Original Research Article

Pulmonary Function Impairment in Female Workers Exposed to Environments with Varied Ambient Air Pollution in the central business area of Lusaka-Zambia

ABSTRACT

AIMS: To determine the lung function of workers exposed to particulate matter of aerodynamic diameter less than 2.5 micrometer ($PM_{2.5}$) in the streets and offices in Lusaka, Zambia.

STUDY DESIGN: This was a cross sectional study between two groups.

PLACE AND DURATION OF STUDY: Lusaka city, central business area, between June and August 2014.

METHODOLOGY: The study included women between 18-50 years of age who had been working as street or office cleaners for 6 months or more. Males and individuals in both groups who used to smoke or were currently smokers, as well as those with a history of respiratory related illnesses or had cardiopulmonary conditions were excluded from the study. The cleaners were interviewed to get information on socio-demographic characteristics and other information using a structured interview schedule. The participants' lung volumes, forced expiratory volume in one second (FEV_1), forced vital capacity (FVC) and their ratio (FEV_1/FVC) were measured using a MRI spirobank G spirometer. On the day of the interview, $PM_{2.5}$ in their work environment was sampled using a personal aerosol monitor (SIDEPAK AM510).

RESULTS: Out of the 90 participants, 45 were street sweepers and 45 were office cleaners. More street sweepers had impaired lung function (FEV1/FVC) 15(75%) than office cleaners 5(25%) p=.01. FEV_1 was also significantly different among street sweepers 12(70.6%) and office cleaners 5(29.4%) p=.05. $PM_{2.5}$ measurements revealed significantly high levels of exposure among street sweepers (p=.001). Participants with impaired lung function (p=.005) and those with reduced FEV_1percent predicted were exposed to significantly high concentrations of $PM_{2.5}$ (p=.012).

CONCLUSION: Exposure to high $PM_{2.5}$ concentration is associated with pulmonary function impairment and reduced FEV_1 % predicted among cleaners.

Ambient Pollution, Fine Particulate matter ($PM_{2.5}$), Forced Expiratory Volume in 1 second (FEV_1), Forced Vital Capacity (FVC), Lung Function Status.

1. INTRODUCTION

Air pollution is considered a hazard to human health [1]. In the past decades, studies have highlighted the role of ambient air pollution as an important cause of both mortality and morbidity for many different cardiopulmonary diseases [2]. Ambient pollutants include suspended or respirable particulate matter (PM), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), and sulphur dioxide (SO_2) [3]. Among these ambient pollutants, respirable particulate matter (PM) is said to have the greatest effect on human health [4]. Airborne PM consists of a mixture of liquid and solid air-suspended particles, which are released straight into the atmosphere or after the transformation of gas into particles from natural or human-induced processes [5]. Some of the important sources of fine particulate matter include burning fuels emitted from vehicles, open air burning of house hold wastes and biomass cooking fuels such as charcoal and fire wood [6]. Studies conducted in many developing countries have reported an increase in $PM_{2.5}$ burden and its constituents [7, 8]. In Africa, the increase in the burden of $PM_{2.5}$ is due to the growing ownership of motor vehicles, unpaved roads as well as continued use of biomass (firewood and charcoal) as a major domestic energy source [7]. Indeed combustion of biomass fuels is usually incomplete and is said to release several pollutants among them Particulate Matter [6, 7].

The most important parameter for defining the toxicity of PM is particle diameter and composition [9]. The United States Environmental Protection Agency (US EPA) and other agencies that regulate air pollution have three main categories for PM: PM $_{0.1}$ (ultrafine particles) $PM_{2.5}$ (fine particulate matter) and PM_{10} (coarse particulate matter), which refer to particles with aerodynamic diameter smaller than 0.1, 2.5 and 10 micrometres (µm), respectively [10]. Studies show that it is the fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$) fraction that are capable of penetrating deep into lung tissue and induce oxidative stress that are more harmful [9]. Furthermore, studies in electron microscopy show that most of the effectively retained particles in the lung parenchyma are $PM_{2.5}$ [2]. Therefore, particle size and the ability to penetrate into the lung tissue and subsequent retention of the fine particles play an important role in causing lung function impairment [9].

When inhaled, air pollutants cause obstructive, restrictive or both types of functional impairment of the respiratory system manifested by reduced functional vital capacity (FVC), forced expiratory volume in one second (FEV_1) and their ratio FEV_1/ FVC [11]. $PM_{2.5}$ induces cell injury and death of respiratory epithelial cells; it also leads to decreases in immunity defences through the destruction of macrophages (9). It also increases airway reactivity and induces allergic symptoms [12]. Presence of allergies has been associated with impaired lung function status among susceptible occupational groups such as street sweepers, steel plant workers and so on [13,14].

Spirometry is an important as well as simple tool, in assessing the functioning ability of the lungs [15]. Spirometric measures of lung function, namely maximum forced vital capacity (FVC) and maximum forced expiratory volume in 1 s (FEV_1) have been described as early indicators of chronic respiratory and systemic inflammation [11]. The lowering of both the FEV_1 (FEV1< 75% predicted for age and height) and FVC (FVC<80% predicted for age and height) indicates a restrictive lung impairment while the ratio thereof maybe greater than 70% [16, 17]. In obstructive impairment, the FVC may be normal but FEV_1 is reduced [17].

1.2 Occupational exposure to fine particulate matter ($PM_{2.5}$) pollution

Occupation plays an important role on the level of personal exposure to pollutants as demonstrated in a study that showed that female street sweepers exposed to high concentrations of dust had lower lung function values compared to females of the same category working in an office [19]. The study further revealed that use of personal protective equipment (PPE) was essential in preventing this. Other studies have equally revealed that street sweepers by virtue of their exposure to dust were more likely to have a FEV_1/FVC ratio less than 60% [18,19,20]. Office cleaners are also at risk of developing lung function impairment due to exposure to indoor sources of $PM_{2.5}$ like chemical detergents and fungal spores from furniture [20].

Despite belonging to an organised workforce, cleaners in Zambia like many other African countries are not sufficiently taken care of in terms of periodical health check-ups and provision of personal protective equipment such as gloves, facemasks and respirators. Sometimes, due to poor sensitization on the need to use this equipment others feel there is no need to use it, whilst the protective equipment maybe worn out and/or not replaced in good time [21].

Air pollution is a hazard to lung function but this has not been documented in cleaners in Lusaka. There is no air quality monitoring hence the levels of $PM_{2.5}$ in ambient Lusaka air are not known and health-based limits for dust control in the various work places are lacking. Although studies on lung impairment have been carried out on specific occupational groups in Zambia such as miners and stone crashers [22, 23], no study has been carried out on other occupational groups including sweepers.

This study was therefore, aimed at determining the level of air pollution particularly $PM_{2.5}$ in the work environments and the possible effects of this pollutant on the lung function of individuals that are exposed to these pollutants such as street sweepers and office cleaners. The data obtained would be useful as an advocate tool for provision of protective equipment for the cleaners. It will also provide insights on the possible effects of $PM_{2.5}$ on lung function to policy makers, health care providers and researchers and provide a baseline for further study. We envisage that this study will help improve enforcement and implementation of air quality regulations around the city.

2. MATERIAL AND METHODS

The study was conducted in the central business area of Lusaka Zambia. The study sites included all the 12 streets of the central business area. The indoor study sites along these streets were purposively sampled and included offices that had as little outdoor air circulation as possible.

2.1 Selection of Participants

The study population included female cleaners working within the central business area and these were divided into two groups according to their job category, 45 office cleaners and 45 street sweepers. Females aged between 18 and 50 years of age who had been working as street or office cleaners for 6 months or more were invited to participate in the study. Individuals in both groups who used to smoke or were currently smokers, as well as those with a history of respiratory related illnesses or had cardiopulmonary conditions were excluded from the study. Males were also excluded from the study as they constitute a very small proportion of the people in this sector. The participants in both groups were identified using a list of employees provided by the supervisor. The lists were used as a sampling frame for which random sampling technique was employed to select the participants. Informed consent was obtained from those selected who agreed to participate in the study. The study protocol was cleared by the University of Zambia Biomedical Ethics Committee (UNZABREC).

2.2 Data Collection

Data collection was carried out between the months of June and August 2014. A structured interview schedule, with questions adapted from the American Thoracic Society (ATS) respiratory questionnaire, was used to collect demographic information and to record Spirometry data from participants. Prior to its use, the interview schedule was pilot tested on fifteen (15) randomly selected female cleaners to ascertain the levels of understanding. The questions were administered in commonly spoken language. The language used was simple and the cleaners had no difficulty understanding the questions. Information pertaining to the use of protective wear, cooking fuel, smoking history, occupation history, allergies and history of respiratory diseases were captured using the interview schedule.

2.3 Measurement of Lung Function

The lung function tests were carried out, using a portable MRI spirobank G spirometer (Medical Research International, Spirobank G, Rome, Italy). The device allowed for calibration and it had the software to predict lung function indices for age, sex and height. The tests were taken with participants in the sitting position by a trained spirometry technician. The procedure was explained to the participants who were urged to seal their lips tightly around the mouthpiece, breathe in fully (maximal inspiration) at the start of the test, immediately blast air out as fast and as far as possible until the lungs were completely empty.

Three maneuvers were done at 5-minute intervals and the best of the three results was recorded. The predicted FEV_1, FVC were determined using height and age of the participants. Lung function status of each participant was determined using the FEV_1/FVC ratio. The lung function measures were stored on the device and also recorded.

2.4 Measurement of Fine Particulate Matter ($PM_{2.5}$)

A TSI SidePak AM510 Personal Aerosol Monitor (TSI incorporation St. Paul, MN United States of America) was used to sample and record the levels of fine particulate matter ($PM_{2.5}$) in the air. The aerosol monitor was attached to the participant and the sampling tube placed near the participants' breathing zone. The built in impactors of the aerosol monitor were set on the 2.5 cut off in order to sample only $PM_{2.5}$ concentrations in mg/m^3 then converted to µg/m^3. The SidePak was zero-calibrated prior to each use by attaching a zero filter according to the instructions provided in the user guide. Measurements of $PM_{2.5}$ for both indoor and outdoor areas were taken in the morning, midday, and in the afternoon during cleaning for 30-60 minutes. $PM_{2.5}$ readings were stored in the sampling device and manually transferred to a data sheet for analysis.

2.5 Data Analysis

The Independent Samples Mann-Whitney U test for non-parametric data was used to compare medians of PM $_{2.5}$ across the indoor and outdoor cleaning sites. Explorative statistics using the Independent Samples Median Test were used to determine the association of PM $_{2.5}$ with lung function characteristics (predicted FEV_1% and FVC% and the ratio FEV_1/FVC).

Chi-square was used to determine the association between the dependent variable (lung function status) and the independent variables (age, cooking fuel, presence of allergies and use of PPE). It was also used to determine association of pulmonary function in the two groups of cleaners. Statistics were done at the 5% level of significance. Data analysis was done using IBM SPSS Statistics for Windows Version 20.0 (IBM Corp. Armonk, NY, USA).

3. RESULTS

The study consisted of 90 participants divided into two groups; 45 street sweepers and 45 office cleaners, all female, none were tobacco smokers or had previously smoked tobacco, all working within the central business area of Lusaka.

3.1. Lung Function Status of Participants

Figure 1 is a description of lung function status of the two groups of cleaners. The street sweepers had significantly lower values for the predicted values for FEV_1, and FEV_1/FVC ratios. (Table 2)

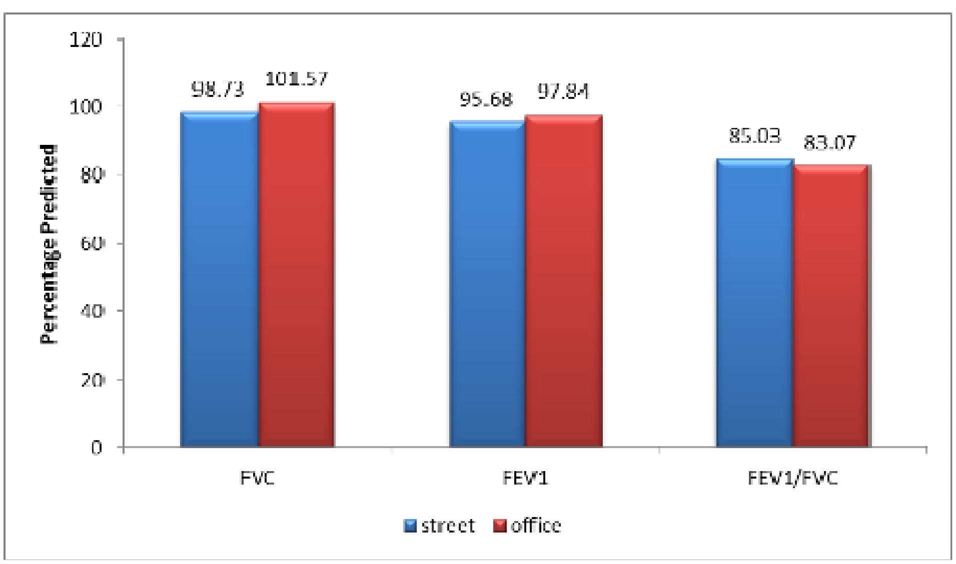

Figure 1; Percentage predicted values of lung function parameters between the cleaners.

Table 2 describes the lung function characteristics of the participants. More street sweepers had impaired lung function 15(75% within lung function) compared to office cleaners 5(25%). The street sweepers also had significantly reduced FEV_1 12(70.6%) as compared to office cleaners 5(29.4%).

Table 2: Lung Function Status of Participants

Lung function variable	Street sweepers No (%)	Office cleaners No (%)	p-value
Lung function status (FEV_1/FVC)			
Normal	30(42.9)	40(57.1)	
Impaired	15(75.0)	5(25.0)	.01*
FEV_1 percent predicted			
Normal	33(45.2)	40(54.8)	
Reduced	12(70.6)	5(29.4)	.05*
FVC percent Predicted			
Normal	36(46.2)	42(53.8)	
Reduced	9(75.0)	3(25.0)	.06

*[p] Pearson's Chi-Squared Test (2-sided), *Indicates significant p-value at .05 confidence level .*

3.2 Contributing Factors to $PM_{2.5}$ Exposure

Table 3 shows factors that could possibly contribute to participants' exposure to $PM_{2.5}$ such as use of PPE, cooking fuel, previous occupation and allergy symptoms and their association with lung function status.

Based on these characteristics, 58 (64.4%) of the 90 participants reported using PPE sometimes or not at all. Among those with impaired lung function 12 (60%) reported not using PPE consistently while 8 (40%) reported always using PPE. There was no significant difference in lung function between those always using PPE and those that used PPE occasionally or never (p=.792).

There was no significant difference in lung function status between participants who used charcoal as cooking fuel and those who used electricity (p=.355).However, among those that reported using charcoal as a cooking fuel 14(70%) had impaired lung function status while among those that reported using electricity as cooking fuel, only 6 (30%) had impaired lung function status. Most (70%) of the participants with impaired lung function status used charcoal as cooking fuel.

Among the participants with normal lung function status, 2.9% had previously worked in Metal fabrication or mining related industries, 15.7% had worked as stone crushers or at stone crushing sites, 7.1% previously worked in industries associated with dust and fume generation and 74.3% had only worked as cleaners. Of those with impaired lung function status, 40.0% had previously worked in the above-mentioned industries, while 60.0% have only worked as cleaners. The association of previous occupation and lung function status was statistically significant (p = .046). Previous occupation predisposes to lung impairment.

About half (53%) of the participants reported that they suffered from allergic symptoms while at work. However, most of those with impaired lung function status (75%) reported having allergy symptoms. Table 3, shows lung function status and allergy symptoms among these participants. Among the participants with normal lung function status, 33(47.1%) had allergies while among those with impaired lung function status 15(75%) had allergies. There was a statistically significant association between presence of allergy symptoms and pulmonary function impairment (p=.038).

The data in table 3 on the two groups of cleaners, reveals that, 29 (41.4%) of the participants with normal lung function were street sweepers, and 41(58.6%) were office cleaners. 80% of those with impaired lung function, were street sweepers and 20% were office cleaners. There was significant difference in pulmonary function between the two groups of cleaners p=.002.

Table 3: Lung Function status by Key characteristics of participants

	Lung function Status		
	Normal (n=70, $FEV_1/FVC>70\%$)	**Impaired (n = 20, $FEV_1/FVC < 70\%$)**	
	No (%)	**No (%)**	**P-Value***
Use of PPE			
Always	24 (34.3)	8 (40.0)	
Sometimes /never	46 (65.7)	12 (60.0)	.79
Cooking Fuel			
Charcoal	41 (58.6)	14 (70.0)	
Electricity	29 (41.4)	6 (30.0)	.35
Occupational History[p]			
Metal fabrication/ mining	2 (2.9)	0 (0.0)	
stone crushing/ milling plant	11 (15.7)	2 (10.0)	
Dusts/fumes	5 (7.1)	6 (30.0)	

Other (no previous occupation)	52 (74.3)	12 (60.0)	**.04***
Cleaning Location[p]			
Indoor -office cleaners	41 (58.6)	4 (20.0)	
Outdoor -street sweepers	29 (41.4)	16 (80.0)	**.002***
Allergies[p]			
No	37 (52.9)	5 (25.0)	
Yes	33 (47.1)	15 (75.0)	**.02***

[p]Pearson's Chi-Squared Test (2-sided), *Indicates significant *p*-value at *confidence interval* = 0.05.

3.3 $PM_{2.5}$ concentrations in the study areas.

The highest observed value for $PM_{2.5}$ outdoors, was 398µg/m^3 whilst indoors it was 53µg/m^3. The lowest observed value outdoors was 123µg/m^3 while indoors it was 10µg/m^3 (Figure 2). The $PM_{2.5}$ concentration between the indoor and outdoor study sites was significantly different (p=.0001).

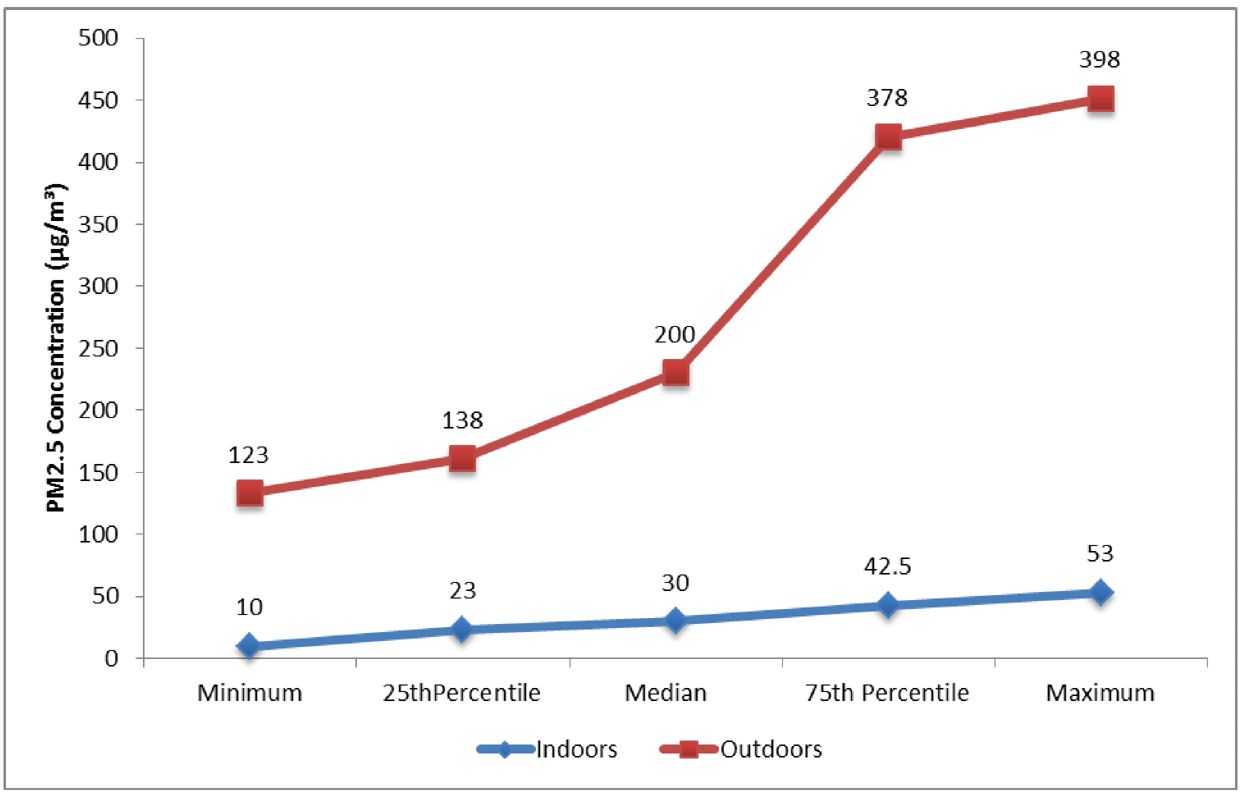

Figure. 2. Distribution of $PM_{2.5}$ Concentrations in Indoor and Outdoor Locations

3.4 $PM_{2.5}$ concentrations and pulmonary function indices (FEV_1/FVC FEV_1 and FVC)

The Figure 3 shows the $PM_{2.5}$ exposures among the participants and the percent predicted values of FEV_1, FVC and FEV_1/FVC. The participants in the two lung function categories were exposed to significantly different concentrations of $PM_{2.5.}$ (p=.001).The median of $PM_{2.5}$ concentration among those with normal lung function status was 44.00µg/m^3 while among the participants with impaired lung function the median of $PM_{2.5}$ concentration was 171.00 µg/m^3.

Participants with reduced FEV_1percent predicted were exposed to significantly high concentrations of $PM_{2.5}$ (200 µg/m^3)in comparison to those with normal FEV_1percentage predicted for age and height(45 µg/m^3) p=.03.

Participants with normal predicted FVC were exposed to lower $PM_{2.5}$ concentrations (49 µg/m^3) compared to those with reduced FVC (260 µg/m^3) predicted for age and height. There was no significant difference in FVC percent predicted between those exposed to high $PM_{2.5}$ concentrations and those exposed to low $PM_{2.5}$ concentrations p=.121.

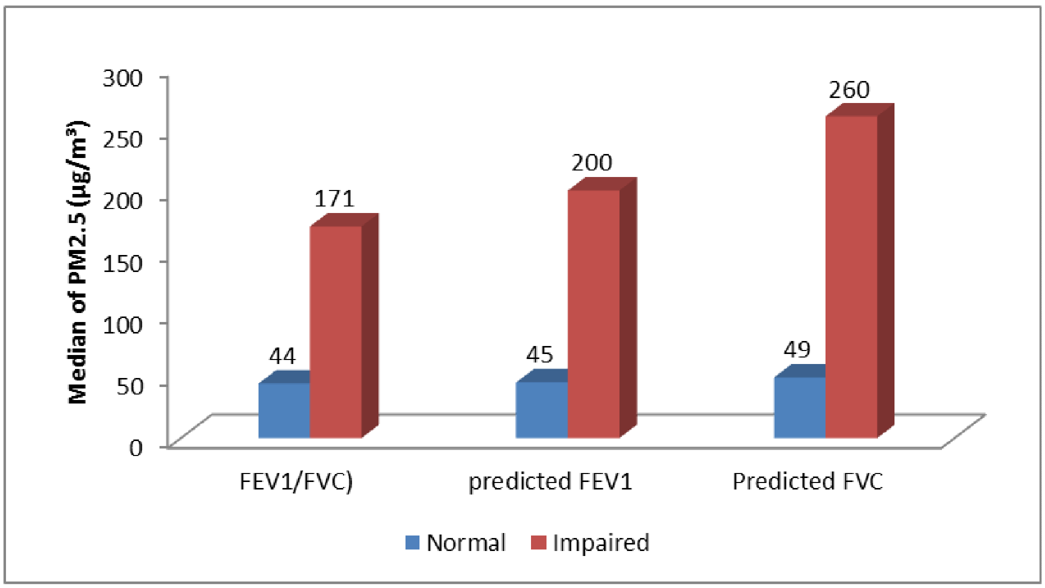

Figure. 3. Medians of $PM_{2.5}$ Concentration (µg/m^3) and predicted values of FEV_1, FVC and FEV_1/FVC.

4 Discussion

Lung Function Characteristics of Participants

The study confirmed the presence of impaired lung function status among cleaners exposed to fine particulate air pollution ($PM_{2.5}$) in ambient Lusaka air. The street sweepers showed significantly reduced FEV_1/FVC ratio and predicted value for FEV_1 than office cleaners. This shows that street sweepers are more likely to have impaired pulmonary function than office cleaners. Studies have associated street sweeping and exposures to large amounts of dust resulting in respiratory conditions [11,14,17,]. However, there was no significant difference in FVC between the two groups of cleaners.

Contributing Factors to $PM_{2.5}$ Exposure

The levels of $PM_{2.5}$ depend on several factors. Among these, cooking fuel is important. Most (61.1%) of the participants in the present study used charcoal as a cooking fuel. Biomass fuel use is likely to be a major driver of respiratory and cardiovascular disease [24]. Cooking fuel used was not associated with lung function status in the current study. These findings differ from a previous study, which reported an association between biomass (Charcoal and firewood) cooking fuels and impaired lung function [6].

The cleaners recruited to the study had low frequency of PPE use. This could be a possible explanation for the observed lung function impairment in the two groups. Studies show that street sweeping without precautionary measures such as proper use of personal protective equipment in the form of facemasks and respirators may predispose to respiratory conditions [18,19, 25]. This is based on the observation that the use of precautionary measures such as PPE tend to reduce the levels of inhaled particulates and subsequent pathological effects [24].

Occupational history was significantly associated with lung function in the current study. A finding supported by previous studies that have long associated workers in foundry, cement plants, mining and stone crushing plants or quarries with lung function impairment [13, 22, 23, 25]. Such occupations act as pre-exposures to causes of lung function impairment. However, the relationship is not causal but that previous occupation could be an important factor in determining respiratory health outcomes among individuals due to the risks involved such as dust, chemical particulates, metals, asbestos and so on [26].

The current study showed a relationship between presence of allergies and lung function status. This finding was consistent with studies that revealed that allergy symptoms such as those present in asthmatic individuals are worsened in cases of exposure to pollutants and these further indicate a decrease in lung function measurements especially FEV_1 [12,27,28]. In the current study, 25% of those with impaired lung function status had no allergy symptoms while 75% of those who reported having allergy symptoms had impaired lung function status. The presence of allergy symptoms may be an indicator of increased susceptibility to the effects of $PM_{2.5}$ exposure [28].

$PM_{2.5}$ Concentration ($\mu g/m^3$) in the Study Areas

The results in the present study show that real-time $PM_{2.5}$ concentrations were significantly elevated in both indoor and outdoor areas. The measured $PM_{2.5}$ concentrations outdoors were high, ranging from $123\mu g/m^3$-$398\mu g/m^3$ compared to 10 $\mu g/m^3$- $53\mu g/m^3$indoors. These findings are consistent with other studies carried out in other African cities, which revealed that air pollution levels particularly $PM_{2.5}$ concentrations were quiet high and that they exceeded international guidelines [7, 8]. In indoor areas air circulation is controlled by the presence of air conditioners hence the small variations in the $PM_{2.5}$ however; this does not prevent increases in $PM_{2.5}$ [29]. Because of these elevated concentrations, 80% of those with lung function impairment were street sweepers and only 20% were office cleaners

$PM_{2.5}$ and Pulmonary Function indices (FEV_1/FVC FEV_1 and FVC)

A significant association was observed between $PM_{2.5}$ concentration and lung impairment (FEV1/FVC). This finding collaborated with those that reported that interquartile increases in $PM_{2.5}$ exposure results in increased respiratory impairment [27]. The ability for the fine particulate matter ($PM_{2.5}$) to penetrate the alveoli and cause endothelial damage by release of inflammatory mediators such as chemokines and cytokines causes reduction in lung function [5, 8].

The results of this study has shown that the concentration of $PM_{2.5}$ across the lung function status categories were different. High concentrations of $PM_{2.5}$ (median 171.00) were associated with impaired lung function status whereas low concentrations of $PM_{2.5}$ (median 44.00) were associated with normal lung function status. The level of lung function impairment is related to the dosage of PM an individual is exposed to [30].

In line with other studies [27, 31] the current study further revealed that $PM_{2.5}$ concentration had an effect on the FEV_1 percent predicted and not on the FVC percent predicted. FEV_1 reduces because the inhaled particulates cause irritation in the airways resulting in over production of mucus and proinflammatory mediators that block the airways. The tendency to resist airflow under forced conditions in blocked airways reduced the volume of air that could be forcibly expired as a result FEV_1 is reduced but not the FVC.

5. CONCLUSION

The real-time $PM_{2.5}$ concentrations were quiet high outdoors compared to indoors. A statistically significant association was observed between exposure to fine particulate pollution $PM_{2.5}$ and lung function status. Higher levels of exposure to $PM_{2.5}$ were associated with lung function impairment and reduction in the lung function indices (FEV_1% predicted and FEV_1/FVC), whereas low levels of exposure were associated with normal lung function status. Most of those with impaired lung function status were street sweepers and were exposed to higher levels of $PM_{2.5}$ compared to the office cleaners.

CONSENT

An informed consent form prepared according to the Research Ethics Committee guidelines was given to the participants in order to guarantee voluntary participation. The contents of the information sheet were translated into the commonly spoken language. Simple language was used in providing the participants with sufficient knowledge to ensure the decision to take part is a well-informed one. Contents such as the purpose of the study, its nature and methods to be used in the study were explained. The information sheet was kept by the participants, while the consent forms were kept by the principal investigator. Participants gave consent either through written or using the thumb prints for those who could not write. The participants were allowed to ask questions pertaining to the study and were free to withdraw from the study at any time if they felt uncomfortable without any penalty or loss.

ETHICAL APPROVAL

Approval to carry out the study was granted in writing by The University of Zambia Biomedical Research Ethics Committee (Assurance No. FWA 00000338, IRB 00001131 of IORG 0000774, Ref: 013-03-14). Permission to conduct the study was obtained from the various employers of the groups of cleaners and the Lusaka City Council.

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DEFINITIONS

Ambient Air: refers to the air in the surrounding environment.

Particulate Pollution: Tiny solid and liquid droplets suspended in the air that when inhaled can cause damage to the lungs.

Fine Particulate matter: is a complex mixture of extremely small particles and liquid droplets. Fine particulate matter is 2.5 micrometres in diameter.

Spirometry: The measurement of how quickly air can be expelled from the Lungs.

Forced Expiratory Volume in 1 second : The volume of air that can be forcibly exhaled from the lungs in the first second of forced expiration.

Forced Vital Capacity: The total volume of air that can be forcibly exhaled after taking the deepest breath possible.

Lung Function status: refers to how well air flows in and out of the lungs or an FEV_1/FVC ratio of greater than 70%, FEV_1% predicted greater than 80% in women, or FVC% predicted greater than 80%.

Impaired Lung Function Status: when an individual has an FEV_1/FVC ratio of less than 70% or the loss or distortion or weakening of lung tissue leading to difficulty in air flowing out of the lungs.

Personal Protective Equipment: This is the protective clothing, facemasks, respirators, goggles, or other garment designed to protect the wearer's body from injury by blunt impacts, electrical hazards, heat, chemicals, and infection, for job-related occupational safety and health purposes.

Exposure: The act of subjecting or an instance of being subjected to an action or an influence, (fine particulate air Pollution).