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Emission Level of $PM_{2.5}$ and its Association With Chronic Respiratory Symptoms Among Workers in Cement Industry: A Case of Mugher Cement Industry, Central Ethiopia

Mahlet Mekasha[1], Alemayehu Haddis[2], Tamrat Shaweno[3*], Seid Tiku Mereta[2]

[1]Disease Prevention and Control, Addis Ababa Health Bureau, Addis Ababa, Ethiopia
[2]Department of Environmental Health Sciences, Faculty of Public Health, Jimma University Institute of Health, Ethiopia
[3]Department of Epidemiology, Faculty of Public Health, Jimma University Institute of Health, Ethiopia

***Correspondence to**
Tamrat Shaweno,
Tel: +251912493482
Email:babiynos@gmail.com

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Abstract
In Ethiopia, occupation-related respiratory symptoms are extensively increasing with the expansion of cement manufacturing industries. However, little information is available on the extent of emissions and its association with chronic respiratory diseases. This study assessed the emission level of $PM_{2.5}$ and its association with chronic respiratory symptoms among workers in Mugher Cement Factory, in 2018. A cross sectional study was employed on a total of 309 cement factory workers. Air check sampler, model 224-54, was used to measure the concentration of $PM_{2.5}$. Variables with *P* value <0.2 during bivariate analysis were selected as candidate for multiple logistic regressions. Significance level was set at *P* value <0.05. A total of 309 workers participated in the study with an overall response rate of 97%. The mean age of the respondents was 32.02 years (±4.7 SD). Emission levels of all $PM_{2.5}$ samples were above the allowed standard. Among the workers, 50.8% had chronic respiratory symptoms and factors associated were: working in raw material receiving unit (adjusted odds ratio [AOR]= 7.5, 95% CI, 2.9, 19.4), cement milling unit (AOR=2.4, 95 % CI,1.2, 4.8), packing unit (AOR= 2.2, 95% CI= 1.1, 4.3), workers' monthly income level below 3000 ETB (AOR; 5.8, 95% CI,1.9, 17.6), and workers' regular medical checkup (AOR=2.4, 95 % CI, 1.0, 5.2). The concentration level of $PM_{2.5}$ and prevalence of chronic respiratory symptoms were high in the study area. Use of personal protective devices and periodic monitoring of installed pollution control devices is highly recommended.

Keywords: Chronic respiratory symptoms, Ethiopia, $PM_{2.5}$, Workers of cement industry

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1. Introduction

Cement production and consumption has an increasing trend in Ethiopia (1-2) and construction has boomed since 1990 (3,4). Cement production industries can be a main source of air pollutants (5), specifically those emitted from different units including crusher, crane, raw mill, kiln, cement mill and packing units in the cement production process (6,7). Particulate matter (PM) is composed of both coarse and fine particles, and fine particles have an aerodynamic diameter less than 2.5 μm ($PM_{2.5}$), an inhalable particle being easily transformed into gaseous emission (8-10). The emission of PM from cement industry has detrimental effects on both the human health and the environment. There is an increasing evidence and concern that PM from different industries affects the workers. One of the most critical particles involved in manufacture of cement is dust generated during transportation, storage, and milling (8).

According to the World Health Organization (WHO), the recommended stringent standard for $PM_{2.5}$ should be less than 25 $\mu g/m^3/d$ (10) and $PM_{2.5}$ concentration levels in cement plants are much higher than the existing standard (5,11), with a very high concentration of $PM_{2.5}$ in crusher and packing units compared to administrative and management areas (12).

The world communities, especially the people in developing countries are faced with the increasing risks of respiratory diseases due to the generation of smoke and dust in different industrial sectors by the use of outdated machines (13-15). Occupation-related respiratory symptoms are extensively abundant in Ethiopia, especially among cement production workers exposed to dusty environment, and these workers are not well informed about the harmful effect of work environment on their health (16). Chronic respiratory diseases represent a public health challenge in both industrialized and developing countries, being more prevalent in cement factories of developing countries, where occupational

health and safety issues are less emphasized (17).

According to a review conducted on emission level of $PM_{2.5}$ in cement industries, countries like China have experienced an increased $PM_{2.5}$ level exceeding 166.8 μg/m^3 for 24 hours compared to the reference level declared by WHO; which resulted in a hospital admission due to respiratory problems (18). Globally, around 3% of cardiopulmonary deaths and 5% of lung cancer deaths are attributed to PM (8). In the European region, the rate of cardiopulmonary and lung cancer deaths attributed to $PM_{2.5}$ are 1%–3% and 2%–5%, respectively. However, there is no clear evidence on a safe level of exposure to PM or on a threshold below which an adverse health effects occur (19). In developed countries like Great Britain, about 12 000 deaths annually occur due to the occupational respiratory diseases, about two-third of which occur because of dust-related diseases (20). In developing countries, especially those of sub-Saharan African region, respiratory problems are the sixth cause of death and most of these problems occur due to dust exposure majorly in cement factories (21).

A study done in Ethiopia showed that a high prevalence of chronic respiratory symptoms was observed among cement factory workers. In this study, age, sex, education level, working department, smoking, work experience, and training were identified as the factors associated with chronic respiratory symptoms (17). We aimed to assess the emission level of $PM_{2.5}$ from cement industries and its association with respiratory symptoms among workers in a cement factory in Mugher, Addis Ababa, Ethiopia.

2. Materials and Methods

2.1. Study Setting, Design and Population

This cross-sectional study was conducted in Mugher cement factory located in Oromia special zone, surrounding Addis Ababa, the capital of Ethiopia. From a total of 17 cement factories in Ethiopia, six of them are located in Oromia special zone, and only Mugher cement factory is a state owned plant, constructed in 1984. The enterprise's first production line was commissioned and officially inaugurated in 1984. In the enterprise, it was also constructed a second plant, which was located 10 km far from Addis Ababa to the west, and operationalized in 2012 around Tatek. A total of 318 workers were working in the factory during the study. This study was conducted from September 9 to October 13, 2018 in Mugher cement factory among workers aged 18-65, with minimum of 1 year of experience.

2.2. Operational Definitions

In this study, chronic respiratory symptom was defined as the development of one or more of the symptoms of chronic cough, chronic phlegm, and chronic wheezing which lasts at least for three months in one year. Chronic cough was defined as the experience of cough as much as 4–6 times per day occurring for most days of the week (≥4 days) for at least three months in one year (22). The sputum expectoration as much as twice a day for most days of the week (≥4 days) for at least three months in one year was considered as chronic phlegm; and wheeze and chest tightness (asthma) was defined as attacks or episodes of wheeze in the past year with or without other symptoms (22). $PM_{2.5}$ was measured as respirable PM with the aerodynamic diameter <2.5 microns.

2.3. Data Collection

2.3.1. Respiratory Health Problems of Factory Workers

There were 318 eligible workers in the factory during the study and all of them were included in this study. The respiratory health problems of workers were assessed through structured interview questions. The major outcome was chronic respiratory symptom. Age, sex, marital status, total working hours, occupational health and safety training, and monthly household income were among the demographic information recorded for each respondent. Smoking, availability and use of personal protective equipment (PPE), medical checkup, availability and use of bath/shower were also recorded as behavioral factors. Modified, pretested and structured interview questionnaire adapted from related literature was used to collect data. The questionnaire was prepared in English language and translated to local language (Amharic) and then retranslated back to English by an independent translator to check for its consistency. Data were collected by five environmental health professionals holding diploma degree using administered structured questionnaire and face to face interview and observational checklist. Data collection process was supervised by a nurse and an environmental health professional both holding bachelor of science.

2.3.2. Sampling and Analysis of Particulate Matter

$PM_{2.5}$ sample was collected by an air check sampler, model 224-54, in which a known volume of air is pumped at a flow rate of 2.5 L/min through a glass fiber (23). The filter paper and the PM was dried and desiccated in oven and desiccator, respectively. The increase in weight due to the trapped particles was measured using analytical balance. The emission levels were measured from 4 main departments (administration, raw material receiving, cement milling, and packing). In addition, samples were collected from an ambient air of the factor within a range of 100-400 m and outside the factor within the distance of 1 km. The samples were collected within two hours of sampling duration from each sampling location. The results obtained from 2 hours of sampling was computed for 24 hours of exposure to compare with the available standards.

2.3.3. Observational Checklist

We used observational checklist to assess the practice of dust control mechanism, availability of PPE, use of

PPE among workers on cement, waste management conditions of the factory. and cleanliness of the rooms in each department.

2.4. Data Quality Control

AIRCHECK sampler was calibrated with a flow meter after each occasion. To ensure the quality of data, appropriate data collection tool was designed and pretested. Pretesting was done on 5% of the sample size in another factory, which was almost identical to the study setting. One-day training was provided for both data collectors and supervisors about the objectives of the study, data collection tools, interview technique, how to approach potential respondents, and how to keep confidentiality.

2.5. Data Management and Analysis

Data were checked for its completeness and consistency. Accurate data were entered into the CS-Pro software and exported to the SPSS version 21.0 for further analysis. Descriptive statistics (frequency, percentage, mean and standard deviation) were computed to summarize the characteristics of the study participants. We did bivariate analysis to select candidate variables for multivariable analysis. Variables with *P* values less than 0.2 in bivariate analysis were entered into multivariate logistic regression analysis to identify variables independently associated with chronic respiratory symptoms. Significance level for adjusted odds ratio was adjusted at 95% CI with a *P* value <0.05.

3. Results and Discussion

3.1. Socio-demographic Characteristics of the Study Participants

A total of 309 factory workers participated in the study with an overall response rate of 97%. Majorities of the participants (127, 41 %) were between 25 and 34 years of age with the mean age of 30.02 years (±4.7 SD). About 70% (216) of the study participants were married and 41% (126) of the factory workers earned monthly income of 1000-3000 ETB (Table 1).

Table 1. Sociodemographic Characteristics of the Study Population in Mugher Cement Factory, Ethiopia, 2018

Characteristics	Category	No. (%)
Age	< 25	58 (18.8)
	25-34	127 (41)
	35-44	93 (30)
	≥ 45	31 (10)
Sex	Male	262 (84.8)
	Female	47 (15.2)
Education	Primary and below	38 (12.3)
	Secondary	89 (28.8)
	Higher	126 (40.8)
	Graduate and above	56 (18.1)
Marital status	Never married	93 (30.1)
	Married	216 (70)
Income category(with Ethiopian currency, Birr)	1000-3000	126 (40.8)
	3001-7500	111 (36)
	7501-10000	40 (13)
	>10000	32 (10.4)

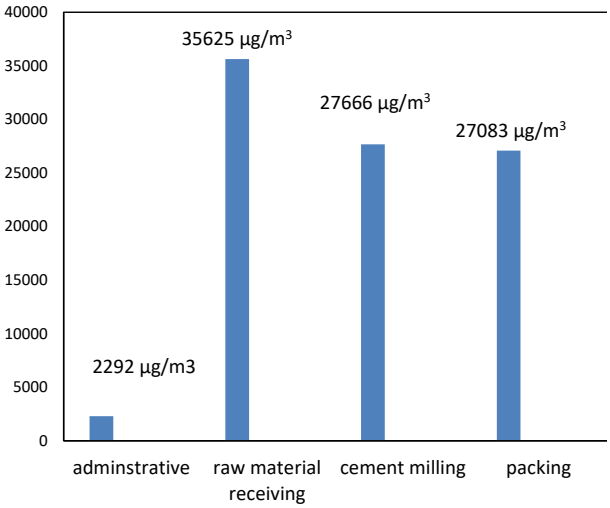

Fig. 1. $PM_{2.5}$ Emission Level in Each Working Unit of Mugher Cement Factory.

3.2.Particulate Matter Emission Level at Different Departments of Mugher Cement Factory

The emission level of $PM_{2.5}$ from each working unit in the factory widely varies from the highest (35625 µg/m³) in material receiving unit to the lowest (2292 µg/m³) in administrative unit (Fig. 1).

All recorded levels of $PM_{2.5}$ in each working unit of the cement factory were very higher than the 24-hour limit $PM_{2.5}$ concentration set by the Canadian air quality standard set by Federal–Provincial Advisory Committee, 1989; ANSI/ASHRAE (i.e 40 µg/m³) (24) and WHO for indoor pollution (< 25 µg/m³/d) (26). One study indicated that a $PM_{2.5}$ concentration of 1796 µg/m³ was recorded at the main crusher in the cement industry of Pakistan (25), which was lower than the findings of this study (25). High concentration level of $PM_{2.5}$ recorded in this study may be due to dust absorber/sucker which was not working regularly and the factory had been using open-belt transport system, in which dust particles were easily dropped into the working area.

Concentration of $PM_{2.5}$ decreased with increasing the measuring distance away from the production plant. The high concentration of $PM_{2.5}$ was observed in the place near to the production area within 100 m (35 833 µg/m³) while the least was observed in the area far from the production plant within 400 m (1666 µg/m³). However, we did not observe any significant increment in $PM_{2.5}$ concentration beyond 400 m. This might be due to the light weight of

$PM_{2.5}$ which was easy to be transported by wind, hence they were blown further away from the point source. Clinker transport machine which was used to transport clinker from the raw-material-receiving department to cement mill department with an open-belt transportation system was the main source for the emission of $PM_{2.5}$ in compounds ambient air, since the machine had a leakage of dust. One study done in Nigeria also revealed that concentrations of air pollutants specifically $PM_{2.5}$ decreased with distance increase. It was observed that within the range of 400–800 m, the value of 27.79-75.87 $\mu g/m^3$ was higher than the standard value of 25 $\mu g/m^3$ set by the WHO, whereas in 1000 m it was found to be 9.33 $\mu g/m^3$, a value which was within the range recommended by the WHO. The cause of this variation might be the variation in study period between these two studies; in Nigerian study, data were collected during the rainy season which might affect the concentration of $PM_{2.5}$.

3.3. Occupation-Related Health Factors of the Study Participants

From the total study participants, 58.3% were laborers in three production units (raw material receiving, cement milling, and packing department), thus they were directly exposed to dust. Regarding the work experience, 56.3% (174) of workers had served the factory for less than or equal to 5 years and 73.5% (227) of the participants spent more than 36 h/wk on work. Considering the smoking, 10% (31) of the workers were smokers and only 20.7% (64) used PPE regularly. Among the reasons forwarded for not using PPE, 41.6% (102) thought that it was unnecessary, 39.2% (96) asserted unavailability of the equipment, and 19.2% (47) did not use it because the instruments were not comfortable. Regarding medical checkup, 83.8% (259) of the workers were not checked up on regular basis due to unavailability of service (64.6% (144), negligence to the service 30.5%(79) and for unknown reasons 13.9 %(36) (Table 2).

Table 2. Work-Related and Behavioral Characteristics of the Study Population in Mugher Cement Factory

Variables	Category	No. (%)
Working department (unit)	Administrative unit	129 (41.7)
	Raw material receiving	41 (13.3)
	Cement milling	70 (22.7)
	Cement packing	69 (22.3)
Years of service	≤5 years	174 (56.3)
	>5 years	135(43.7)
Total work hour per week	≤ 36 hours	82 (26.5)
	> 36 hours	227 (73.5)
Previous work exposure to dust	Yes	27 (8.7)
	No	282 (91.3)
Ever smoker	Yes	31 (10)
	No	278 (90)
Use of PPE	Regular	64 (20.7)
	Not regular	245 (79.3)
Use of bath/shower	Regularly	95 (30.7)
	Not regular	214 (69.3)
Medical checkup	Regularly	50 (16.2)
	Not regular	259 (83.8)

3.4. Prevalence of Chronic Respiratory Symptoms Among Mugher Cement Factory Workers

In this study, prevalence of chronic respiratory symptoms in Mugher cement factory was seen in 157 workers (50.8%). Todays, occupational health and safety standards are emphasized to focus on the prevention and control of respiratory diseases in Ethiopia (1). This finding was in line with a study from India (12) and lower by 15% and 12% when compared to the studies from North Shoa (29) and Dejen (17), respectively. This variation may be due to the difference in study population in that previous studies only considered those working in cement milling and clinker units, while we included workers from all working units. In the current study, among workers with chronic respiratory symptoms, the prevalence of chronic cough, chronic phlegm, and chest wheezing were 98.7%, 91.7%, and 30.6%, respectively. The prevalence of cough and phlegm in this study was higher compared to the prevalence of chronic cough in Iran (28,30) and prevalence of phlegm in UAE (19.5%) (35). These variations may be due to the use of modified filter and enclosed belt transport system by their employees in those countries, which can reduce exposure to dust (Table 3).

3.5. Factors Associated With Chronic Respiratory Symptoms Among Factory Workers

The explanatory variables including sex, educational status, monthly income, working hour, occupational and safety training, previous work exposure, previous history of respiratory illness, smoking, PPE use, post work bathing, medical checkup, and working department with *P* value less than 0.20 were selected for multivariate logistic regression model during bivariate analysis of factors associated with chronic respiratory symptoms.

From a total of 12 candidate variables entered into the multivariate logistic regression analysis, monthly income, working unit and individuals with regular medical

Table 3. Distribution of Chronic Respiratory Symptoms Among Workers in Each Department of Mugher Cement Factory

Unit	Chronic respiratory symptom		Total No. (%)
	Yes No. (%)	No No. (%)	
Administrative	40(31.0)	89(69.0)	129(100)
Raw material receiving	34(82.9)	7(17.1)	41(100)
Cement milling	45(64.3)	25(35.7)	70(100)
Cement packing	38(55.1)	31(44.9)	69(100)
Total	152(49.2)	157(50.8)	309(100)

Table 4. Multivariate Logistic Regression Analysis of Factors Associated With Chronic Respiratory Symptoms Among Workers in Mugher Cement Factory

Variables	Categories	COR	*P* Value	AOR	*P* Value
Sex	Male	2.8 (1.5, 5.5)	0.002	1.5 (0.6, 3.8)	1.5
	Female	1			
Educational status	Primary and below	2.7 (1.1, 6.4)	0.24	0.6 (0.2, 2.4)	0.6
	Secondary	2.2 (1.1, 4.4)	0.02	0.8 (0.3, 2.6)	0.8
	Higher	1.7 (0.9, 3.3)	0.10	0.9 (0.3, 2.3)	0.9
	Graduate and above	1			
Income	1000-3000	8.6 (3.3, 22.6)	0.000	5.7(1.8, 17.5)	0.002*
	3001-7500	3.4 (1.3, 8.9)	0.012	2.2 (0.7, 6.5)	0.150
	7501-10 000	3.5 (1.2, 10.5)	0.022	2.4 (0.7, 7.8)	0.139
	>10 000	1		1	
Working hour	≤ 36 h	1			
	> 36 h	4.7 (2.7, 8.3)	0.000	0.5 (0.1,1.7)	0.3
OSH training	Yes	1		1	
	No	2.0 (1.3, 3.3)	0.005	1.2 (0.6, 2.7) 0.2	
Previous work exposure	Yes	3.0 (1.2,7.4)	0.015	3.2 (1, 9)	0.04
	No	1			
Previous history of RI	Yes	11.4 (1.4, 89.3)	0.021	28 (2.2, 370)	0.01
	No	1			
Smoking	Yes	35.7 (4.8, 265.2)	0.000	37 (4.5, 309)	0.00
	No	1			
PPE use	Regular	1.9 (1.1, 3.5)	0.018	1.6 (0.7, 3.4)	0.1
	Non regular	1			
Post work bathing	Regular	4.9 (2.9, 8.3)	0.000	0.5 (0.2, 1.7)	0.3
	Non regular	1			
Department of work	Administration	1		1	
	R.M receiving	10.8 (4.4, 26.4)	0.000	7.5 (2.9, 19.4)	0.000*
	C. Milling	4.0 (2.1, 4.4)	0.000	2.5 (1.2, 4.8)	0.011*
	Packing	2.7 (1.5, 4.9)	0.001	2.2 (1.2, 4.3)	0.016*
Medical checkup	Regular	1.9 (1.0, 3.5)	0.044	2.4 (1.0, 5.2)	0.034*
	Not regular	1		1	

1.00: reference. CI: Confidence Interval. AOR: Adjusted Odd Ratio.*$P<0.05$

checkup were found to be independently associated with chronic respiratory symptoms (Table 4). This finding was in line with a study from Iran (34). Workers with monthly income of 1000-3000 ETB were 6 times more likely to develop chronic respiratory symptoms compared to the workers whose monthly income was more than 10 000 birr (adjusted odds ratio [AOR]: 5.8, 95% CI: 1.9-17.6). This finding was in line with a study from India in that workers with low monthly income were roughly two times more likely to develop chronic respiratory symptoms compared to those with relatively high monthly income (12). This might be because workers whose monthly income was above 10 000 ETB were mostly working in administrative units, but workers whose monthly income was below 3000 ETB were those directly exposed to cement dust. Among four working units in the factory, employees working in raw material receiving unit (AOR: 7.5, 95% CI: 2.9, 19.4), cement milling unit (AOR: 2.5, 95% CI: 1.2, 4.8), and cement packing unit (AOR: 2.2, 95% CI: 1.2, 4.3) were 8, 3, and 2 times more likely to develop chronic respiratory symptoms, respectively, compared to the workers in administrative unit. Similarly, a study with different settings indicated that compared to the administrative workers, the highest chronic respiratory symptoms were observed among workers in cement milling unit (17) and cement packing unit (12,31). This could be because most workers were not using the appropriate PPE in their respective working units regularly; thus, they were exposed to high PM concentration. High PM concentration may contribute to the chronic respiratory problems among workers in these high dust exposure units. Studies have shown that PM less than 2.5 μm in size ($PM_{2.5}$) has been directly linked to respiratory illnesses and infections such as asthma, as well as cardiovascular and respiratory diseases, including lung cancer (8,24).

Regarding medical checkup, those who had a regular medical checkup were two times more likely to develop respiratory symptoms (AOR: 2.4, 95% CI: 1.0, 5.2), compared to those with irregular medical checkup (Table 4). However, this finding was not in line with the studies

conducted in different settings within cement factory. This deviation might be because workers with regular medical checkup were those who worked for many years in the cement factory, so they were indirectly susceptible to the respiratory problems.

This study was a robust one in that there was no published data on the level of PM concentration specifically $PM_{2.5}$ in Ethiopia context. The results of this study can be used as a baseline for further studies. Apart from its strengths, this study has also short comings: since the study was a cross sectional study, the possibility of recall bias may result in under reporting and misreporting of outcomes. Only one cement factory was used for this study, this was due to the involuntariness of other factories to participate in the study. Due to financial reason to supply the instrument, which was used to assess the lung function test on workers, it was obtained subjective data from the participants which may affect the result of the study. Lack of studies with similar methodology and similar topic particularly in Ethiopia context made difficulties in comparing the results.

4. Conclusion

Chronic respiratory symptoms were observed among almost half of the study participants and the concentration level of $PM_{2.5}$ was very higher than the recommended level in the cement factory. Analysis of associated factors indicated that high prevalence of chronic respiratory symptoms was associated with low monthly income, working in cement milling, packing and raw material receiving departments, and workers with regularly medical checkup.

Increasing worker's level of income and monitoring dust level in vulnerable working units is highly recommended.

Conflict of Interest Disclosures

The authors declare that they have no conflict of interests.

Ethical Statement

The study was approved by the institutional review board of Jimma University Institute of Health (JUIH), Jimma, Ethiopia and permission letter was obtained from Addis Ababa administration health bureau. Verbal consent was also obtained from each study participant.

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