	0.95	0.22-4.04
Wheeze at work	3.04	1.12-8.27	2.58	0.93-7.20
Other symptoms:				
Headaches	2.25	1.02-4.96	2.14	0.85-5.40
Light-headedness	1.44	0.73-2.83	1.98	0.91-4.33
Nausea	1.65	0.56-4.83	1.32	0.43-4.02

*Smoking status = "ever smoked"

**Both "duration of employment on the current mine", and "duration of employment on all mines"

In all cases, the CIs were wide due to the relatively low prevalence of symptoms, which indicated that the ORs were not precise. Therefore, the findings should be treated with caution and more research with a larger study population is required to reach a definite conclusion.

6 DISCUSSION AND CONCLUSIONS

This paper describes the results of a baseline exposure measurement study conducted in three platinum mines in South Africa. During the survey, exposure measurements were collected from nearly 300 mine workers. The GM exposure level for EC was found to be 0.09 mg/m^3 in this study. However, this dataset also includes measurements in non-diesel mines (used as controls). The GM exposure levels in the diesel shafts varied from 0.06 mg/m^3 to 0.23 mg/m^3.

In addition to the measurement survey used to provide insight into the exposure levels, the data were also analysed to derive predictive exposure models. Exposure levels appeared to be strongly influenced by the job title or performed task and by the location in the mine. Operating diesel-powered vehicles near the face resulted in the highest exposure to EC. Performing maintenance work in the workshops was found to result in the lowest exposure levels. The outcomes from this study are in line with the findings by Coble et al. (2010) for underground mines in the USA.

The derived exposure model explained 30% of the variability found in the exposure levels. Exposure levels did not vary significantly between mines or shafts. Within a shaft, however, substantial variability in exposure levels was found, even when exposure levels were adjusted for the effect of exposure determinants (task performed and location). This indicates there are more factors that influence exposure to DPM in the mines than were elicited in this study. The employees in the mines are very mobile and therefore difficult to follow physically. Exact documentation of potentially important exposure determinants is, however, necessary to derive better models.

The results from the health questionnaire showed that 13% of the subjects sampled reported at least one respiratory symptom that has been associated with DPM exposure. Only five workers had symptoms of asthma and these were equally distributed across the two exposure groups. Significant associations of DPM exposure and several respiratory symptoms and headaches were observed after adjusting for smoking. These associations were attenuated (ORs were slightly lower) and no longer statistically significant when the data were also adjusted for duration of employment suggesting that cumulative exposure to diesel may be a better predictor of the symptoms than current exposure to diesel. The CIs of the ORs were wide due to the relatively low prevalence of the symptoms in some of the exposure categories. This suggests that these results need to be confirmed using a larger study population.

Only 20% of the platinum mine employees in this study were recorded as being smokers. This shows a reduction in smokers when compared to findings from previous studies, where 43% were smokers in 1998 and 30% in 2002 (Cheyip et al., 2007).

One of the limitations was that participants were in a hurry to finish answering the questionnaire and might not have been truthful about their health (resulting in potential underreporting of symptoms). Since it is unlikely that symptoms were systematically underreported by workers with either higher or lower exposure, the effect of this would most likely be non-differential. Nonetheless, this may have resulted in a 'dilution' of the effect, resulting in smaller ORs than is actually the case or in wider CIs. In future studies, more attention should be focused on obtaining valid questionnaire data and on the validation of the data using the medical records.

7 RECOMMENDATIONS

This study focused on three platinum mines. It is recommended that the study be repeated to include other mining sectors (such as gold, coal and chrome) that make use of diesel-powered equipment. This will enable a larger study group to be measured and will take the different mining environments (with associated confounders such as silica) into account. To improve the results from such studies, further recommendations are to:

- Develop a quantifiable measure to determine the amount of time employees spend close to a diesel source, especially for roving employees;
- Develop a quantifiable measure to determine the location of an employee in relation to fresh, intake air;
- Focus on more factors that can explain differences in DPM exposure (type of engine, type of diesel, efficiency of maintenance etc.);
- Conduct repeat exposure measurements on the same study participants;
- Confirm the indicated health effects in a larger population to have enough power for the results to be statistically meaningful (i.e. to narrow the CIs); and
- The combination of duration of employment and current levels as a measure of cumulative exposure would need to be studied.

A recommendation to the mines is that the medical examination is reviewed to ensure that information is elicited about health symptoms from literature that are associated with DPM exposure. This will enable the validation of reported health symptoms in future studies. The respiratory health of the highest exposed mine employees (i.e. diesel engine operators) should be closely monitored and Part B of the health questionnaire can be repeated during the annual medical examination.

There is sufficient evidence from this study that health symptoms are associated with exposure to DPM. This supports the recommendation to the regulator that OELs should be implemented for DPM for the mining industry. The phased-in approach proposed by the Chamber of Mines is a good place to start until the exposure levels have decreased and local limits are in line with international limits.

8 ACKNOWLEDGEMENTS

The Platmine Collaborative Research Programme is acknowledged for funding the project. The research team would like to thank the subject mines, the occupational hygienists, ventilation officers and volunteers for their participation in this project.

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