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Presence of Quartz Dust in Jewelry Workshops Around Islamabad, Rawalpindi and its Health Impacts on Lungs

Noor Ul Huda[1], Stephen Javed[2], Fiza Sarwar[3]
[1,2] Department of Earth and Environmental Sciences, Bahria School of Engineering and Applied Sciences (BSEAS), Bahria University H-11 campus, Islamabad, Pakistan,
Email: hudagillani8080@gmail.com, stephenjaved22@gmail.com, fizasarwar@bahria.edu.pk

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Abstract
The study investigated airborne particulate matter in the jewelry workshops of Islamabad, and Rawalpindi focusing on quartz and potentially toxic elements to assess respiratory health impacts among workers. Five jewelry workshops were selected two (A, B) in F-7 and three (C, D, E) in Sarafa bazar, Rawalpindi. Human and environmental PM samples were collected. Analysis of PM 2.5 in pm 10 revealed elevated levels of elements majorly Cd, Silica, and slightly high Ni, Pb, Ba, and Ag exceeding safe exposure limits. SEM imaging showed PM 10 particles as elongated rod like structures predominantly composed of Fe and silica followed by Ca, O, Al, and K. Ca based compounds including calcium carbonate and oxides were identified as raw materials from jewelry manufacturing processes like casting, ceramics, abrasives, and polishing. Additionally, workshops showed peaks of Si, C, Ca, O Zn, Cu, Al, and K indicating the presence of silicates, concretes, ceramics and glass particles which may form rods during aerosolization. The survey found that employees in all five workplaces had worsened respiratory issues, affecting their health and well-being. The survey indicated 65% of workers had frequent respiratory difficulties including cough (65%), phlegm (50%), breathlessness (67%), and wheeze (55%). Workers with a mean BMI of 25.26 ± 10.38 were classified overweight. The highest Exposure Concentration values were found for Fe, Mg, Sr, and silica. Certain workshops (A, B, D, E) had surpassed LTCR values for Si and Cr. The highest EC for non-carcinogenic metals were found for Mg, Fe, and Sr, indicating health hazards from prolonged exposure. Zn, Cu, and Fe had the greatest PM10 EDI (mg/kg). Workshops C, D, and E, had the most Zn intake, while A, B, and D had the most Fe and Cu intake. Workshop A exhibited high EDI levels for Zn, Si, Fe, and Cu. Ba and Si had the highest PM 2.5 intake values in all workshops, with Zn on top. Workshop C had the most Zn take. In all five workshops, Pb, Cd, Zn, Fe, Mn, Ba HQ surpassed the limit. However, the HQ of Cd, Pb, exceeded in just one of the workshops (A and E). The HQ of Si, Cu, Ni, and Cr was under the acceptable level. Pulmonary function test (PFT) demonstrated substantial decline in parameters such as FVC, FEV1 and the PEF, especially among smokers with statistically significant correlation showing higher elemental concentration in PM negatively impacting lungs capacity. The finding suggested regular exposure to high concentration of toxic elements in aerosolized particles poses serious health risks to workers notably impairing respiratory functions and increasing potential long term health hazards.

Keywords: FEV1, FVC, PEF, PM 10, PM 2.5, Spirometry, Jewelry Workshops, Sarafa Bazar, Quartz Dust

Introduction
One of the oldest industries in the world is jewelry manufacturing, and it has always required certain risky procedures [1]. From plying precious metals like gold into various designs, to cheaper,

imitation jewelry the industry is thriving. Demand for jewelry is consistent among all generations [2]. The conventional method of creating gold jewelry is carried out sequentially in several units, including the units for refining, soldering, design, enameling, polishing and buffing, cutting, and setting. The various unit's techniques for producing gold ornaments regularly endanger the workers' health [3]. Nearly 70% of goldsmiths work in the soldering unit, which is followed by those in the polishing, cutting, refining, and enameling units at roughly 12%, 6%, 4%, 3%, and 2%, respectively, of the workforce. Each unit has a cramped, dark studio environment [4]. Small scale industries in developing countries pose an occupational health risks due to lack of hygiene and safety protocols. Studies have investigated these risks in Pakistan, India, South Africa, and Nepal highlighting the need for attention to this neglected sector [5-6]. In the jewelry industry of Pakistan, the artisan works with materials like gemstone. Cutting, grinding and polishing of these materials can lead to the release of small particles into the air [7]. The presence of dust in workshops is inevitable owing to the very nature of jewelry making process [8]. The various intricate steps like polishing, cutting and soldering lead to an atmosphere impregnated with dust comprising of toxic substances. This dust can contain silica, metals and particulate matter as well [9]. The workers in the jewelry making industry are exposed to these harmful constituents of dust daily, leading to respiratory problems like Asthma, COPD, and bronchitis etc. [8]. Dust particles can create significant problems for workers in their occupations especially countries like Pakistan, where occupational regulations are either inadequate or nonexistent. Jewelry workers are more likely to have pulmonary diseases. Acid, wax, and dust vapors can result in pulmonary and extra pulmonary issues [10]. Symptoms like sneezing, rhinitis, cough, dyspnea, chest pain, and other symptoms of pulmonary issues may appear. Musculoskeletal pain, mechanical injury, conjunctivitis, foreign bodies in the eyes, dermatitis, vertigo, headaches, hyperacidity, etc. are examples of non-pulmonary consequences [8, 11]. Dermatitis, respiratory tract irritation, gastrointestinal tract irritation, and nervous system impairment can all be brought on by toxic substances. Airborne particulate matter is a hazard in industries that involve steps like cutting and grinding, where very fine particles are released in the air (12). Quartz is a common constituent of this dust [13]. It is a crystalline form of silica which is particularly hazardous if inhaled as Respirable dust [14]. Prolonged exposures led to development of lung cancer. The findings of the International Agency for Research on Cancer (IARC) have classified types of crystalline like silica, like quartz, from occupational sources as type 1 carcinogens for humans [15]. Salles et al. (2021) found informal jewelry workers in Brazil having elevated Cd levels in urine posing health risks in workers. Soldering and assembly workers were particularly exposed to the metal [16]. Barnes et al. (2019) highlighted silicosis exposure in nontraditional occupational workplaces in the jewelry industry. The study identified three forms of silicosis development, accelerated silicosis which develops within 10 years of exposure to crystalline silica [8]. Bruske et al. (2014) doing occupational exposure to quartz dust linked to reduced lung function and increased risk of COPD. Exposed workers had 4.6% lower FEV1 and airways obstruction [17]. Islamabad, and Rawalpindi, the twin cities of Pakistan, hosts numerous small-scale jewelry workshops in which intricate work, including polishing and engraving, is carried out, which leads to an inevitable release of dust (quartz). The released dust with different chemical composition can lead to diseases like silicosis, pulmonary diseases, and renal failure. Other health effects go as far as cancer and serve to jeopardize the health of the workers [8, 18]. Despite an increasing interest in occupational health and safety, the jewelry-making business remains highly neglected in terms of research. The nature of jewelry making process with various steps involving grinding, polishing, buffing and smelting have an increased chances for health complications. Few studies have focused on this problem. This leads to a research gap that needs scholarly attention and contribution [19]. Therefore, the goal of the present study was to assess presence of quartz (PM10 and PM2.5) in dust in jewelry workshops around Islamabad and Rawalpindi. To assess the pulmonary health of cohorts involved in the jewelry making process and to determine the correlation between pulmonary health indicators, and elemental composition of particulate matter (PM10 and PM2.5) leading to reduced lung function.

Materials and Methods

Study area and site selection

The Islamabad-Rawalpindi area combined served as the study area for this research (Figure 1). Jewelry stores are found everywhere because of their demand. The study is designed to focus on the workshops where artisan engage in different jewelry making processes like soldering, enameling, polishing and buffing etc. [20]. All these processes contribute to air borne quartz exposure. The site selection was based on the higher worker density and resultant exposure to particulate matter, use of silica containing material contributing to exposure [21].

Research design

In this study a cross-sectional approach research design was employed focused on prevalence of quartz dust and its impact on lung functions and contribution to pulmonary impairments of the workers. Data collection includes environmental sampling (PM 10 and 2.5) and human health via spirometry-based lung-function test. The study was design to align with the USEPA and Pakistan Environmental protection agency (Pak-EPA) [22].

Study sites

A total of five workshops were selected across the mentioned area. Of these five sites two were located in the F-7 sector of Islamabad (Table 1). The rest of the three workshops were located in Sarafa bazar Rawalpindi. The choice was based on their proximity to allow for comparative analysis of working conditions and present hazards. Sampling was conducted for two consecutive days per workshop. Each site had 20 workers with a total of 100 participants in the study.

Sampling strategy

Human Sampling

Human subjects were sampled from each of the Five sites. Each of these workshops had 20 human subjects employed in jewelry making for more than 15 years on average. The sample was collected for two days from each site using a ContecSPW10 spirometer. Lung functions parameters like forced expiratory volume (FEV1), forced vital capacity (FVC) and peak expiratory flow (PEF). The spirometer data was recorded onsite and analyzed thereby. The results obtained were then used to analyze prevalence of pulmonary issues like silicosis.

Inclusion and exclusion criteria

All the worker thus tested were employed in the workshops for more than 10 years. They were all aged between 18-60 years. No female was observed however. Individuals with preexisting conditions and smokers were excluded from the study

Particulate matter sampling

1. **Sampling height:** Adjusted to workers breathing zones
2. **Filter type:** Hydrophilic filters (0.22µm pore size) for high efficiency.
3. **Sampling duration:**8 hours a day ensuring representative exposure
4. **Airflow rate:** Maintained at 17L/m for consistency
5. **Sample storage:** Sealed and then transported to Bahria university for analysis [23].

St. George questionnaire surveys

The St. George questionnaire for respiratory health was employed to assess the pulmonary health of the workers. A structured questionnaire with a total of four sections assessing respiratory health was administered to 100 male workers, collecting data on their bio-demographics, including weight, height, smoking status, and spirometry measurements, tailored to the study context [24].

Analytical techniques

Elemental analysis of particulate matter (ICP-MS)

For the elemental analysis an inductively coupled plasma mass spectrometer (ICPMSPerkin ELMER with Cetax ADX-500) was used to analyze elements in PM 2.5 and PM 10 sampled from five workshops. Acid digestion was conducted to eliminate impurities from the filter sheets and to prepare the filtrate for analysis. For acid digestion, 10 ml of perchloric acid ($HClO_4$) was added to each sample, followed by distilled water, and then heated on a hotplate for 15 minutes until the solution became clear. Upon cooling the solution, 30 ml of distilled water was incorporated into each sample, followed by double filtration utilizing Whatman filter paper. The solution was contained in various bottles. Each bottle containing the solution was labeled with its location, name, and time, after which the prepared solutions were sent out for further analysis [25]. For ascertaining quartz, the Perkin Elmer Nexion 350 ICP-MS was utilized. Reference materials were used to confirm accuracy.

SEM-EDX characterization

SEM EDX (Scanning Electron Microscopy with Energy Dispersive X-ray Analysis) was used because it enables us to get a through description of various parameters of interest. SEM EDX was utilized to characterize the particulate matter PM 2.5 and PM 10.

Spirometry (lung function test)

Spirometry was performed in the workshops in four selected sites of Islamabad. A handheld digital spirometer (SP10W, Contec) was used to record FEV1, FVC, and FEV1% (FEV1/FVC), both pre- and post-bronchodilation. For validation and accuracy of testing, equipment quality control was carried out with regular calibration checks before testing was performed, according to American Thoracic Society recommendations. Bronchodilation was done with a combination of 0.4 mg salbutamol and 80 micrograms ipratropium bromide. Spirometry was used to measure: Three spirometry attempts were made with each volunteer and the results were the validated against ATS/ERS standards.

Health risk assessment

The health risk assessment was carried out using USEPA guidelines. For this purpose, the concentration of pollutants (C) in air samples was taken in (µg/m³). Exposure duration (ED) was taken 15 years (minimum occupational exposure). Exposure time (ET) was taken 8 hours/day. Inhalation rate (IR) was taken 20 m³/day (standard for adult workers). The average Body weight (BW) was 70 kg. The exposure frequency (EF): 250 days/year (working days). In this research heavy metals cancerous and non-cancerous risk was determined by calculating the Exposure Concentration (EC µg/m³), the Estimated Daily Intake (EDI mg/kg/day) of metals through PM inhalation and then calculating the Hazard Quotient (HQ) and Lifetime Cancer risk (LTCR) [26].

Exposure Concentration (EC) Calculation

The exposure concentration for carcinogenic risk was calculated using the following formula [27]:

$$EC\ (\mu g/m^3) = (C\ (\mu g/m^3) \times ET\ (hour/day) \times EF\ (days/year) \times ED\ (years))/AT \times 250\ days \times 24hours \quad (1)$$

$$AT = ED \times 250 \text{ days/year} \times 8 \text{ hours per day} \ldots\ldots (2)$$

Where EC is exposure concentration, C is concentration of pollutant, ET is exposure time which is taken 8 hours per day for the exposed group of workers, EF is exposure frequency (250 days/year), ED is exposure duration (15 years) and AT is averaging time. Averaging Time (AT) was calculated using equation 2 [28].

Estimated Daily Intake (EDI)

It is represented as mg/kg/day [29]. Formula for the calculation of estimated daily intake (EDI) is given by [30].

$$EDI\ (mg/kg/day) = (C \times 1/\ 1000\ (mg/\mu g) \times IR\ (m^3/day) \times ET \times EF \times ED/BW \times AT \times 250\ (days/year) \times 24\ (hrs./day) \ldots\ldots (3)$$

EDI = Estimated Daily Intake (mg/kg-day), C = Concentration of Contaminant (mg/L, mg/m^3), InR = Inhalation Rate (20 m^3/day), EF = Exposure frequency (250 days/year), ED= Exposure duration (15 years), BW= Body Weight (70 kg) and AT= Average time (days/year).

Hazard Quotient (HQ)

According to the kind and harmful characteristics, many pollutants have diverse impacts on our bodies that are either carcinogenic or non-carcinogenic. A measure used to evaluate the non-carcinogenic effects is the hazard quotient (HQ) [31]. It was calculated using the equation below [26, 32].

$$HQ = EDI/RfD \ldots\ldots\ldots (4)$$

Where HQ is hazard quotient, EDI is estimated daily intake and RfD is reference dose level. The hazard quotient for inhalation was calculated. When the HQ value exceeds 1, it is thought that the body exhibits non-carcinogenic effects. It is assumed to have insignificant non-carcinogenic effects on the human body if it has a value of less than 1 [33]**.** Table 2 shows the values utilized for Inhalation RfD, and IUR values used for risk assessment for tested elements.

Lifetime Cancer Risk (LTCR)

The formula given by the United States Environmental Protection Agency (USEPA) was used for the assessment of cancerous risks for heavy metals [28]:

$$LTCR = EC \times IUR \ldots\ldots\ldots (5)$$

Where, LTCR is lifetime cancer risk, IUR is Inhalation cancer unit risk and EC is exposure concentration.

Ethical considerations

Prior to collecting any information and conducting spirometry tests, consent was secured from each respondent worker in the study region. Rigorous ethical standards and protocols were followed, ensuring confidentiality for participants by omitting any identifying information from the data collection, hence preventing linkage to individuals. The acquired data was managed securely. All participants were briefed of the study and its significance. Subjects requesting to withdraw from the study were permitted to do so.

Statistical Analysis

Statistical analysis was performed by using one-way ANOVA. Paired T test was used to compare pre and post bronchodilator spirometry results. Relationship between quartz exposure and lung impairment was established using Pearson correlation. Differences were considered statistically significant at $P<0.05$. SPSS version 25 was employed for statistical analysis. Microsoft Excel was employed for making pivot charts and descriptive statistics (mean and standard deviation). For mapping ArcGIS 10.7 version was utilized.

Results

Elemental composition of PM 10 and PM 2.5

The analysis of dust samples (PM 10 and 2.5) across five workshops revealed concentrations of elements such as Cd, Si, Ag, Ni, Ba, and Pb exceeded the occupational exposure limits (OELs). In PM 10 silica levels exceeded the permissible limit in all workshops while Cd, Ag, Ni, also exceeded the limits in only one workshop. Similarly in PM 2.5 Cd, Si, surpassed the safe levels with particularly high concentrations in workshop E. Ag, Ni, Pb surpassed limits in only one workshop. The statistical analysis showed a highly significant difference. Exposure to dust containing elevated levels of these elements especially Ag, Cd, silica poses serious health risks including respiratory issues, and throat irritation, silicosis, lung cancer, COPD, renal diseases, and metal fume fever [7, 35]. Workers who inhale this contaminated dust at regular intervals are at more risk of getting acute and chronic health problems related to inhalation of toxic crystalline silica and metal fumes. The average concentrations of all the elements Cd, Cr, Pb, Si, Ba, Cu, Mg, Mn, Fe, Zn, Ni, Sr, and Ag, in environmental dust samples PM 10 and 2.5, are shown in Table 3.1.

Characterization of Particulate Matter using SEM-EDX

Characterization of PM 10

SEM images from workshop A and B showed that PM 10 particles are conglomerates of elongated rod-like structures with Fe, O, Ca, and K dominating in workshop A, likely from metalworking and raw materials. In workshop B, B, Si, Ca, O, Al and K were predominant indicating the use of abrasives, ceramics, and aluminosilicates. SEM EDX analysis of jewelry workshops C D and E in Rawalpindi revealed interconnected tubular particles likely from high temperature processes. Workshop C mainly used brass (Zn and Cu), workshop D had calcium-based materials and E involved silica, calcium, and Aluminosilicates for ceramics, abrasives, and polishing. Characterization figures can be seen in Figure 2 (a), (b) and 3 (a) (b).

Characterization of PM 2.5

SEM EDX images from PM 2.5 from workshops A and B showed elongated road like structures likely originating from silicate, concrete, ceramics, or glass materials emitted during cutting, grinding, and polishing processes. Workshop A consisted of Si, Ca, O, Al, and K while workshop B showed high fluorine, silica, Ca, and Al with particles forming layered aggregates. SEM EDX images from workshops C, D and E showed diverse patterns. Workshop C showed dense pair of tubular structures and fine particles rich in Ca, O, and Al indicating alloy use and respiratory risk. Workshop d showed fused tubular formations dominated by Cu, indicating extensive copper use with layered deposits linked to high energy processes. Workshop E showed thick tubular structures with varying densities primarily having Cu, Ca, O, and metallic oxidized materials implying potential risks from inhalation of metal bearing dust. Characterization figures can be seen in Figure 4 (a), (b) and 5 (a) (b).

Results of SGR surveys

The survey involved 100 workers twenty from each workshop with an average age of 33.63± 8.68 years. They had a mean height of 5.83 ±0.258, 73.21± 8.03 weight and BMI (25.26 ± 10.38) indicating they were generally in the overweight category. They had been employed in the workshops for an average of 22.82 years. About 40% reported health conditions such as asthma, allergies, diabetes, or hypertension while 65% reported mobility issues, avoided heavy activities and faced restrictions in sports and outings due to respiratory health problems. Social demographic data from a respiratory health survey of workers showed that 35.7% of workers were 36-45 years old, and 30.5% were 25-35. Educationally, 81.2% of workers had primary education, 15% secondary, and 3.9% higher secondary. This indicated that most male workers had only primary education and few advanced degrees. About 59% were married, while 41% were single. Most workers (72.8%) worked more than 8 hours a day, while 27.2% worked 6 or 8 hours, often trainees and less experienced workers. Most workers (41%) have worked here for over 10 years. The survey showed high rates of respiratory issues among workshop workers including frequent cough, phlegm, shortness of breath, wheezing, and chest pain. These symptoms significantly impact their health and job performance with many reported reduced work efficiencies. The study substantiates the high prevalence of respiratory symptoms among jewelry workers which poses substantial health problems and an adverse effect on job performance. Many are using medications in the face of side-effect concerns, and some are taking health-promoting actions. These findings are consistent with previous researches (Moitra, et al., 2014; Kim, et al., 2017; Panchadhyayee, et al., 2015; Rafeemanesh, et al 2014) [10, 11, 18, 39] which associated jewelry work with respiratory, musculoskeletal, eye, and systemic health problems as a consequence of exposure to hazardous substances, silica dust, inadequate ventilation, and absence of safety equipment (Choudhari et al., 2014; Pednekar et al., 2011) [40-41]. All results have been summarized in tables (3.2) (a, b, and c).

Health risk assessment

Cancerous risk of metals

The EC values were higher for Fe, Mg, Sr, and Silica among all the elements. Long-term exposure poses serious health risks, with LTCR values for Si and Cr in some (A, B, D, E) workshops exceeding USEPA's acceptable range, indicating intolerable cancer risk. Among non-carcinogenic elements, the highest ECs were found for Magnesium (Mg), Iron (Fe), and Strontium (Sr), suggesting potential health concerns from prolonged exposure. EC and LTCR values are summarized in Table 3.3 (a and b).

Non-Cancerous risk of metals

The study assessed non-carcinogenic risks from PM10 and PM2.5 dust in jewelry workshops by calculating Estimated Daily Intake (EDI) and Hazard Quotient (HQ) for ten elements. Zn, Cu, and Fe, had the highest EDI (mg/kg) values for PM10. Workshop C, D, and E, had the most Zn, while A, B, and D had the most Fe and Cu. Zn, Si, Fe, and Cu, had high EDI levels, especially in workshop A. For PM 2.5, Ba and Silica (Si) had the greatest intake values in all workshops, with Zn on top. Workshop C had the most Zn intake. The HQ of six elements: Pb, Cd, Zn, Fe, Mn, Ba, exceeded the recommended limit in all five workshops. However, the HQ of Cd, Pb, exceeded in just one of the workshops (A and E). The HQ of Si, Cu, Ni, and Cr, was within the recommended limit in all workshops and PM samples. These findings align with past studies from Bangladesh, Brazil, Iran, and other regions, which also reported hazardous levels of metals like Cd, Cr, Pb, Ni, and Ag in jewelry manufacturing environments (Sikder, et al., 2017; Salles, et al., 2021; Gonzales, et al., 2004; Shekoohiyan, and Mehrabi, 2024) [7, 16, 43, 43]. The EDI and HQ values are shown in Tables 3.4 (a and b).

Lung Function Test

Lung function tests conducted in five jewelry workshops showed reduced respiratory capacity among workers, with particularly low FEV1 and FVC values in workshops A and B. Significant improvements were observed after bronchodilation. One-way ANOVA and post-hoc analysis confirmed statistically significant differences in FEV1, FVC, and PEF across workshops ($p < 0.001$), indicating consistent respiratory impairment and partial reversibility across units. Lung function tests showed significantly lower FVC, FEV1, and PEF values among smoking workers compared to non-smokers, with reduced FEV1/FVC ratios indicating impaired respiratory health. Across workshops in Sarafa Bazar, lung function values were consistently low, with slight post-bronchodilation improvements. The decline in respiratory parameters is linked to smoking, prolonged exposure to hazardous dust and fumes, poor ventilation, and physical strain, highlighting elevated respiratory risks for jewelry workers. The Tables 3.5 (a, b, and c) shows the results of lung function test parameters for all workshops.

Correlation of PM Chemical Composition with Lung Function Decline

Pearson correlation analysis demonstrated significant negative correlations between lung function (FVC, FEV1, PEF) and PM10 constituents such as Ni, Cd, Cr, Cu, Pb, Sr, and Si, signifying a notable deterioration in lung function with heightened exposure. Elements such as Ag, Ba, Mn, Mg, and Fe exhibited moderate negative associations, further substantiating the detrimental effects of PM10 pollution on respiratory health. In PM2.5, elements such as Zn, Si, Pb, Mn, Sr, Cd, Cr, Cu, and Fe showed strong negative correlations with lung function (FVC, FEV1, PEF), indicating that regular inhalation of these particles may significantly impair respiratory health in jewelry workers. Other elements showed moderate negative effects. The study confirmed a strong negative correlation between PM10 and PM2.5 elemental pollutants and lung function decline in jewelry workers. Similar findings by Hadi et al. (2022) and Eeftens et al. (2014) reported reduced FVC, FEV1, and PEF linked to exposure to elements like cadmium, sulfur, and nickel, reinforcing the present study's results [44-45]. The study highlighted significant health risks from exposure to quartz and silica dust during jewelry-making processes like cutting, grinding, and polishing. Prolonged inhalation of these particles can lead to severe conditions such as silicosis, COPD, asthma, and even cancer. Symptoms observed in workers included coughing, shortness of breath, and reduced lung function. To mitigate these risks, the study emphasized reducing working hours, enforcing PPE use, improving ventilation, using water sprays to control dust, and conducting regular health checkups to monitor workers' respiratory health (Ahmad, and Balkhyour 2020; Mamane, et al., 2015; Momtazmanesh, et al., 2023) [46-48]. The correlation plots are shown in Figures 6 (a, b, and c) and 7 (a, b, and c).

Conclusion

The study examined airborne quartz and hazardous components at five jewelry factories in Islamabad and Rawalpindi and how they affected the respiratory health of the workers. The results of the elemental analysis showed that PM 10 and 2.5 majorly high levels of Cd and silica whereas Ba, Ni, Pb and Ag surpassed only in one workshop. Images from the SEM showed small, rod-like particles made mostly of Si, Fe, Ca, and Al that were connected to materials used in soldering, casting, and polishing. This confirmed the presence of silicates and metal oxides. Surveys and spirometry evaluation showed that workers including smokers had more severe respiratory symptoms and a significant decline in lung function (FVC, FEV1, PEF) ($p < 0.001$). The highest EC values were observed for Fe, Mg, Sr, and silica. Certain workshops (A, B, D, E) exhibited surpassed LTCR values for Si and Cr. The highest EC for non-carcinogenic metals were found for Mg, Fe, and Sr, indicating health hazards from prolonged exposure. Zn, Cu, and Fe had the greatest PM10 EDI (mg/kg). Workshops C, D, and E, had the most Zn intake, while A, B, and D had the most Fe and Cu intake. Workshop A exhibited high EDI levels for Zn, Si, Fe, and Cu. Ba and Si had the highest PM 2.5 intake values in all workshops, with Zn on top. Workshop C had the most Zn take. In all five workshops, Pb, Cd, Zn, Fe, Mn, Ba HQ surpassed the limit. However, the HQ of Cd, Pb, exceeded in just one of the workshops (A and E). The HQ of Si, Cu, Ni, and Cr was under the acceptable level. There were strong negative correlations ($p < 0.001$) between lung function indices and elements in PM 10 and PM 2.5, especially Ni, Cd, Cr, Cu, Pb, Sr, and Si. This confirms that inhaling in these substances for a long time is detrimental for workers health. The study showed that jewelry workers are at considerable risk for health problems since they are exposed to small particles that contain hazardous metals and silica for lengthy periods of time. In order to protect worker's health, immediate actions including better ventilation, using PPE, controlling dust, and regular health checks are necessary.

Recommendations

To reduce health risks in jewelry workshops, high-efficiency PPE, especially respirators, should be used in high-exposure workshops (A, B, D, and E) and workers must be trained regularly. Exhaust systems at emission locations, dust control techniques including water sprays and wet cutting, and airflow by separating high-fume areas must be addressed. PM10 and PM 2.5 levels must be monitored regularly to assess safety measures and ensure occupational exposure guidelines are met. A health surveillance system should check lung function often, especially for high-risk workers. Work plans should incorporate rotation and rest breaks to reduce exposure, especially in high-LTCR environments. Increased government and regulatory participation are needed to enforce workplace safety standards, update policies, and update air quality legislation to reflect scientific results.

Data Availability Statement

The data that support the findings of this study are openly available.

Conflict of Interest

The authors declare no conflict of interest.

Nomenclature

COPD Chronic Obstructive Pulmonary Disease
HQ Hazard Quotient
IARC International Agency for Research on Cancer
LTCR Lifetime Cancer Risk
NIOSH National Institute for Occupational Safety and Health
PEF Peak Expiratory Flow
PFT Pulmonary Function Test
PTE Potentially hazardous element
RCS Respirable Crystalline Silica
SEM EDX Scanning Electron Microscopy Energy Dispersive X-Ray Spectroscopy

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Appendices

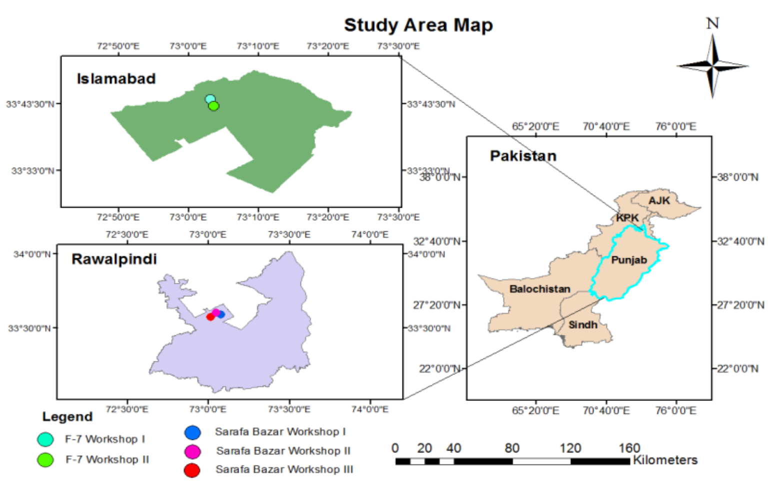

Figure 1: Sampling sites in Islamabad and Rawalpindi

Table 1: Samples taken from sites, workshops in Islamabad and Rawalpindi

Sample No.	Locations	Workshops Name
1	F-7 Markaz	A
2	F-7 Markaz	B
3	Sarafa Bazar	C
4	Sarafa Bazar	D
5	Sarafa Bazar	E

Table 2: Inhalation Reference dose and IUR values used for risk assessment for tested elements

Elements	Reference Dose (RfD Inhalation) mg-kg/day	Inhalation Unit Risk (IUR) μgm^{-3}	References
Cd	$1.0E^{-5}$	$1.8E^{-3}$	Di Vaio, et al., 2018
Cr	$2.86E^{-5}$	$8.4E^{-2}$	Zhang et al., 2015
Pb	$3.52E^{-3}$	$8.0E^{-5}$	Faiz, et al., 2012
Si	$3.0E^{-3}$	$2.1E^{-3}$	Pavilonis, et al., 2017
Ba	$1.43E^{-5}$		Faiz, et al., 2012
Cu	$4.02E^{-3}$		Aguilera, et al., 2020
Mn	$1.43E^{-5}$		Aguilera, et al., 2020
Fe	$2.2E^{-4}$		Aguilera, et al., 2020
Zn	$3.0E^{-1}$		Faiz, et al., 2012
Ni	$2.1E^{-2}$	$2.6E^{-4}$	Di Vaio, et al., 2018

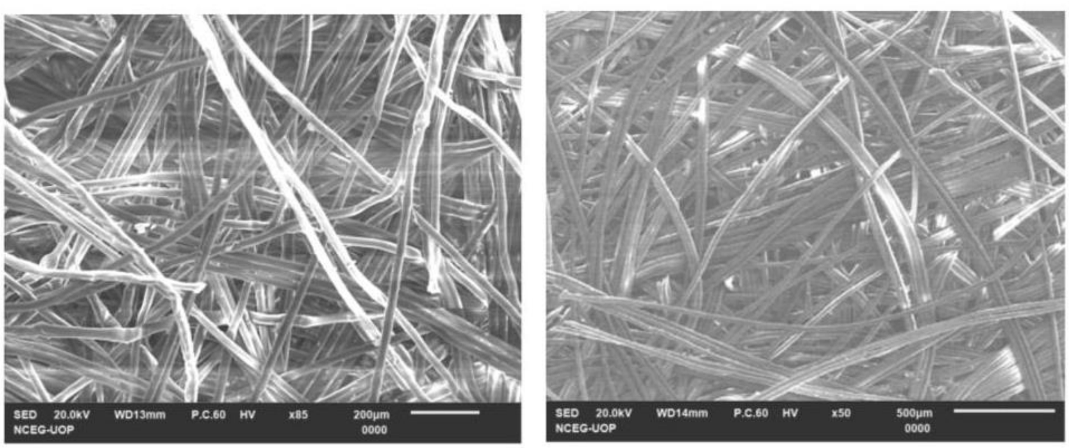

Figure 2(a): Representative SEM images of workshops A and B for PM 10

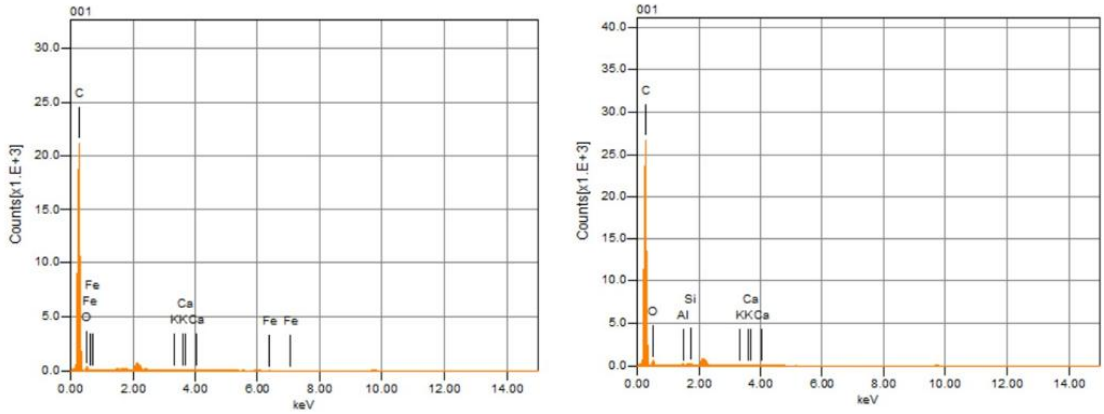

Figure 2(b): Representative peaks of PM 10 in workshops A and B

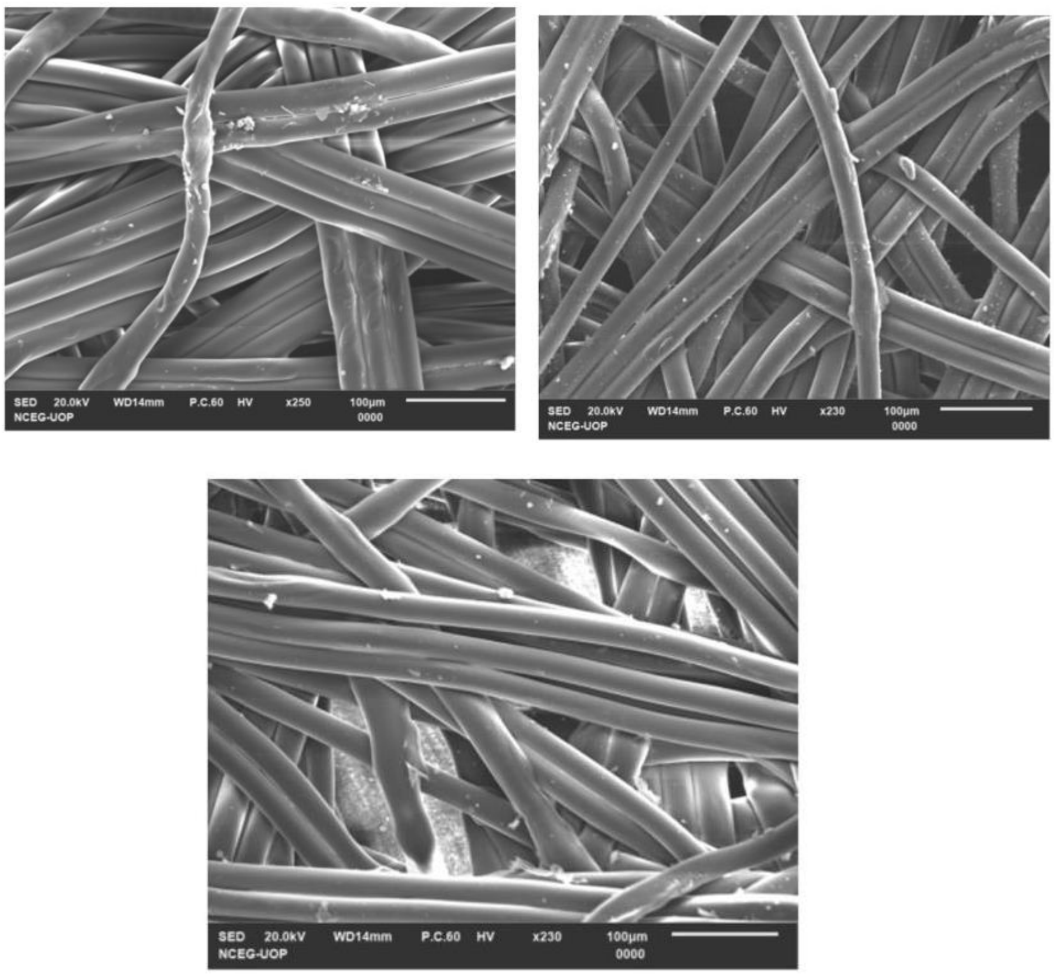

Figure 3(a): Representative SEM images of workshops C, D, E for PM 10

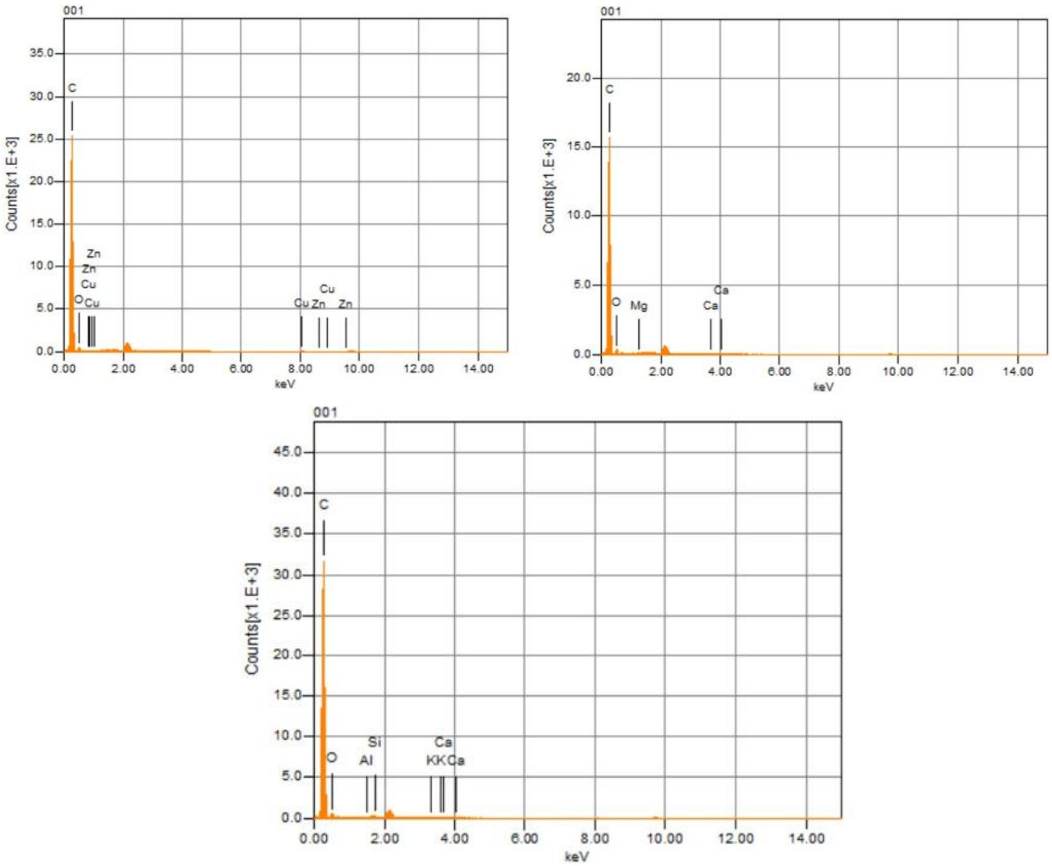

Figure 3(b): Representative peaks of PM 10 in workshops C, D, E

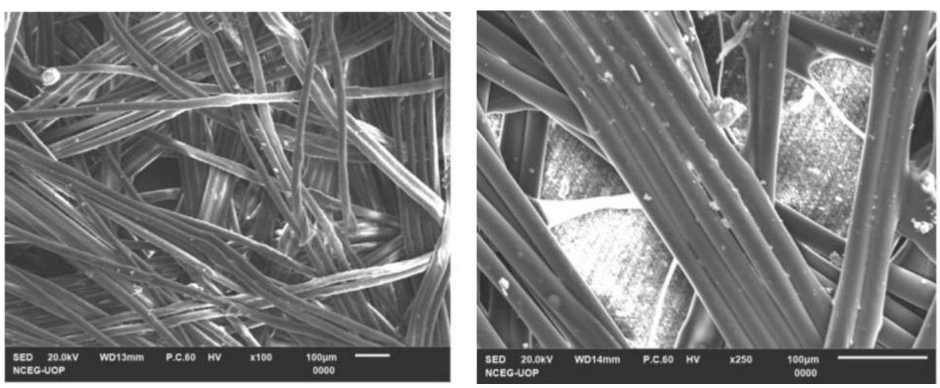

Figure 4(a): Representative SEM images of 2.5 from workshops A&B

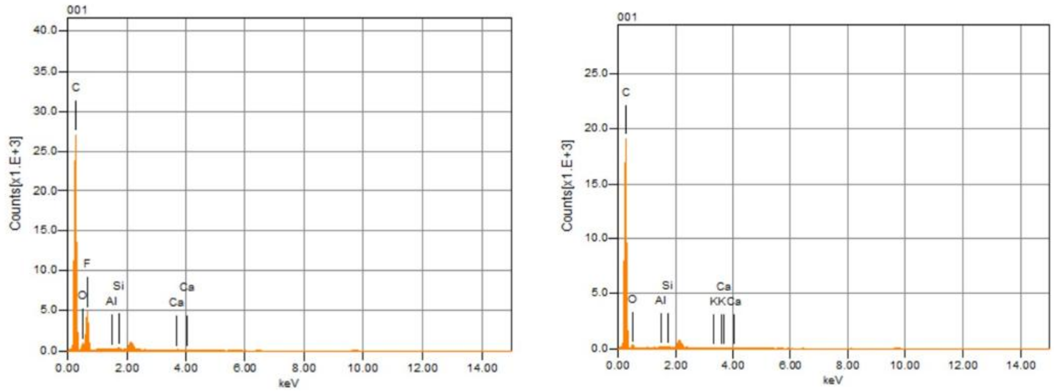

Figure 4(b): Representative SEM peaks of PM 2.5 from workshops A & B

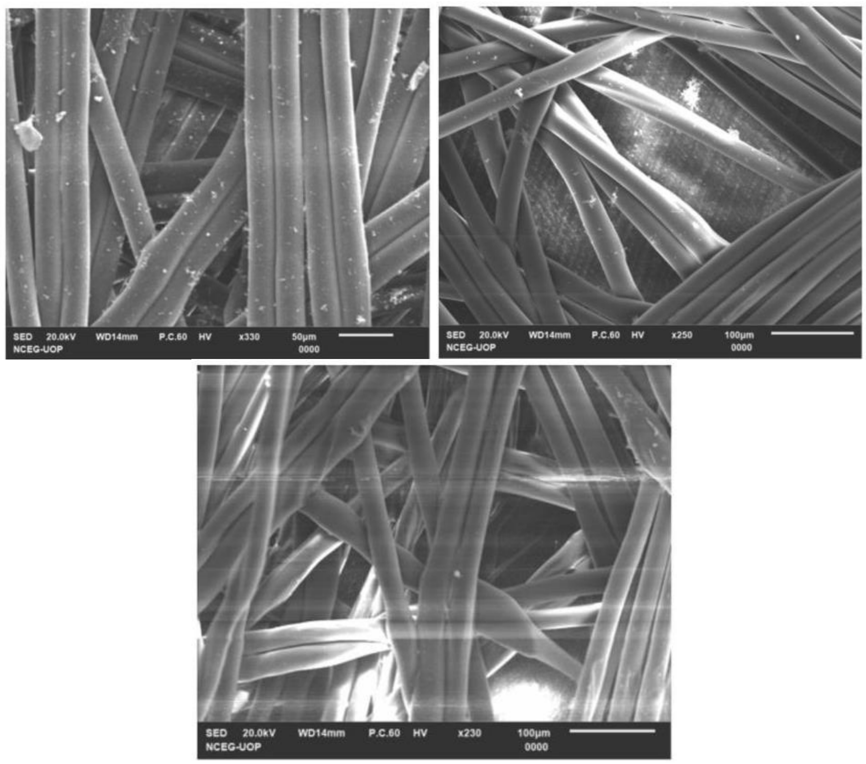

Figure 5 (a): Representative SEM Images of PM 2.5 from workshops C D E

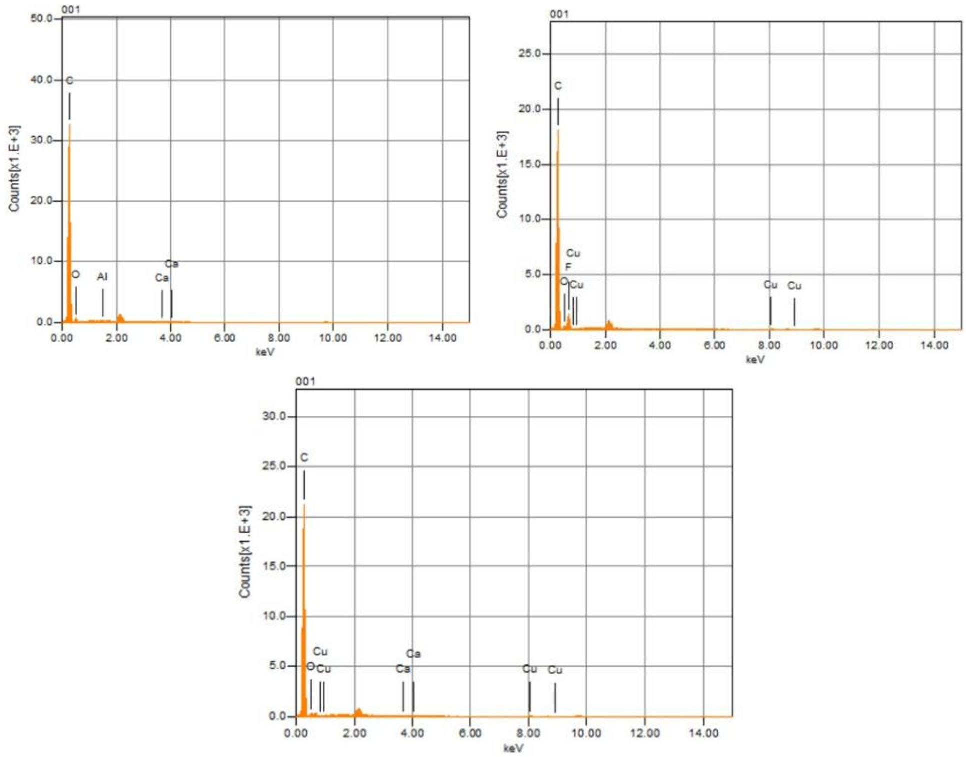

Figure 5 (b): Representative SEM peaks of PM 2.5 from workshops C D E

Table 3.2(a): Demographic/occupational characteristics of respondents

Variables	**Workers (n=100)**
Age	33.63± 8.68
Height	5.83 ±0.258
Weight	73.21± 8.03
BMI	25.26 ± 10.38
Years of employment	22.82± 11.34
Smoking years	14.16 ±9.52
Exposure time (hrs.)	11.38 ±1.87
Smoking Pack Years	18.26 ± 9.88

Table 3.2 (b): Socio-demographic characteristics of survey respondents (5 workshops)

Variables	Workers n=100
Age	
18–25	25%
26–35	30.5%
36–45	35.7%
46–50	6.25%
55+	2.55%
	33.63± 8.68
Education	
Primary	81.2%
Secondary	15%
Higher Secondary	3.9%-
Undergraduate	-
Postgraduate	
Marital Status	
Single	41%
Married	59%
Divorced	-
Working hours	
Less than 4 hours	-
4–6 hours	-
6–8 hours	27.2%
More than 8 hours	72.8%
Duration of work (years)	
5 or less than 5	21%
5-10 years	38%
10 & more	41%

Table 3.2(c): Responses of respiratory health surveys among 5 workshop workers

Variables	Responses	Workers (n=100)
		Frequency %
Frequency of Cough	Mostly	25%
	Frequently	40%
	Occasionally	20%
	Never	15%
Frequency of phlegm	Mostly	35%
	Frequently	15%
	Occasionally	25%
	Never	20%
Shortness of breath	Mostly	35%
	Repeatedly	32%
	Occasionally	28%
	Once	5%
Wheezing attacks	Mostly	25%
	Frequently	30%
	Regularly	20%

	Occasionally Never	15% 10%
Severe Chest attacks	Zero occurrences A couple of times Twice or thrice Just once Severe episodes	3% 30% 22% 25% 20%
Chest condition impact	Severely impacts Major impact Minor issues No issues	40% 30% 25% 5%
Employment impact	Does not impact work Stopped Work Interferes with Work	20% 32% 48%
Coughing Hurts	Yes No	77% 23%
Easily exhausted	Yes No	76% 24%
Exercise safety concern	Yes No	68% 32%
Medication helps	Yes No	87% 13%
Medication side effects	Yes No	62% 38%

Table 3.3(a): Pulmonary Cancerous risk of heavy metals in PM2.5 and PM10
*Exposure concentration= EC (µgm^{-3}) *Bold values of LTCR represent intolerable cancer risk*

	Metals		**A**	**B**	**C**	**D**	**E**
PM 10	Cd	EC	0.13	0.003	1E-3	2E-4	9E-4
		LTCR	2.3E-4	5.4E-6	1.8E-6	3.6E-7	1.6E-6
	Cr	EC	5E-4	3E-4	-	-	0.008
		LTCR	4.2E-5	2.5E-5	-	-	6.7E-4
	Pb	EC	0.001	-	-	-	0.014
		LTCR	8E-8	-	-	-	1.1E-6
	Si	EC	3.274	0.680	0.476	0.798	0.474
		LTCR	**4E-3**	**8.4E-3**	5.9E-4	**9.9E-3**	5.9E-4
	Ni	EC	0.011	0.271	2.7E-3	4.5E-3	0.059
		LTCR	1.8E-6	5.2E-7	2.6E-7	5.2E-7	9.3E-6
PM 2.5	Cd	EC	0.01	0.004	0.01	8E-5	5E-3
		LTCR	7.2E-5	7.2E-6	1.8E-5	1.4E-7	9.0E-6
	Cr	EC	3E-3	6E-4	-	-	0.009
		LTCR	2.5E-4	5E-5	-	-	**7.5E-3**
	Pb	EC	9E-4	-	0.003	-	0.146
		LTCR	7.2E-8	-	2.4E-7	-	1.1E-5
	Si	EC	-	0.378	0.416	0.568	0.578
		LTCR	-	4.6E-4	5.2E-4	**7.0E-3**	**7.2E-3**
	Ni	EC	0.011	2.7E-3	1.8E-3	5.3E-3	0.132
		LTCR	1.8E-6	2.6E-7	1.3E-7	7.8E-7	2E-5

Table 3.3(b): Exposure concentration of other elements in PM2.5 and PM10

	Elements	EC	A	B	C	D	E
PM 10	Ba	EC	0.15	0.439	0.05	0.06	-
	Cu	EC	0.018	0.007	0.004	0.009	0.009
	Mg	EC	4.74	4.98	4.27	4.98	3.39
	Mn	EC	0.33	0.162	0.016	0.509	0.18
	Fe	EC	1.74	1.59	0.27	1.67	0.67
	Zn	EC	0.26	0.11	0.14	0.30	0.38
	Ag	EC	0.11	0.009	0.001	0.009	0.001
	Sr	EC	0.76	0.47	0.38	0.92	0.21
PM2.5	Ba	EC	0.11	0.07	0.04	0.10	1.23
	Cu	EC	0.013	0.007	0.03	0.007	0.006
	Mg	EC	6.09	2.80	2.41	6.16	2.59
	Mn	EC	0.26	0.07	0.053	0.017	0.06
	Fe	EC	1.12	0.55	0.58	0.22	0.52
	Zn	EC	0.14	0.09	0.41	0.20	0.30
	Ag	EC	0.01	0.002	0.002	0.007	0.006
	Sr	EC	-	0.18	0.13	1.27	0.16

Table 3.1: Elemental Composition of PM 2.5 and PM10 in 5 workshops (values in red shows surpassed values OELS)

Parameters (ug/m^3)	**Cd**	**Cr**	**Pb**	**Si**	**Ba**	**Cu**	**Mg**	**Mn**	**Fe**	**Zn**	**Ni**	**Sr**	**Ag**
OELs	2.5	500	50	50	500	1000	10000	1000	5000	1000	15	5000	10
PM 10													
A	99±45	0.4±0.8	1.1±0.9	1451±132	113±63	13.5±3.5	3558±353	253±56	1312±299	202±54	5.4±1.3	573±206	85.6±3.7
B	2.4±1.1	0.2±0.04	-	303±32	85.6±48	5.4±1.5	3740±372	121±27	1195±273	83.4±22	1.6±29	354±127	7.25±3.2
C	1.35±0.6	-	-	213±52	39.8±22	3.7±0.9	3208±319	12±2.8	208±47.6	110±29	1.2±0.3	284±101	1.2±0.5
D	0.22±0.2	-	-	354±87	49±27	7.3±1.9	3739±371	382±86	1255±287	227±60	1.7±0.5	692±248	6.8±3
E	0.67±0.3	6.1±1.3	10±4.1	212±52	-	6.9±1.8	2544±250	135±31	508±115	291±77	27±6.2	157±56	1.4±0.6
Anova (p value)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
PM 2.5													
A	36±13	2.6±0.5	0.7±0.1	-	87.4±38	9.9±2.5	4571±450	195±44	840±190	107±27	5.4±1.3	-	13±0.6
B	3.5±1.2	0.5±0.01	-	168.5±12	53.1±22	5.4±1.3	2102±208	52.5±11	413±92	73±18	1.2±0.3	137±48	1.97±0.2
C	12.2±5.2	-	2.9±1.1	186±45	33.4±18	26±6.5	1810±181	40±9.5	436±98	310±81	0.4±0.2	94.6±32	1.6±0.7
D	0.06±0.1	-	-	253±61	81±44	5.7±1.7	4627±451	13±2.1	169±39	157±42	2.5±0.6	958±35	5.8±2.5
E	4.35±1.9	7.1±1.3	110±21	258±65	924±515	5±1.2	1946±192	47±99	390±88	232±63	60±14	118±42	4.8±2.1
Anova (p value)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 3.4(a): Pulmonary non-cancerous risk and EDI estimated for elements in PM10
Bold red values represent exceeding HQ >1

	Elements		**A**	**B**	**C**	**D**	**E**
PM 10	Cd	EDI	1.7E-4	4.1E-6	2.3E-6	3.8E-7	1.1E-6
		HQ	**17**	0.41	0.23	0.04	0.11
	Cr	EDI	3.2E-7	3.8E-7	-	-	4.9E-6
		HQ	0.01	0.01	-	-	0.2
	Pb	EDI	3.5E-6	-	-	-	3.4E-5
		HQ	0.09	-	-	-	**1**
	Si	EDI	1.4E-3	2.8E-4	1.9E-4	3.3E-4	1.9E-4
		HQ	0.4	0.08	0.06	0.11	0.06
	Ba	EDI	2.4E-4	1.8E-4	8.5E-5	1E-4	-
		HQ	**16.7**	**12.5**	**5.9**	**6.9**	-
	Cu	EDI	9.1E-3	3.8E-3	2.3E-3	4.9E-3	4.6E-3
		HQ	0.17	0.06	0.2	0.4	0.1
	Ni	EDI	4.9E-6	1.5E-6	1.1E-5	3.4E-6	1.5E-6
		HQ	0.23	0.71	0.52	0.18	0.72
	Mn	EDI	2.1E-4	1E-5	1.1E-4	3.4E-5	1E-5
		HQ	**14.7**	0.7	0.69	**22.7**	**7.7**
	Fe	EDI	1.1E-3	1.0E-3	1.8E-4	1E-3	4.4E-4
		HQ	**5.0**	**4.5**	0.8	**4.5**	**2.0**
	Zn	EDI	2E-4	8.5E-5	0.295	0.608	0.78
		HQ	0.7	0.4	**1.0**	**2.0**	**2.6**

Table 3.4(b): Pulmonary non-cancerous risk and EDI estimated for elements in PM2.5
Bold values represent exceeding HQ >1

	Elements		**A**	**B**	**C**	**D**	**E**
PM 2.5	Cd	EDI	6.3E-5	6.5E-6	2.1E-5	1.1E-7	7.6E-5
		HQ	**6.3**	0.6	**2.1**	0.01	0.76
	Cr	EDI	2.1E-6	1.3E-5	-	-	3.9E-3
		HQ	0.07	0.45	-	-	0.2
	Pb	EDI	2.6E-6	-	9.5E-6	-	3.5E-4
		HQ	0.07	-	0.27	-	0.09
	Si	EDI	-	1.5E-4	1.7E-4	2.3E-4	2.4E-4
		HQ	-	0.05	0.05	0.07	0.08
	Ba	EDI	1.8E-4	1.1E-4	7.1E-5	1.7E-4	1.9E-3
		HQ	**12.5**	**7.7**	**4.9**	**11.8**	**133**
	Cu	EDI	9.9E-6	5.3E-6	2.5E-5	5.7E-6	4.9E-6
		HQ	0.07	0.12	0.05	0.87	0.12
	Ni	EDI	3.3E-6	1.1E-6	3.2E-7	1.5E-6	2.4E-5
		HQ	0.22	0.52	0.18	0.71	0.14
	Mn	EDI	1.6E-5	4.6E-6	3.4E-5	1.1E-6	4.0E-5

		HQ	**1.12**	**3.15**	**2.4**	0.76	**2.80**
	Fe	EDI	7.3E-4	3.6E-4	3.7E-4	1.4E-4	3.3E-4
		HQ	**3.32**	**1.64**	**1.68**	0.63	**1.5**
	Zn	EDI	1.1E-4	7.5E-5	0.829	0.42	0.62
		HQ	0.37	0.24	**2.7**	**1.4**	**2.1**

Table 3.5(a) Measure of lung function of jewelry workers engaged in workshops A&B

Parameters	A (I) (n=20) Mean± St. dev			B (II) (n=20) Mean± St. dev		
	Pre	Post	P Value	Pre	Post	P value
FEV1	2.19±0.54	2.33±0.64	0.0004	1.86±0.39	2.13±0.51	0.0002
FVC	1.97±0.47	2.34±0.97	0.0002	1.85±0.38	2.36±0.79	0.0003
PEF	2.01±0.56	2.54±0.96	0.0003	3.31±1.15	4.19±1.39	0.0005

Table 3.5(b) Measure of lung function of jewelry workers engaged in workshops (SBRWP)

Parameters	C (I) (n=20) Mean± St. dev			D (II) (n=20) Mean± St. dev			E (III) (n=20) Mean± St. dev		
	Pre-value	Post-value	P value	Pre-value	Post-value	P value	Pre-value	Post-value	P value
FEV1	1.51±0.42	1.84±0.53	0.0002	1.75±0.59	2.17±0.95	0.0005	1.87±0.69	2.11±0.30	0.0002
FVC	1.72±0.54	2.18±0.81	0.0003	1.82±0.65	2.03±0.83	0.0002	1.75±0.57	1.97±0.79	0.0003
PEF	3.78±1.26	4.62±1.83	0.0004	2.89±1.17	3.81±1.21	0.0004	5.52±2.15	6.12±3.10	0.0005

Table 3.5 (c): Comparison of lung function test among smokers and nonsmokers.

	Workers=100			**Workers n=100**		
Variables	S n=32 Pre-B	S n=32 Post-B	t Statistic	NS n=68 Pre-B	NS n=68 Post-B	t Statistic
FEV1	1.793± 0.791	2.01± 0.61	t=2.53 p=0.016	2.265± 0.626	2.342± 0.609	t=3.17 p=0.002
PEF	3.035± 1.576	3.666± 1.552	t=2.19 p=0.035	3.870± 1.530	4.113± 1.545	t=2.51 p=0.014
FVC	2.339± 0.759	2.328± 0.650	t=2.53 p=0.016	2.580± 0.713	2.465± 0.617	t=1.83 p=0.07
FEV1/FVC	0.842± 0.169	1.295± 1.882	t=2.06 p=0.046	0.886± 0.115	0.957± 0.161	t=1.83 p=0.07

S Smokers and NS* Non-smokers*

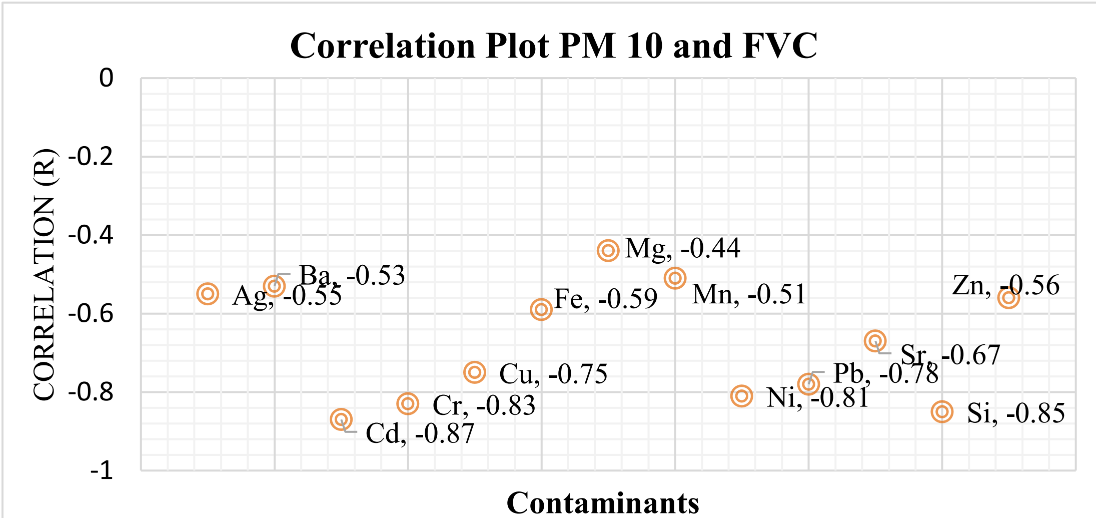

Figure 6(a): Correlation plot between PM 10 and FVC

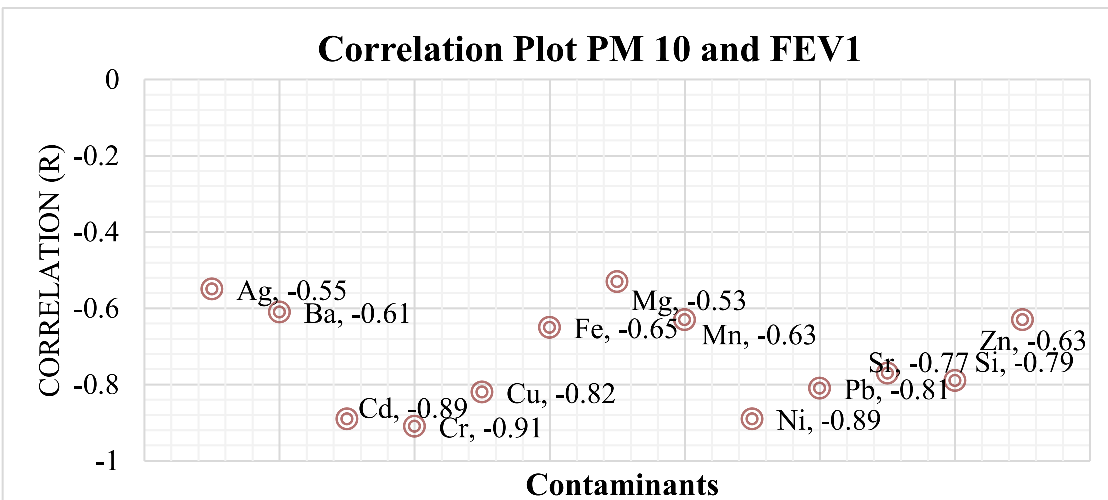

Figure 6(b): Correlation plot between PM 10 and FEV1

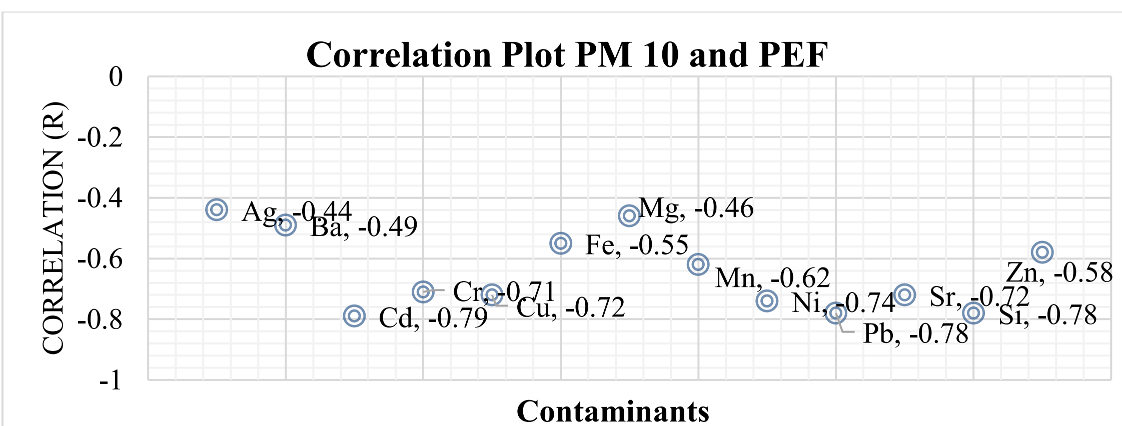

Figure 6(c): Correlation plot between PM 10 and PEF

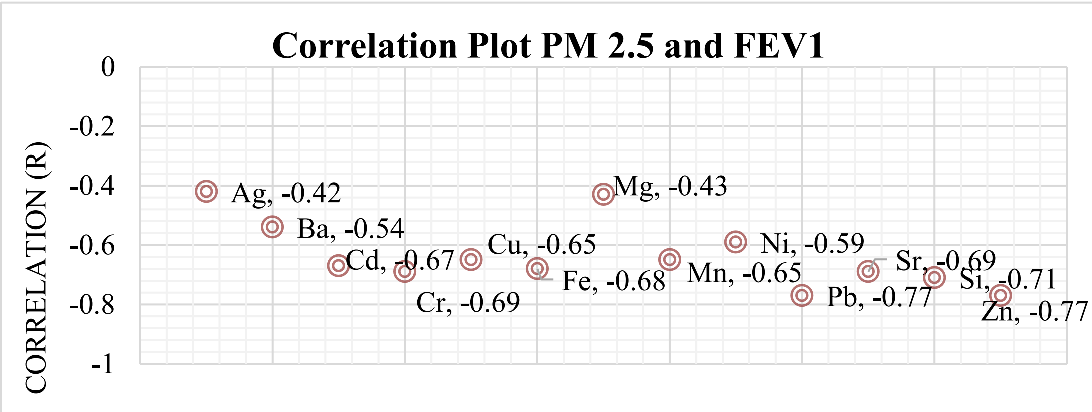

Figure 7(a): Correlation plot between PM 2.5 and FVC

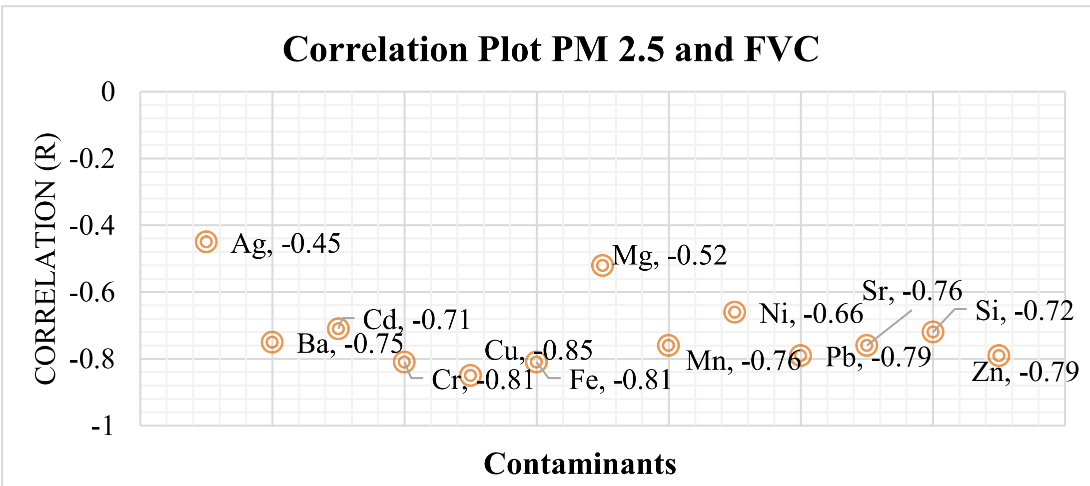

Figure 7(b): Correlation plot between PM 2.5 and FEV1

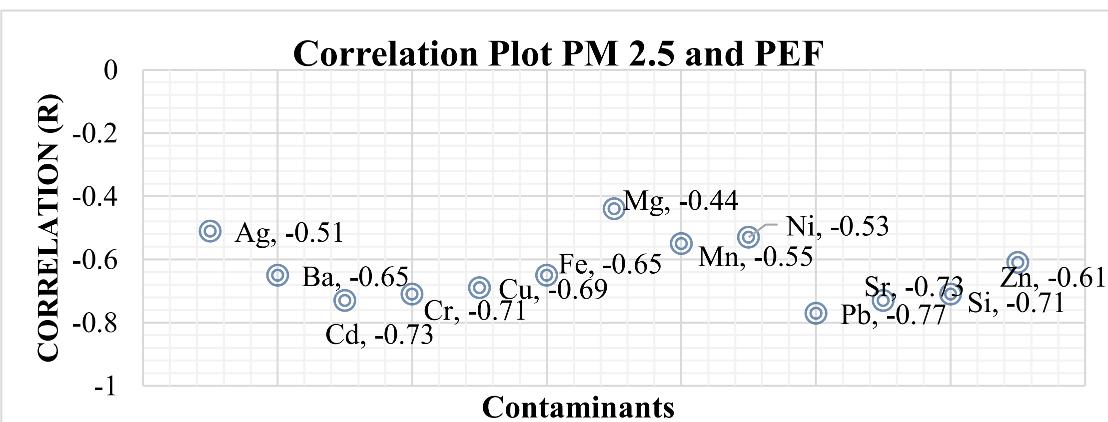

Figure 7(c): Correlation plot between PM 2.5 and PEF