

**PARTICULATE MATTER EXPOSURE AND LUNG  
FUNCTION ASSESSMENT OF DAIRY FARM AND  
CATTLE FEED MANUFACTURING WORKFORCE IN  
SAHIWAL, PAKISTAN**



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**Department of Earth and Environmental Sciences**  
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## ABSTRACT

The air quality within livestock facilities is adversely affected by elevated levels of dust, particulate matter, and microorganisms, posing significant health risks to both animals and farm workers. Studies show that exposure to bioaerosols, particulate matter (PM), and harmful gases raises the risk of respiratory diseases like asthma and chronic obstructive pulmonary disease COPD in individuals in these environments. The present study was carried out to investigate the pulmonic health effect of air borne particulate matter in Dairy Farm and Animal feed Manufacturing industry in Sahiwal, Pakistan. The air samples were collected using Potable low-volume Air sampler. The selected particulate matter includes PM<sub>2.5</sub> and PM<sub>10</sub>. The highest PM concentrations were recorded in the Feed Manufacturing department (PM<sub>2.5</sub> 149 ± 27 µg/m<sup>3</sup>; PM<sub>10</sub> 191 ± 23 µg/m<sup>3</sup>), while the lowest concentrations were observed in the Goat Pen (PM<sub>2.5</sub> 27 ± 9 µg/m<sup>3</sup>) and Feed Dispatch (PM<sub>10</sub> 53 ± 22 µg/m<sup>3</sup>) departments. PM concentrations in all departments exceeded the threshold limit values (TLV) of 5 µg/m<sup>3</sup> for PM<sub>2.5</sub> and 15 µg/m<sup>3</sup> for PM<sub>10</sub>. Heavy Metals (Pb, Cd, Zn, and Cu) in collected Particulate Matter samples were analyzed through Atomic Absorption Spectrophotometer. The maximum concentrations detected were Pb 2.90 ppm, Cu 0.83 ppm, Zn 4.42 ppm, and Cd 0.016 ppm, all of which remained below the Occupational Exposure Limits (OELs) of Cu 200 ppm, Pb 50 ppm, Zn 2000 ppm, and Cd 2 ppm. For the evaluation of lung's function test, among workers in dairy farm and Animal feed manufacturing industry, a digital handheld spirometer was used to conduct the test in 70 subject group and 30 control group and demographic data was also collected through questionnaire. Smokers are present in both the groups, but COPD patients were identified only in subject group where 21% of workers exhibited obstructive lung disease, 13% restrictive lung disease, 16% mixed lung disease, and 50% normal lung function, whereas the control group showed 20% obstructive lung disease, 10% restrictive lung disease, no mixed lung disease, and 70% normal lung function. The lung function test results were based on FEV1, FVC, FVC/FEV1, PEF. The maximum values observed were in sites of Cow Byre>Goat Pen>Feed Manufacturing sites. Obstructive lung diseases were prevailing in both the group. The mix-lung disease was only present in subject group. No HQ value exceeds the permissible limit set by US EPA. The Pearson correlation was conducted between heavy metals concentration and human lung function. A strong negative correlation occurred between zinc and FVC. Correlation analysis of heavy

metals vs PM concentration indicated that Pb and Zn were moderately associated with PM<sub>2.5</sub> concentrations, whereas PM 10 showed weak relationship with most heavy metals. A significant inverse correlation was observed between Pb and Zn in PM<sub>10</sub> samples, indicating distinct emission sources.

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## ABBREVIATIONS

|                  |                                                          |
|------------------|----------------------------------------------------------|
| AAS              | Atomic Absorption Spectrophotometry                      |
| ACGIH            | American Conference of Governmental Industrial Hygienist |
| As               | Arsenic                                                  |
| AV               | Average                                                  |
| BMI              | Body Mass Index                                          |
| BDL              | Below Detection Limit                                    |
| Cd               | Cadmium                                                  |
| CH <sub>4</sub>  | Methane                                                  |
| CO <sub>2</sub>  | Carbon Dioxide                                           |
| COPD             | Chronic Obstructive Pulmonary Disease                    |
| CR               | Cancerous Risk                                           |
| Cu               | Copper                                                   |
| EC               | Exposure Concentration                                   |
| EDI              | Estimated Daily Intake                                   |
| FEV1             | Force Expiratory volume in 1 second                      |
| FVC              | Force Vital Capacity                                     |
| FEF              | Force Expiratory flow                                    |
| GDP              | Gross domestic product                                   |
| HI               | Hazard Index                                             |
| HQ               | Hazard Quotient                                          |
| H <sub>2</sub> S | Hydrogen sulfide                                         |
| LTCR             | Lifetime Cancer Risk                                     |
| ME               | Milk Extraction                                          |
| NH <sub>3</sub>  | Ammonia                                                  |
| NIOSH            | National institute of Occupational Safety and Health     |
| Ni               | Nickle                                                   |
| OEL              | Occupational Exposure Limits                             |
| Pb               | Lead                                                     |
| PEF              | Peak Expiratory flow                                     |

|        |                                              |
|--------|----------------------------------------------|
| PM     | Particulate matter                           |
| PPE    | Personal Protective Equipment                |
| FM     | Feed Manufacturing site                      |
| SD     | Standard Deviation                           |
| TLV    | Threshold limit value                        |
| TWA    | Time-Weighted Average                        |
| US EPA | United State Environmental Protection Agency |
| VOC    | Volatile Organic Compound                    |
| WHO    | World health Organization                    |
| Zn     | Zinc                                         |

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## CHAPTER 1

### INTRODUCTION:

#### **1.1 Dairy farming and Animal feed Manufacturing Industry in Pakistan:**

Pakistan's economy is largely supported by the cattle industry, which also makes a significant contribution to rural livelihoods and agricultural output. Pakistan is one of the top milk-producing nations in the world; the cattle industry accounts for over 63% of the country's agricultural GDP (Gross domestic product) and over 15% of its GDP (Government of Pakistan, 2024). In recent years, there has been a progressive shift toward commercial and semi-commercial dairy farming systems, although smallholder systems still account for the bulk of dairy farming, with most farmers owning a modest number of cows. A vital part of Pakistan's economy, the livestock industry greatly boosts agricultural production and rural lifestyles (Sarwar, et al., 2002)

Although there has been a slow transition in recent years toward commercialized dairy production, smallholder farming methods still provide the bulk of milk (Abbas, et al., 2024). Punjab is the leading province in Pakistan when it comes to livestock production; it produces the most milk and has the greatest number of dairy animals. In Punjab, dairy production is usually included into mixed crop-livestock systems, where livestock recycles manure to improve soil fertility and crop leftovers are utilized as animal feed (Ali et al., 2024). Particularly in rural regions, this integration promotes sustainable farming practices and food security.

Sahiwal, a major dairy-producing area in Punjab, is well-known worldwide for its native Sahiwal cow breed. One of the most significant dairy breeds in South Asia, Sahiwal cattle are prized for their excellent milk output, heat tolerance, and disease resistance. They are also well suited to tropical environments (Sher et al., 2025). Because of government breeding initiatives, research facilities, and growing commercial farms, the district has emerged as a hub for dairy development, all of which help to enhance genetics and boost production (Rehman and Mumntaz 2023).

Due to the growing need for increased livestock production, Pakistan's animal feed manufacturing sector has expanded dramatically in tandem with dairy farming. To improve milk production and animal health, balanced and complex feeds that include grains, oilseed meals, vitamins, and minerals are crucial. A greater reliance on commercially prepared feed has resulted from the development of the dairy and poultry industries (Tariq, 2021). Due to the abundance of raw materials like maize and wheat byproducts as well as well-established agro-industrial infrastructure, Punjab, especially areas like Sahiwal, functions as a significant hub for feed manufacturing.

Despite this expansion, the dairy farming and feed production industries still confront a number of difficulties, such as inconsistent feed quality, lax enforcement of regulations, and dust and bioaerosol exposure at work. These exposures are becoming more widely acknowledged as significant risk factors influencing the health of workers in livestock-related businesses (Donham et al., 2007).

## **1.2 Air quality of dairy farms:**

The air quality within livestock facilities is adversely affected by elevated levels of dust, particulate matter, and microorganisms, posing significant health risks to both animals and farm workers (May et al., 2012). Studies indicate that exposure to bioaerosols, particulate matter (PM), and harmful gases such as methane (CH<sub>4</sub>), ammonia (NH<sub>3</sub>), hydrogen sulfide (H<sub>2</sub>S), and carbon dioxide (CO<sub>2</sub>) increases the likelihood of respiratory diseases, including asthma and chronic obstructive pulmonary disease (COPD), among individuals working in or living near these environments (Guidry et al., 2017, Schultz et al 2019). This heightened risk was confirmed through multiple research findings citing increased vulnerability to respiratory ailments for caretakers and livestock alike. In Pakistan, where major cities consistently rank low in air quality assessments, the situation is exacerbated by recurring annual smog episodes, particularly in regions like Central Punjab, leading to severe implications for both human and animal populations due to the universal nature of inhalation (Jamil et al., 2023).

Recent research highlights a clear connection between deteriorating air quality and the rise in respiratory illnesses, alongside increased mortality rates among affected populations. Notably, as of 2019, an astounding 99% of the global population was

exposed to air that did not conform to the World Health Organization's (WHO) air quality guidelines. The consequences are dire, with 91% of the 4.2 million premature deaths attributed to poor air quality in 2016 occurring within low and middle-income countries, including regions of South East Asia and the West-Pacific. Thus, the critical need for improved air quality standards and practices in livestock facilities is underscored, both for the health of farm workers and for the welfare of the animals they care for (Baccarelli et al., 2011; WHO Fact Sheet, 2022).

Livestock farms are not frequently observed in this environment, despite several studies documenting the air quality in metropolitan areas. There are relatively few studies worldwide, including those by Szulc et al. (2020) and Guo et al. (2022), none on air pollution monitoring, especially particulate matter from cow ranches in Pakistan. Nonetheless, these studies have been documented for chicken farms both domestically and internationally (Yasmeen et al., 2020b).

### **1.3 Occupational risks in dairy farm workers:**

Although dairy farming has many advantages, there are a number of occupational risks that dairy farm workers must deal with (Barrett et al., 2021). There is strong proof that dairy farming affects the respiratory, gastrointestinal, skin, and brain systems (Leah Grout et al., 2020). Additionally, a number of international studies have documented issues among dairy farm workers, including hypersensitivity, pneumonitis, rhinitis, conjunctivitis, asthma, and dermatitis. These allergic reactions are common among workers who have intimate contact with animals (Pilarczyk, 2022). Workers on dairy farms are particularly vulnerable to respiratory health risks due to exposure to allergens, dust, and toxins (Sigsgaard et al., 2020).

Research over the last 20 years has clearly linked respiratory diseases to the job, making them a widespread and avoidable risk. Research from throughout the world indicates that musculoskeletal, bone, and joint problems are widespread among dairy farm workers, mainly affecting the hands, feet, shoulders, elbows, and lower back (Serya et al., 2023). Workers on dairy farms may come into contact with dangerous chemicals and animals directly or indirectly. Because of their demanding workload and dangerous working circumstances, dairy farm workers frequently suffer accidents and injuries (Stoleski et al., 2019).

The respiratory health of dairy farmworkers has gained greater attention in the last decade, after being shown to have higher-than-expected proportionate mortality ratios for respiratory diseases. Dairy farmworkers are exposed to a complex range of respiratory hazards including inorganic and organic dust, allergens, fungi, disinfectants, smog-forming volatile organic compounds, and gases emitted by cows and their sites, such as hydrogen sulfide, methane, and ammonia. Of these, organic dust is considered the most important clinically due to its pro-inflammatory properties (Martenies et al., 2020) (Nonnenmann, 2017).

Organic dust is a mixture of air-suspended particles derived from plants, animals, and microbes. On dairy farms, faecal matter, urine, animal feed, animal dander, and hair are common sources of organic dust. Inhaled dust is treated as foreign material and can induce either inflammation or toxic reactions resulting in a range of adverse respiratory health effects including nonallergic flu-like illness, organic dust toxic syndrome, asthma, irreversible chronic bronchitis, and reduced lung functions, with a variety of symptoms, such as nose and throat irritation, chest tightness, cough, shortness of breath, and wheezing (Mitchell, 2015) (Martenies et al., 2020).

#### **1.4 Heavy Metals in Dairy Farm and Animal feed industry:**

Airborne particulate matter (PM), particularly fine particles like PM<sub>10</sub> and PM<sub>2.5</sub>, poses significant environmental and occupational risks within livestock production systems, including dairy farms and animal feed industries. These particulate matters consist of organic materials, such as feed dust and bioaerosols, and serve as carriers for toxic heavy metals—lead (Pb), cadmium (Cd), arsenic (As), nickel (Ni), zinc (Zn), and copper (Cu)—that can adversely affect human health. In dairy farm settings, PM levels are affected by both internal activities and external atmospheric pollution. A recent study by Zhang et al. (2022) revealed a strong correlation ( $R = 0.95$ ) between indoor and outdoor PM levels, underscoring the influence of ambient pollution on indoor air quality, with significant detection of heavy metals in environmental matrices. Additionally, environments related to livestock and feed are noted for high dust emissions that occur during feed handling, grinding, and animal movements, which facilitate the adsorption and mobility of these heavy metals (Cambra-López et al., 2010).

The sources of these metals are diverse, stemming from mineral feed additives, contaminated raw materials, wear and tear of machinery, soil resuspension, and emissions from combustion processes (Morawska et al., 2001). The small size and large surface area of fine particles allow them to penetrate deep into the respiratory tract, reaching alveolar regions where they can be systemically absorbed.

Occupational exposure to this metal-laden PM is associated with various adverse health outcomes, including respiratory diseases like asthma, chronic bronchitis, obstructive lung disorders, and systemic effects such as neurotoxicity, nephrotoxicity, and heightened cardiovascular risk (Cambra-López et al., 2010). Furthermore, concerns regarding food safety emerge from the potential transfer of inhaled contaminants into animal-derived products, such as milk, thus highlighting an additional human exposure pathway (Zhang et al., 2023).

#### **1.4.1. Lead**

Lead (Pb) is a persistent environmental pollutant that is frequently found in livestock production systems, such as dairy farms and settings that manufacture animal feed, where it poses serious threats to human health and occupational safety. The main sources of lead contamination in the animal feed industry include contaminated raw materials, premixes, binders, and mineral supplements that can introduce heavy metals during feed formulation. Lead was found in a variety of feed ingredients, according to large-scale monitoring research by Adamse et al. (2017). It was noted that clay-based binders and mineral feed additives frequently had high lead contents, with some samples very close to legal limits. Lead was found to be a significant pollutant, especially in mineral ingredients, in a global evaluation of feedstuffs conducted between 2009 and 2016, which showed that up to 20% of feed samples exceeded allowable heavy metal levels (Elliot et al., 2017).

Lead contamination in dairy farm environments is mostly linked to environmental deposition from industrial and human activities, such as car emissions, battery recycling, machinery wear, and past use of leaded fuels. Lead-containing dust can enter the cattle feeding cycle by settling on soil and fodder crops. Research shows that the deposition of lead-contaminated soil and airborne particles is frequently associated with fodder contamination, underscoring the relevance of environmental pollution in

agricultural exposure routes. The danger in dairy systems is further increased by the possibility that cattle may be exposed by consuming tainted feed, water, or grazing on contaminated terrain (Shehzad et al., 2025).

Workers may inhale lead-bound dust particles that are mobilized by airborne particulate matter produced during feed processing (grinding, mixing, transport) and regular agricultural operations. Because of their huge surface area and significant penetration into the respiratory system, fine particles (PM<sub>2.5</sub> and PM<sub>10</sub>) increase the bioavailability of lead. Lead is a non-essential hazardous element with no biological role, and its presence in cattle settings is deemed completely unwanted, according to recent evaluations (Hejna et al., 2018).

Lead exposure at work has serious health effects, especially for employees in dusty settings like dairy farms and feed mills. Lead is a well-known neurotoxic that damages the central nervous system, resulting in neurological dysfunction and cognitive decline. Chronic exposure is also linked to respiratory issues, such as impaired lung function and inflammation of the airways, particularly when particulate matter is breathed. Lead is a multi-system toxicant since it also causes haematological illnesses (such as anemia), renal damage, hypertension, and cardiovascular ailments. Concerns regarding indirect human exposure through the food chain are raised by recent findings that lead exposure in livestock systems can lead to bioaccumulation in animal tissues and products (Kim et al., 2018).

#### **1.4.2. Cadmium**

Dairy farms and animal feed manufacturing facilities are among the livestock production areas where cadmium (Cd), a very hazardous and unnecessary heavy metal, is increasingly found. The main sources of cadmium contamination in the animal feed industry include contaminated raw materials such grains and oilseed meals, premixes, and mineral supplements (particularly phosphate-based additives). According to thorough monitoring research conducted by Adamse et al. (2017), cadmium is often found in feed materials throughout Europe, with mineral feed additives having especially high quantities because to geogenic pollution of phosphate sources.

In a similar way, Kim et al. (2018) demonstrated that contamination may happen at any point in the feed supply chain by confirming the presence of cadmium in commercial animal diets. Cadmium accumulates in fodder crops and then enters the

cattle system in dairy farm environments due to polluted soil, irrigation water, fertilizers (particularly phosphate fertilizers), and atmospheric deposition from industrial and traffic emissions. Cadmium exposure and transportation in dairy and feed settings are significantly influenced by airborne particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>). Cadmium-bound particles may be present in dust produced during feed production (grinding, mixing, and handling) and regular farm operations (moving animals, managing manure, and disturbing bedding).

Hejna et al. (2018) state that because of their high surface reactivity, heavy metals like cadmium can attach to tiny particulate matter, increasing their mobility and inhalation potential. Cadmium may enter the systemic circulation after fine particles are inhaled and settle in alveolar regions of the respiratory tract. Because dust concentrations are frequently higher in enclosed or poorly ventilated livestock and feed production facilities, this exposure route is especially important for employees.

Because of its high toxicity, lengthy biological half-life, and bioaccumulative nature, cadmium poses significant health concerns to workers who are exposed to it over an extended period of time. Cadmium mostly affects the kidneys and lungs, resulting in tubular damage, reduced filtration capacity, and renal failure. Cadmium is categorized as a human carcinogen (Group 1) because of its connection to lung cancer, and inhalation exposure has been closely linked to respiratory symptoms such chronic bronchitis, emphysema, and reduced lung function (Genchi et al., 2020).

#### **1.4.3. Zinc**

Although zinc (Zn) is a necessary trace metal that is frequently utilized in the production of livestock, high quantities in dairy farms and animal feed settings can cause environmental pollution and increase the danger of occupational exposure. Zinc is frequently given to animal feed as a nutritional supplement in the form of zinc oxide or zinc sulfate to support growth, immunological response, and general animal health. Studies have revealed that high zinc levels in feed dust and ambient matrices are mostly caused by feed additives and mineral premixes, notwithstanding zinc's nutritional significance. Zinc is often found in feed materials, frequently at higher quantities than other heavy metals since it is purposefully added to feed formulations, according to monitoring research by Adamse et al. (2017).

In a similar study, Hejna et al. (2018) noted that overuse of zinc in animal feed can lead to its buildup in soil, dung, and adjacent habitats. Zinc contamination in feed and farm dust can also result from galvanized equipment, fertilizers, and atmospheric deposition in dairy farms.

In feed mills and dairy farms, airborne particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) is a crucial medium for zinc transportation and dispersion. Particularly in confined or poorly ventilated environments, activities including feed grinding, mixing, transportation, and animal movement produce dust particles enhanced with zinc. Because of its physicochemical characteristics and capacity to bond with both organic and inorganic dust constituents, zinc has a great attraction for particulate matter.

Zinc is a necessary micronutrient, but too much of it can have negative health effects. Respiratory irritation, coughing, chest tightness, and metal fume fever—a flu-like illness frequently reported in work environments—have all been linked to inhaling zinc-containing particulate matter (Plum et al., 2010). Prolonged exposure to high zinc levels can also cause immunological dysfunction and metabolic abnormalities by upsetting the equilibrium of other vital elements like iron and copper. Concerns regarding indirect human exposure through food products are also raised by high ambient zinc levels, which can lead to ecotoxicological consequences and bioaccumulation in livestock systems (Genchi et al., 2020).

#### **1.4.4. Copper**

Although copper (Cu) is a necessary trace metal that is frequently used in livestock production, high concentrations in dairy farm and animal feed settings might increase the danger of occupational exposure and environmental pollution. Copper is frequently added to animal feed as copper sulfate or other inorganic salts to improve animal development and assist metabolic processes. Despite its nutritional advantages, research shows that the main causes of high copper levels in feed and related dust emissions are feed additives and mineral premixes. According to a thorough analysis by (Shehzad et al., 2025), copper supplementation in animal diets frequently surpasses physiological needs, leading to substantial excretion and environmental loading. Fertilizers, fungicides, water supply systems, and mechanical equipment wear are other sources of copper in dairy farm settings, all of which add to the metal's presence in farm dust and feed.

In both the dairy and feed industries, airborne particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) is a major factor in the transportation and exposure of copper. Copper bonded to tiny particles is frequently found in dust produced during feed processing operations (such as grinding, mixing, and transport) and agricultural activities (such as animal movement and manure management). Heavy metals like copper have a great affinity for particulate matter, especially in tiny fractions, which increases their potential for inhalation and absorption (Cambra-López et al., 2010). Because of this, workers in enclosed livestock and feed production settings are more likely to be exposed by breathing in dust that contains metals. These tiny particles can have both local and systemic harmful effects after being breathed. They can also settle in the respiratory system and perhaps reach the bloodstream.

Even though copper is necessary for human health, too much of it can have negative effects on one's health, especially in the workplace. Particularly in cases of long-term exposure, inhaling copper-containing particulate matter has been linked to respiratory irritation, airway inflammation, and decreased lung function. According to Jaishankar et al. (2014), high amounts of copper can cause oxidative stress, damage to the liver and kidneys, gastrointestinal problems, and upset the equilibrium of other vital trace elements.

### **1.5 Research gap:**

Despite various research that has examined the impact of dust exposure and general respiratory health hazards among feed mill and dairy farm workers, the majority of them have focused solely on respiratory symptoms or spirometric abnormalities. A few studies have evaluated site-specific particulate matter concentrations (PM<sub>10</sub> and PM<sub>2.5</sub>) and explicitly associated them with lung function results in dairy farm and feed sector workers. Furthermore, most previous research focuses on single-industry comparisons (e.g., feed mills vs. controls, or dairy farms vs. controls), leaving a void in comparative exposure studies across the feed and dairy sectors.

## 1.6 Literature review:

Kimanzi et al. (2022) uses a cross-sectional and case-control design study to evaluate the effects of grain dust exposure on pulmonary function in 355 animal feed mill workers in Kiambu County, Kenya. A Temtop sensor is used to quantify dust exposure ( $PM_{10}$  and  $PM_{2.5}$ ), and 81 employees had spirometry testing done alongside an equal number of matched controls from milk processing facilities. The results indicated minimal usage of engineering controls and inadequate training in dust management. Among exposed workers, lung function measures (FEV1, FVC, FEV1/FVC, and FEF25-75) are considerably lower, and mean  $PM_{10}$  ( $53.72 \mu g/m^3$ ) and  $PM_{2.5}$  ( $36.54 \mu g/m^3$ ) are higher than WHO recommendations. Morning phlegm (13.70%), watery eyes (30.48%), and nasal discomfort (53.77%) are among the most common symptoms. The findings reveal a significant relationship between grain dust exposure and impaired lung function, emphasizing the need for improvements.

The article by Sigaard et al. (2020) examines the data relating to respiratory illnesses associated with intensive livestock husbandry. Animal farming is always linked to an elevated risk of respiratory diseases such as occupational asthma, chronic bronchitis, rhinitis, and COPD—especially in confinement buildings—even though early-life farm exposure may lower the incidence of atopic asthma and rhinitis. These hazards are caused by exposure to endotoxins, irritating gases like ammonia, microbiological debris, organic dust, allergies, and disinfectants. Studies reveal no discernible drop in dust and endotoxin levels over the last 30 years, despite decades of knowledge, suggesting ongoing overexposure. Due to practical and financial limitations in the farming industry, it is still challenging to completely eliminate hazardous exposures, even if preventive actions are crucial.

This descriptive cross-sectional study assessed how industrial workers in Jos South, Nigeria's cereal, oil, and animal feed production industries perceived risk and used personal protective equipment (PPE). A standardized, interviewer-administered questionnaire is used to gather data from the 128 workers who took part. Software

called Epi-Info 3.5.4 is used to examine the data. With a mean age of 31.3 years, the majority of responders (91.4%) are men. While 78.1% of workers had an excellent risk perception (mean score:  $18.0 \pm 3.4$ ) and the majority of workers (99.2%) obtained risk information from media sources, high-risk environmental elements included dust (46.1%), noise (49.2%), chemical exposure (45.3%), and equipment accidents (45.3%). There is a discrepancy between awareness and behavior, though, since 83% of respondents reported using PPE inconsistently (Miner et al., 2016).

The respiratory health of 282 male Egyptian laborer's—141 dairy farmworkers and 141 controls who did not handle livestock—is investigated in Serya, et al. (2023). cross-sectional study. The study discovered that dairy workers had far greater rates of respiratory symptoms, including sore throat, cough, sputum production, and breathing difficulties, based on medical history, clinical examination, and spirometry. Additionally, these workers had higher rates of wheezing, obstructive ventilatory patterns, and bronchitis. The following factors are shown to be independent predictors of impaired pulmonary function: greater age ( $>37$  years), longer smoking history ( $>10$  years), and longer employment duration ( $>4$  years). Large herd dairy farms expose workers to dangerous pulmonary risks even though they are open-air settings, which highlights the necessity of personal protective equipment (PPE), routine lung function testing, and enhanced occupational health regulations.

Work by Baser et al. (2003) determine how common lung function abnormalities and chronic work-related respiratory symptoms are among employees in the animal feed business. A total of 108 unexposed controls and 108 exposed workers (mean age  $32 \pm 7.11$  years) conducted pulmonary function tests (PFTs) and respiratory symptom questionnaires. Using a Casella AFC 123 sampler, airborne respirable dust is also assessed during the course of an 8-hour shift. According to the results, exposed workers had a considerably greater incidence of respiratory symptoms, such as cough (12%), dyspnea (5.6%), and sinusitis (8.3%), as well as irritation symptoms, such as eye pruritus (11.1%), skin lesions (7.4%), and nose symptoms (8.3%), than controls. According to PFT data, exposed workers had substantially worse lung function for FVC, FEV1, PEF, and FEF25–75 (all  $p < 0.0001$ ). The data revealed that the respiratory symptoms and a deterioration in lung function are significantly influenced by exposure to animal feed dust.

Kimanzi, et al. (2022) aimed to evaluate how exposure to grain dust affects the lung function of animal feed mill workers in Kiambu County, Kenya. The study used a case-control study design. A study of 81 animal feed mill workers evaluated their lung function and respiratory symptoms by spirometry and a questionnaire. The matched control group included 81 workers from milk processing industries. Data is processed and analyzed using SPSS. Animal feed mill workers had considerably poorer mean predicted lung function values than control workers across all parameters ( $p < .05$ ). The target group had obstructive lung abnormalities, while the control group had none. The most common symptoms reported by respondents are stuffy, itchy, and runny nose (53.77%), followed by watery and itchy eyes (30.48%), phlegm first thing in the morning during cold times (13.70%), and cough first thing in the morning (12.33%). This study found a link between grain dust exposure and decreased lung function among animal feed mill workers. The report suggests workers get medical tests and follow safety and health rules.

Ishtiaq, et al. (2023) conducted cross-sectional research from November 2022 to February 2023 in the Peshawar and Swat districts of Khyber Pakhtunkhwa, Pakistan, using a self-administered questionnaire to assess the prevalence of health concerns among 206 dairy farm workers. The findings revealed that 63.53% of participants are over 40 years old, 67.48% are illiterate, and 87.86% earned less than PKR 30,000 per month. Most workers (71.36%) had fewer than ten years of dairy farming experience, and nearly half (47.09%) worked more than ten hours each day. Allergies (41.26%), asthma (23.30%), COPD (31.07%), chronic bronchitis (36.89%), and dry cough (52.43%) are among the reported health issues. Other problems included poor sleep (49.03%), nose obstruction (29.61%), ocular discharge (10.68%), bodily pains and backache (41.26%), skin allergies (18.93%), and minor injuries (23.30%). The study highlights the high prevalence of respiratory, musculoskeletal, dermatological, and injury-related health issues in this workforce, underlining the need for focused treatments, enhanced occupational health measures, and increased healthcare access for dairy farm workers.

Manure storage and animal housing contribute to VOC emissions through microbial breakdown of waste (D. Hafner et al., 2013). The feed manufacturing process also generates VOCs through activities like grinding, drying, and oilseed extraction.

Additionally, pollutants are released from on-site fuel combustion, vehicle exhaust, and the evaporation of diesel and gasoline in farm operations (Zhang et al., 2010).

The primary source of heavy metals in the ambient air of dairy farms and feed industries is feed ingredients and feed-processing dust, which releases Pb, Cd, Ni, Zn, and Cu during pelleting and grinding (Waseem et al., 2014), (Sarim et al., 2022). Airborne metal particles are also caused by contaminated soil, fertilizers, and pesticides used in the production of fodder. Other sources include vehicular or machinery emissions, particularly diesel exhaust, and manure dust, which contains metals secreted by animals (Waseem et al., 2014) (Guo et al., 2024).

Emissions of particulate matter (PM) from animal housing facilities are becoming a bigger problem for the environment and public health. In order to evaluate the possible effects on ambient air quality and human health, this study examined the emission rates (ER) and chemical composition of PM<sub>2.1</sub> and PM<sub>12</sub> in a large-scale manure-belt laying hen house in Beijing, China, over the summer, fall, and winter seasons. According to the findings, summertime mean PM<sub>2.5</sub> emission rates were  $9.0 \pm 1.7 \text{ mg hen}^{-1} \text{ day}^{-1}$ , which was significantly higher than autumn ( $2.4 \pm 0.7 \text{ mg hen}^{-1} \text{ day}^{-1}$ ) and winter ( $1.9 \pm 0.7 \text{ mg hen}^{-1} \text{ day}^{-1}$ ). Fall ( $12.8 \pm 1.5 \text{ mg hen}^{-1} \text{ day}^{-1}$ ) and winter ( $10.9 \pm 0.9 \text{ mg hen}^{-1} \text{ day}^{-1}$ ) were the seasons with the highest PM<sub>10</sub> emissions, while summer had the highest at  $30.7 \pm 1.1 \text{ mg}$ . In contrast to less than 1.4% in other seasons, significant concentrations of secondary inorganic aerosols (SIA) were found indoors during the summer, accounting for 11.4% and 9.6% of PM<sub>2.5</sub> and PM<sub>10</sub> mass, respectively. Of the 31 elements found, zinc concentrations in indoor PM<sub>10</sub> (3,403–4,432 ng m<sup>-3</sup>) were 28–71 times greater than those in ambient PM<sub>10</sub>, while arsenic surpassed legal threshold limits. These results demonstrate the need for mitigation techniques to safeguard human health and air quality by showing that poultry housing emits significant levels of PM<sub>2.5</sub> and PM<sub>10</sub> including hazardous metals like zinc and arsenic, with emissions being much higher during the summer (Wang et al., 2023).

The poultry industry in Pakistan has seen substantial growth since the 1960s, yet there is a scarcity of comprehensive data regarding the long-term effects of occupational exposure on the pulmonary health of poultry workers. This study evaluated lung function in 79 poultry workers from intensive farming settings in a warm climate. It employed spirometry tests to measure FVC, FEV<sub>1</sub>, and the FEV<sub>1</sub>/FVC ratio,

and utilized a structured questionnaire to gather demographic information, smoking status, work experience, and respiratory health data. Workers were divided into four categories based on their years of experience. Findings revealed that 86% of participants had normal lung function, while 14% showed mild obstructive impairment, particularly among those with over 11 years of experience. Statistical analyses identified significant associations between lung health and various factors, including work duration, height, and drug use. Regression analyses indicated that spirometric parameters had a stronger predictive value for respiratory symptoms in symptomatic workers. Overall, the study suggests that extended occupational exposure in the poultry industry correlates with decreased lung function and increased respiratory symptoms; however, the majority of workers maintained healthy lung function (Yasmeen, et al., 2019).

Occupational exposure to dust, particularly crystalline silica in marble dust, is associated with an increase in obstructive lung diseases among marble workers in developing countries. This study aimed to compare pulmonary function parameters between 82 marble workers and 82 age-matched healthy individuals in Lahore, Pakistan. Participants were interviewed and assessed using spirometry to evaluate forced vital capacity (FVC%), forced expiratory volume in the first second (FEV1), and the FEV1/FVC ratio. The mean ages of the exposed and non-exposed groups were  $29.92 \pm 6.19$  and  $30.58 \pm 6.37$  years, respectively, with marble workers averaging  $11.92 \pm 5.67$  years of work experience. While demographic differences were statistically insignificant, a significant reduction in lung function parameters was found in marble workers ( $P < 0.001$ ). Notably, 71% exhibited abnormal pulmonary parameters, and 34% had restrictive pulmonary impairment. Workers with over 15 years of service showed a markedly elevated risk of abnormal lung function ( $P < 0.001$ ) (Butt, et al., 2021).

| Study Conducted<br>In                                                                         | Key Findings                                                                                                                           | Similarity with Current<br>Study                                                                                                                        | In-text<br>Citation     |
|-----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| <b>18 controlled<br/>broiler houses,<br/>Raiwind and<br/>Kasur Road,<br/>Lahore, Pakistan</b> | Spirometry assessment of 79 poultry workers showed that <b>86% had normal lung function and 14% had mild obstructive lung disease.</b> | The occurrence of obstructive lung disease is consistent with the present study, although the current study reported a higher prevalence of respiratory | (Yasmeen et al., 2020b) |

|                                                                     |                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                   |                        |
|---------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
|                                                                     |                                                                                                                                                                                                                                                                                                                                                       | impairment among exposed workers.                                                                                                                                                                                                                                                 |                        |
| <b>Eight poultry farms, Lahore and Sheikhpura, Pakistan</b>         | Among 71 poultry workers, <b>65% exhibited restrictive lung disease, 14% obstructive lung disease, and 21% normal lung function.</b>                                                                                                                                                                                                                  | The prevalence of obstructive lung disease is comparable to the current study; however, restrictive lung disease was considerably higher in their study than in the present investigation.                                                                                        | (Hamid et al., 2018)   |
| <b>Ten animal feed processing facilities, Kiambu, Kenya</b>         | Mean PM concentrations were <b>PM<sub>2.5</sub> = 36.5 µg/m<sup>3</sup></b> and <b>PM<sub>10</sub> = 53.7 µg/m<sup>3</sup></b> . Grinding areas had the highest PM levels, while loading and transport areas had comparatively lower concentrations.                                                                                                  | Similar trends of elevated particulate matter were observed in feed manufacturing and feed dispatch areas; however, PM <sub>2.5</sub> and PM <sub>10</sub> concentrations reported in the current study were generally higher.                                                    | (Kimanzi et al., 2022) |
| <b>Large and small ruminant farms, Lahore and Pattoki, Pakistan</b> | Mean PM <sub>2.5</sub> concentrations were <b>224.4 µg/m<sup>3</sup></b> (large farms) and <b>193.7 µg/m<sup>3</sup></b> (small farms), while PM <sub>10</sub> concentrations were <b>577.4 µg/m<sup>3</sup></b> and <b>456.7 µg/m<sup>3</sup></b> , respectively.                                                                                    | The reported particulate matter concentrations were substantially higher than those measured in the present study.                                                                                                                                                                | (Mushtaq et al., 2025) |
| <b>Ten livestock farms, District Kasur and Lahore, Pakistan</b>     | Airborne trace metals followed the order <b>Pb &gt; Zn &gt; Ni</b> , with all mean concentrations below <b>1.5 µg/m<sup>3</sup></b> .                                                                                                                                                                                                                 | Lead concentrations were comparable to those observed in the present study, whereas zinc concentrations were slightly lower than those detected in the current investigation.                                                                                                     | (Jamil et al., 2023)   |
| <b>Animal husbandry farms, Timisoara, Romania</b>                   | Heavy metal abundance in PM <sub>2.5</sub> was <b>Zn &gt; Sr &gt; Mn &gt; Pb &gt; Cr &gt; Cu &gt; As &gt; Cd</b> , while PM <sub>10</sub> showed <b>Zn &gt; Sr &gt; Mn &gt; Pb &gt; Cu &gt; As &gt; Cd</b> . Zn concentrations were considerably higher, Pb exceeded 2.5 ppm in PM <sub>10</sub> , whereas As, Cd, and Cu remained comparatively low. | The current study similarly identified Pb, Zn, Cu, and Cd in particulate matter. However, Zn concentrations reported by Pascu et al. were higher, Pb concentrations were lower, and As, Cd, and Cu concentrations were slightly greater than those observed in the present study. | (Pascu et al., 2024)   |

### **1.7 Research objective:**

- To assess the concentration of PM in the ambient air of cattle feed manufacturing and dairy farm works in Sahiwal.
- To evaluate the lung function of cattle feed manufacturing and dairy farm workers in Sahiwal.
- To estimate the respiratory risks of heavy metals found in PM for exposed workers of Sahiwal.

## CHAPTER 2

### MATERIALS AND METHOD

#### 2.1 Study area:

The study was conducted in a selected dairy farm and animal feed mill located in Sahiwal, Punjab, Latitude 30.5627 and Longitude 73.1685. In the selected industry both the feed production and dairy farm operation is done under one roof. The produced feed is given to farm animals.

The industry is operated 10 hours a day, 6 days a week. The produced milk is sold to large-scale dairy plants to manufacture pasteurized milk and dairy products that are distributed across Pakistan.

Sahiwal district, is famous for its dairy industry and cattle feed production, supporting the high-yielding Sahiwal breed. The region's fertile agricultural base and integrated livestock–feed systems contribute significantly to national milk output (Sardar et al., 2024).

#### 2.2 Study area map:

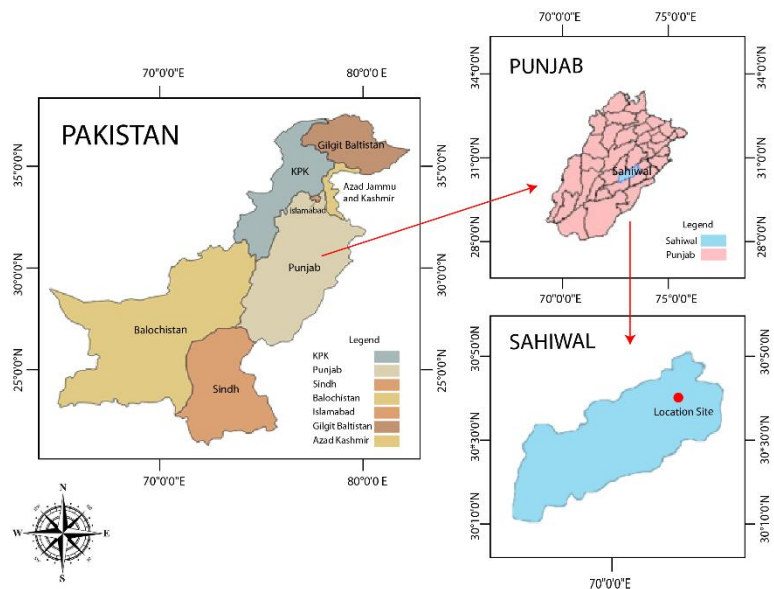
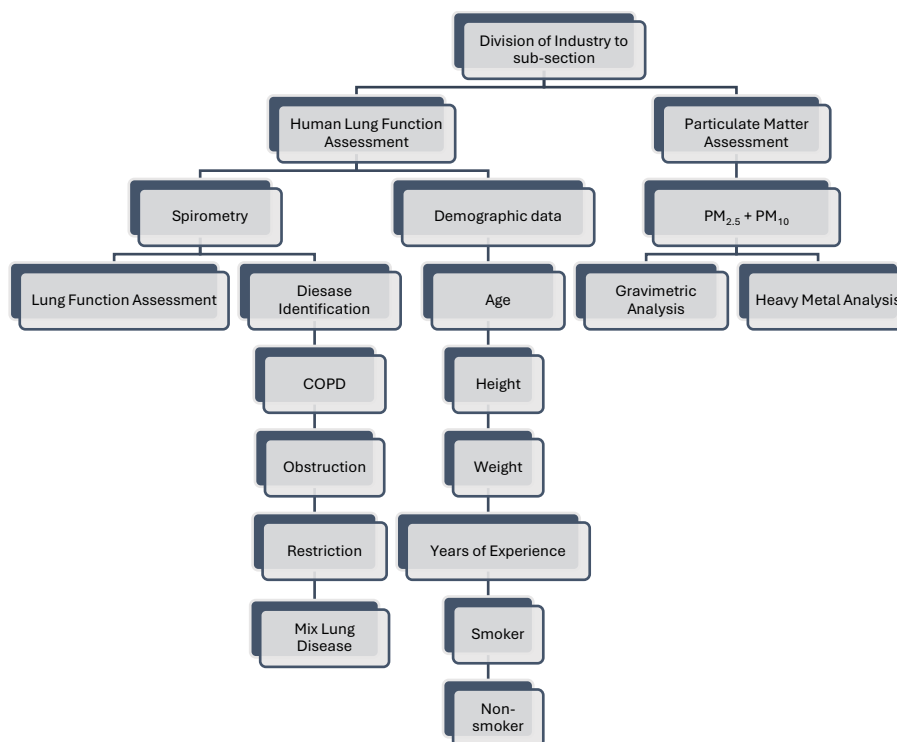


Figure 2. 1 Study area map of Sahiwal showing sample location site

## Flow Chart of Methodology



### 2.3 Human lung function Assessment:

A self-administered questionnaire was utilized for data collection, after comprehensive literature review. Moreover, questions were asked from the dairy farm and feed workers regarding age, height, weight, smokers/nonsmokers, years of working experience, and pulmonary health were taken and response will enter accordingly (Ishtiaq et al., 2023).

The lung function capacity of 70 Farm and feed workers was measured using a spirometer (SP10W, Contec). Along with a spirometry a structured questionnaire will also be administrated to obtain information about demographic background and respiratory symptoms of farm workers. The workers who were directly involved in the care and handling of animals in these intensive facilities are considered. The forced vital capacity (FVC), forced expiratory volume in one second (FEV1) and the FEV1/FVC ratio were considered to identify lung function abnormalities (Serya et al., 2023).

**Control:** 30 males of same age group, but not exposed to cattle feed manufacturing and dairy farming works was analyzed for their lung function for making a comparison of exposed and non-exposed subjects.

#### **Ethical approval:**

Ethical approval was taken from ethical review committee of Bahria University for conducting this research work. Moreover, informed consent was taken from subject before spirometry analysis.

#### **2.3.1 Obstruction and Restriction**

FEV1/FVC <80% but FEV1/FVC >0.7 indicates restriction, FEV1 <80% with decreased FVC indicates obstruction, and FEV1 and FVC >80% was regarded as normal.

#### **2.3.2 Diagnosis of COPD**

COPD subjects were categorized by GOLD into grades 1–4. Based on postbronchodilator- In COPD Patients FEV1/FVC <0.7, the GOLD classification of airflow-limitation severity in COPD is 1 (mild) = FEV1 ≥ 80% expected, 50% ≤ FEV1 <80% anticipated for 2 (moderate), 30% ≤ FEV1 <50% predicted for 3 (severe), and 4 (very severe) FEV1 <30% predicted (Sarwar et al., 2021).

#### **2.3.3 Number of workers for each site:**

*Table 2. 1 Number of workers selected for spirometry test from each site*

| No. | Sampling sites          | No. of workers |
|-----|-------------------------|----------------|
| 1.  | Feed Manufacturing site | 20             |
| 2.  | Feed Dispatching site   | 10             |
| 3.  | Cow Byre                | 15             |
| 4.  | Goat PEN                | 15             |
| 5.  | Milk Extraction site    | 10             |
|     | <b>Control samples</b>  | 30             |

#### 2.3.4. Inclusion and exclusion criteria:

70 male employees between the ages of 18 and 60, who had worked in the same microenvironment at a cattle feed and dairy farm for at least three years were chosen as subjects. The study excluded participants with respiratory or other related conditions, such as anemia, abnormalities of the thoracic cage or spinal column, diabetes, respiratory TB, asthma, or bronchitis, as well as those who were very sick. Since cigarette smoking is thought to play a significant role in the development of lung conditions and occupational COPD, smokers and nonsmokers are included and compared (Bepko and Mansalis, 2016).

#### 2.3.5. Demographic data of human subjects:

Demographic measurements were used to determine the age (years), height (inches), weight (kg), body mass index (BMI in kg/m<sup>2</sup>) to know the health status of participants.

**Height:** All workers were stand straight, bare foot, touching the wall to measure the height. The data of worker's height was recorded with the measuring tape.

**Body Weight:** The body weight of the workers was measured with weight machine. The machine was 0 calibrated and workers were asked to stand barefoot on machine.

**BMI:** Body mass index was used to find weight in relation to height. This data gives the information that whether the participants was underweight, normal weight, overweight or obese.

$$BMI = \frac{Weight(kg)}{height\ (m^2)}$$

The height in inches was converted into meters before using in the formula. Then BMI was calculated from the given information. According to the World Health Organization (WHO) and National Institutes of Health Guidelines, the weight status categorized into the four classes (Irfan, Jabbar, and Hameed, 2019).

Table 2. 2 Reference BMI Range and its corresponding weight status

| Weight Status | BMI Range   |
|---------------|-------------|
| Underweight   | $\leq 18.5$ |
| Normal Weight | 18.5-24.9   |
| Overweight    | 25-29.9     |
| Obese         | $\geq 30$   |

After calculating the BMI for each age group, average and standard deviation was calculated.

### 2.3.6. Questionnaire

Other questions included in the questionnaire were related to the number of years working in the selected industry, smoking and non-smoking status of workers. Questionnaires were completed in face-to-face interview.

## 2.4 Respiratory Risk Assessment and Statistical Analysis

Respiratory risk assessment using standard methods of US-EPA, both cancer risk and hazard quotient was computed among dairy farm workers and feed workers according to workplace (Sarwar et al., 2023), (Othman et al., 2020), (Burk et al., 2022). The t-test was utilized to analyze the variation in lung function between pre and post bronchodilation. Health risk assessment of Heavy Metals was computed using SPSS software (Rostami et al., 2021).

- Cancerous Risk

$$CR = (D \times CSF \text{ or } AAC \times IUR) \times (ED / LY)$$

- Hazard Quotient

$$HQ = \frac{EDI \left( \frac{mg}{kg/day} \right)}{RFD \left( \frac{mg}{kg/day} \right)}$$

- Lifetime Cancer Risk

$$LTCR = EC \left( \frac{\mu g}{m^3} \right) \times IUR \left( \frac{\mu g}{m^3} \right)^{-1}$$

- Exposure Concentration

$$EC \left( \frac{\mu g}{m^3} \right) = \frac{C \left( \frac{\mu g}{m^3} \right) \times ET \left( \frac{hr}{day} \right) \times ED(years) \times EF \left( \frac{days}{year} \right)}{AT(years) \times 365 \left( \frac{days}{year} \right) \times 24 \left( \frac{hr}{day} \right)}$$

- Estimated Daily Intake

$$EDI \left( \frac{mg}{kg/day} \right) = \frac{C \times \frac{1}{1000} \left( \frac{mg}{\mu g} \right) \times IR \left( \frac{m^3}{day} \right) \times ET \left( \frac{hr}{day} \right) \times ED(years) \times EF \left( \frac{days}{year} \right)}{AT(years) \times 365 \left( \frac{days}{year} \right) \times 24 \left( \frac{hr}{day} \right) \times BW(kg)}$$

Correlation was computed between lung function parameters and the contaminants present in PM<sub>10</sub> and PM<sub>2.5</sub> using SPSS (Rostami et al., 2021).

#### 2.4.1. Cancerous Risk (CR)

Cancer Risk is calculated for carcinogens with available cancer risk values (CSFs). A CR value greater than 1.0 E-6 then in-dept toxicological effects analysis was needed (Rostami et al., 2021).

$$CR = (D \times CSF \text{ or } AAC \times IUR) \times (ED / LY)$$

CR= Cancer Risk, D= Age specific Dose (mg/kg/day), CSF= Cancer slope factor ((mg/kg/day)<sup>-1</sup>), AAC= EF-adjusted Air concentration (μg/m<sup>3</sup>), IUR= Inhalation Unit Risk ((μg/m<sup>3</sup>)<sup>-1</sup>), ED= Age specific exposure duration (Years) and LY= Lifetime in years (78 years).

#### 2.4.2. Hazard Quotient (HQ)

The hazard quotient is a ratio of exposure to a reference toxicity level. An HQ below 1 indicates low risk, while values above 1 suggest potential health risk (Sarwar et al., 2023).

$$HQ = \frac{EDI \left( \frac{mg}{kg/day} \right)}{RFD \left( \frac{mg}{kg/day} \right)}$$

EDI= Estimated daily intake (mg/kg/day) and RFD = Reference dose (mg/kg/day)

#### 2.4.3. Lifetime Cancer Risk

Lifetime cancer risk is the probability an individual will develop the cancer over their lifetime due to inhalation of a specific pollutant. (Othman et al., 2020).

$$LTCR = EC \left( \frac{\mu g}{m^3} \right) \times IUR \left( \frac{\mu g}{m^3} \right)^{-1}$$

LTCR= Lifetime Cancer Risk, EC= Exposure Concentration ( $\mu g/m^3$ ) and IUR= Inhalation Unit Risk ( $(\mu g/m^3)^{-1}$ ).

#### 2.4.4. Inhalation Unit Risk

An Inhalation Unit Risk (IUR) quantifies the likelihood of developing cancer from long-term exposure to hazardous substances in the air. It is represented as the maximum excess cancer risk per microgram per cubic meter ( $\mu g/m^3$ ) of air (Sarwar et al., 2023).

#### 2.4.5. Exposure Concentration

Exposure concentration is the average concentration of a pollutant a person is exposed to over their lifetime (Burk et al., 2022).

$$EC \left( \frac{\mu g}{m^3} \right) = \frac{C \left( \frac{\mu g}{m^3} \right) \times ET \left( \frac{hr}{day} \right) \times ED(years) \times EF \left( \frac{days}{year} \right)}{AT(years) \times 365 \left( \frac{days}{year} \right) \times 24 \left( \frac{hr}{day} \right)}$$

EC= Exposure concentration ( $\mu g/m^3$ ), C= concentration of metal ( $\mu g/m^3$ ), ET= Exposure time, ED= Exposure duration, EF = Exposure Frequency, AT= Average time (ED×365)

#### 2.4.6. Estimated Daily Intake

Estimated daily intake is the amount of pollutant a person inhales per kilogram of body weight per day. This is used to estimate non-cancer health risk (Sarwar et al., 2023).

$$EDI \left( \frac{mg}{kg/day} \right) = \frac{C \times \frac{1}{1000} \left( \frac{mg}{\mu g} \right) \times IR \left( \frac{m^3}{day} \right) \times ET \left( \frac{hr}{day} \right) \times ED(years) \times EF \left( \frac{days}{year} \right)}{AT(years) \times 365 \left( \frac{days}{year} \right) \times 24 \left( \frac{hr}{day} \right) \times BW(kg)}$$

EDI= Estimated daily intake (mg/kg/day), C= concentration, IR= Inhalation rate (m<sup>3</sup>/day), ET= Exposure time (hr/day), ED= Exposure duration, EF= Exposure frequency (day/years), AT= Average time (ED×365), BW= Body weight of workers

#### 2.5 Sample collection of Particulate Matter

The feed sector consists of two sites and the samples were taken from each department including Feed Manufacturing site and Feed Dispatching site for three consecutive days. While dairy farm consists of three sites, Cow Byre, Goat PEN, and Milk Extraction site.

Table 2. 3 Work description of selected sites

| S.no | Site area               | Description                                                                                                                            |
|------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| 1.   | Feed Manufacturing site | Where all feed raw materials are stored, fed into an automatic mixing machine and are transferred into dispatching site through pipes. |
| 2.   | Feed Dispatching site   | Where all the feed bags are being filled, stored, and transferred into the trucks.                                                     |
| 3.   | Cow Byre                | Where all the cows are sheltered and fed.                                                                                              |
| 4.   | Goat PEN                | Where all the goats are sheltered and fed.                                                                                             |
| 5.   | Milk Extraction site    | Where both cows and goats' milk are extracted using mechanical milking machines twice daily.                                           |

A two-heads low volume sampler (LVS) was used for collection of PM<sub>2.5</sub> and PM<sub>10</sub> from selected sites within Cattle feed and dairy farm area. The pre-weighed (W1) PTFE (Polytetrafluoroethylene) Membrane filters of 47-mm diameter were used in both heads for PM collection. The flow rate of sampler will keep constant at 16 LPM. The sampling

duration is an 8-hrs work day. A total of three samples were taken from each site (3 consecutive days). The PM sampler was adjusted at the breathing height of 1.5 m (Zheng et al., 2022). Filters after sampling was weighed (W2) and refrigerated to avoid thermal decay. For gravimetric PM mass determination, mass of blank filter (W1) was subtracted from mass of sample laden filter (W2) (Zheng et al., 2022), (Araújo et al., 2014).

### 2.5.1. Sampling sites for particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>):

Table 2. 4 Number of Air samples collected from each site

| S.no | Site area               | No. of Sample collected |       |       |
|------|-------------------------|-------------------------|-------|-------|
|      |                         | PM 2.5                  | PM 10 | TOTAL |
| 1.   | Feed Manufacturing site | 3                       | 3     | 6     |
| 2.   | Feed Dispatching site   | 3                       | 3     | 6     |
| 3.   | Cow Byre                | 3                       | 3     | 6     |
| 4.   | Goat PEN                | 3                       | 3     | 6     |
| 5.   | Milk Extraction site    | 3                       | 3     | 6     |

### 2.6 Analysis of Particulate Matter:

The concentration of PM on each filter is computed using following formula (Araújo et al., 2014),

$$C = \frac{m}{Q \times T}$$

C is particulate concentration (mass/volume), m is net mass collected on the filter (mass), Q is volumetric flow rate (volume/time), and T= duration of sampling (time).

Several test; T-test, ANOVA, and correlation analysis were conducted using software tools like Excel and SPSS.

**a) Elemental Analysis of Particulate Matter:**

The heavy metals, such as lead (Pb), cadmium (Cd), copper (Cu) and zinc (Zn), are extracted from the filter papers by wet digestion using a 2:1 ratio of HCl and HNO<sub>3</sub>. The digestate is then diluted to 25 ml with deionized water. Calibration standards for target metals including Pb, Cd, Cu and Zn were generated in the same matrix, and the samples are analyzed using an Atomic Absorption Spectrophotometer (Shimadzu AA-7000) with metal-specific hollow cathode lamps at suitable wavelengths (Jamil et al., 2023). Concentrations were determined using calibration curves and represented as ppm.

## CHAPTER 3

### RESULTS AND DISCUSSION

#### 3.1 Workforce Demography

Out of all seventy-two (70) workers from all departments of dairy farm and feed manufacturing sites, eighteen (18) are smokers, of which six are in cow byre, three in goat pen, three in feed manufacturing area, two in feed dispatching sites, and four in milk extraction sites. The mean average BMI calculated is  $22.1 \pm 2.8$  which falls into the category of normal weight. The highest BMI recorded is  $25 \pm 1.6$  Feed Manufacturing department in smokers, which lies in overweight category. The mean average age, height, and weight of the workers are  $29.2 \pm 9.18$ ,  $5.48 \pm 0.30$ ,  $61.69 \pm 8.74$ . The average year of employment of all workers is  $5.30 \pm 2.45$ .

Table 3. 1 Demographic characteristics of all workers department wise

| Departement        |             | No. | Avg. Age        | Avg. height   | Avg. Years of work | Avg. BMI       |
|--------------------|-------------|-----|-----------------|---------------|--------------------|----------------|
| COW                | Smokers     | 6   | $30.5 \pm 8.2$  | $5.4 \pm 0.2$ | $4.7 \pm 1.1$      | $21.5 \pm 3.3$ |
|                    | Non-Smokers | 9   | $28.4 \pm 6.3$  | $5.7 \pm 0.3$ | $5.1 \pm 1.4$      | $20.5 \pm 3.0$ |
| GOAT               | Smokers     | 3   | $32 \pm 11$     | $5.3 \pm 0.3$ | $4.7 \pm 1.7$      | $21.5 \pm 2.9$ |
|                    | Non-Smokers | 13  | $26.4 \pm 4.6$  | $5.4 \pm 0.3$ | $4.6 \pm 1.8$      | $22.8 \pm 2.8$ |
| Feed Manufacturing | Smokers     | 8   | $28 \pm 4.3$    | $5.5 \pm 0.2$ | $6.3 \pm 0.5$      | $25 \pm 1.6$   |
|                    | Non-Smokers | 13  | $26.6 \pm 8.8$  | $5.4 \pm 0.3$ | $4.7 \pm 1.7$      | $22.1 \pm 3.3$ |
| Feed Dispatch      | Smokers     | 3   | $52 \pm 5.7$    | $5.7 \pm 0.2$ | $11 \pm 1$         | $23.3 \pm 3.8$ |
|                    | Non-Smokers | 8   | $32.8 \pm 10.5$ | $5.6 \pm 0.2$ | $5.9 \pm 3.5$      | $21.9 \pm 3.1$ |
| Milk Extraction    | Smokers     | 4   | $29.3 \pm 1.3$  | $5.6 \pm 0.2$ | $5.0 \pm 0.7$      | $22.3 \pm 1.3$ |
|                    | Non-Smokers | 4   | $30 \pm 3.9$    | $5.5 \pm 0.1$ | $7.5 \pm 4.4$      | $22.6 \pm 1.7$ |

Department wise demographic characteristics of workers, categorized by smokers and non-smokers are shown in table 3.1.

### 3.2 Comparison of Demographic data between Subject vs Control group:

Table 3.2 shows the Demographic data comparison between Subject and Control group. Average age of Subject workers was  $29.2 \pm 9.18$  and control group was  $30.2 \pm 5.18$ . The average height and weight of subject workers was  $5.48 \pm 0.30$  and  $61.69 \pm 8.74$  and Control group was  $5.54 \pm 0.70$  and  $62.69 \pm 6.74$  respectively. The average BMI of subject workers was  $22.1 \pm 2.8$ , which fall in normal range while average BMI of control group was  $25.2 \pm 2.5$ , which fall in overweight range.

In subject group, non-smokers were prevailing and accounts for 74% and 26% was smokers, while in control group, 50% were smokers and 50% were non-smokers.

Table 3. 2 Demographic characteristics of Subject vs Control group

| Variables           | Subject (n=70)   | Control group (n=30) |
|---------------------|------------------|----------------------|
| Age                 | $29.2 \pm 9.18$  | $30.2 \pm 5.18$      |
| Height              | $5.48 \pm 0.30$  | $5.54 \pm 0.70$      |
| Weight              | $61.69 \pm 8.74$ | $62.69 \pm 6.74$     |
| BMI                 | $22.1 \pm 2.8$   | $25.2 \pm 2.5$       |
| Years of employment | $5.30 \pm 2.45$  |                      |
| Smokers             | 18 (26%)         | 15 (50%)             |
| Non-Smokers         | 52 (74%)         | 15 (50%)             |

### 3.3 Lung Function of Dairy farm and Feed Manufacturing workers

Lung Function test also called spirometry test was performed in each department of dairy farm and feed industry i.e., Cow byre, Goat Pen, Milk Extraction, Feed Manufacturing area and dispatching area. The result of each department was shown in table 3.3.

Three parameters including FEV1, FVC, and PEF was analyzed in each worker to analyze their lung functioning. Force Expiratory Volume in one second (FEV1) is defined as the maximum amount of air expelled in one second. Force Vital Capacity (FVC) explained total amount of air exhaled. Peak Expiratory Flow (PEF) measures the maximum speed of a person's forced exhalation.

The table 3.3 analyses the pulmonary function test results, specifically FVC (Forced Vital Capacity), FEV<sub>1</sub> (Forced Expiratory Volume in one second), and PEF (Peak Expiratory Flow), among smoker and non-smoker workers in various departments exposed to occupational pollutants. Significant findings include a p-value of 0.01 for FVC in the Goat Pen department, indicating substantial impairment in lung volume post-bronchodilator, likely related to airborne pollutant exposure. Additionally, a p-value of 0.04 for FEV<sub>1</sub> highlights airflow limitations and potential obstructive respiratory changes among smokers in the same department.

In the Feed Manufacturing department, smokers exhibited significant airway obstruction indicated by a p-value of 0.04 for PEF, while non-smokers also demonstrated significant reductions with p-values of 0.04 for FEV<sub>1</sub> and 0.05 for PEF, indicating that even non-smokers are adversely affected by occupational exposure. The Cow Byre department noted a significant p-value of 0.02 for PEF among non-smokers, implying narrowed airways and reduced peak expiratory flow. A significant p-value of 0.05 for FEV<sub>1</sub> in the Feed Dispatch department further suggests reduced airflow and initial obstructive impacts in exposed workers.

Conversely, no significant differences were noted in the Milk Extraction department ( $p > 0.05$ ), indicating comparatively better respiratory health among its workers. Overall, the significant reductions in FVC, FEV<sub>1</sub>, and PEF observed in the Goat pen, feed manufacturing, Cow Byre, and feed dispatch departments indicates that occupational exposure to PM and associated contaminants contribute to decreased lung function and increased risk of obstructive respiratory disorders.

Overall, the data points to critical declines in FVC, FEV<sub>1</sub>, and PEF in the Goat Pen, Feed Manufacturing, Cow Byre, and Feed Dispatch departments, emphasizing the detrimental effects of occupational exposure to particulate matter and contaminants on lung function and increasing the risk of obstructive respiratory diseases.

### **3.3.1. COPD in workers**

The table 3.3 also shows the different stages of COPD diagnosed in all five departments. According to Gold Criteria, 4 (6%) out of 70 workers had moderate cases of COPD, two belongs to smoker's category, two belongs to non-smokers category.

One was diagnosed in Cow Byre, second in goat pen, third in feed manufacturing site and fourth in feed dispatching area respectively.

According to Jouneau et al. (2018), the prevalence and risk variables of chronic obstructive pulmonary disease in dairy farmers showed that COPD cases were found among mostly non-smoking dairy farmers, suggesting that occupational exposure plays an important independent role. The literature review identifies a marked increase in the COPD incidence linked to occupational exposure over recent decades, pointing to a rising public health concern (PD, 2012)

Cushen et al. (2016) conducted a spirometry study in Ireland to explore the relationship between occupation and Chronic Obstructive Pulmonary Disease (COPD), revealing a prevalence rate of 12 among farmers. This study highlights the detrimental impact of occupational exposure in agriculture on respiratory health, particularly chronic bronchitis, which is identified as a work-related condition for farmers, independent of smoking factors. In a related study, Dalphin et al. investigated the prevalence of chronic bronchitis among French cattle breeders, indicating an elevated risk of developing this condition along with obstructive airway patterns 38. Additionally, Eduard et al. (2009) mentioned the notably higher mortality risk associated with respiratory diseases among livestock farmers. The findings also suggest that ex-smokers in this demographic exhibit a greater prevalence of asthma compared to individuals who have never smoked. Together, these studies underscore the significant health risks faced by individuals in agricultural occupations, linking occupational exposure to adverse respiratory conditions.

Epidemiological studies underscore tobacco smoke as the primary contributor to COPD; however, the significance of occupational exposure to dust, gases, vapors, and fumes is also acknowledged, with estimates suggesting it accounts for 15–20% of COPD cases in the general population, potentially reaching 30% among non-smokers. Moreover, emerging research points to evidence of chronic airflow limitation even in non-smokers who are occupationally exposed to harmful substances (Lamprecht et al., 2011). Similarly, large-scale research conducted by Liu et al. (2015) with over 5,000 agricultural workers found that occupational exposure to pesticides and dust was a major risk factor for COPD that affected both smokers and non-smokers. These results are in line with data that, regardless of smoking status, airborne pollutants in

agricultural settings, such as organic dust, microbiological agents, and particulate matter, can cause chronic airway inflammation and obstructive lung disease.

Recent studies have expanded the understanding of chronic airflow limitation, indicating it can also occur in non-smokers who have been occupationally exposed to various harmful substances such as dust, gases, vapors, and fumes. Evidence from chronic obstructive lung diseases research supports this claim (Cushen et al., 2016). Notably, a study conducted by Stoleski et al., 2015 among cow breeders examined the prevalence of Chronic Obstructive Pulmonary Disease (COPD) in non-smokers, highlighting the significant impact of specific occupational exposures on the onset and characteristics of COPD.

Table 3. 3 Lung function Assessment of all workers working in selected departments on the basis of smokers and non-smoker and COPD Gold classification

| Departement        |             | No. | Lung Function |            |         |            |            |         |            |            |         | COPD |          |        |             |
|--------------------|-------------|-----|---------------|------------|---------|------------|------------|---------|------------|------------|---------|------|----------|--------|-------------|
|                    |             |     | FVC           |            |         | FEV1       |            |         | PEF        |            |         | mild | moderate | severe | Very severe |
|                    |             |     | Pre. B        | Post. B    | P value | Pre. B     | Post. B    | P value | Pre. B     | Post. B    | P value | 1    | 2        | 3      | 4           |
| COW                | Smokers     | 6   | 3.63 ± 1.32   | 3.43 ± 2.1 | 0.23    | 2.29 ± 1.1 | 2.62 ± 1.1 | 0.42    | 4.47 ± 1.1 | 5.93 ± 3.1 | 0.02    |      | 1        |        |             |
|                    | Non-Smokers | 9   | 2.96 ± 0.56   | 2.62 ± 1.9 | 0.29    | 2.37 ± 1.7 | 2.25 ± 1.8 | 0.28    | 4.62 ± 2.1 | 5.06 ± 2.1 | 0.16    |      |          |        |             |
| GOAT               | Smokers     | 3   | 3.16 ± 1.25   | 2.97 ± 2.1 | 0.01    | 2.76 ± 1.8 | 2.98 ± 0.7 | 0.04    | 5.04 ± 3.7 | 5.53 ± 2.6 | 0.55    |      | 1        |        |             |
|                    | Non-Smokers | 13  | 3.07 ± 2.14   | 2.65 ± 1.1 | 0.06    | 2.60 ± 2.1 | 2.51 ± 1.1 | 0.45    | 4.46 ± 2.1 | 5.22 ± 3.7 | 0.17    |      |          |        |             |
| Feed Manufacturing | Smokers     | 8   | 2.48 ± 1.68   | 2.68 ± 1.6 | 0.55    | 1.83 ± 2.5 | 2.35 ± 0.9 | 0.06    | 2.85 ± 1.7 | 3.59 ± 2.1 | 0.04    |      |          |        |             |
|                    | Non-Smokers | 12  | 2.81 ± 0.91   | 2.65 ± 1.5 | 0.47    | 2.32 ± 1.6 | 2.68 ± 0.6 | 0.04    | 3.89 ± 2.1 | 4.69 ± 3.1 | 0.05    |      | 1        |        |             |
| Feed Dispatch      | Smokers     | 3   | 2.29 ± 0.75   | 2.61 ± 0.9 | 0.32    | 2.22 ± 1.1 | 3.35 ± 2.9 | 0.48    | 4.16 ± 2.1 | 4.57 ± 2.7 | 0.77    |      |          |        |             |
|                    | Non-Smokers | 8   | 2.70 ± 1.8    | 3.01 ± 1.1 | 0.43    | 2.14 ± 1.8 | 2.90 ± 2.1 | 0.05    | 4.26 ± 2.5 | 4.79 ± 2.3 | 0.26    |      | 1        |        |             |
| Milk Extraction    | Smokers     | 4   | 2.97 ± 1.11   | 2.92 ± 2.1 | 0.89    | 2.53 ± 1.9 | 2.90 ± 1.3 | 0.21    | 3.88 ± 2.6 | 4.80 ± 2.8 | 0.11    |      |          |        |             |
|                    | Non-Smokers | 4   | 3.14 ± 2.1    | 3.64 ± 1.7 | 0.59    | 2.58 ± 1.1 | 3.49 ± 1.2 | 0.29    | 4.05 ± 2.7 | 5.15 ± 3.7 | 0.14    |      |          |        |             |

P-value > 0.05                      no significance difference

P-value ≤ 0.05                      significant difference

### **3.3.2. Obstructive, Restrictive and Mix-lung diseases**

Table 3.4 illustrates the obstructive, restrictive, and mix lung diseases among all workers in their respective departments. The data shows that obstructive lung diseases are most common among all workers in all departments, out of total of 70 workers, 14 (20%) show obstructive diseases, 3 (4%) restrictive diseases, 11 (16%) mix lung diseases respectively.

Out of the 14 obstructive diseases in workers, 10 (71%) were smokers while 4 (29%) were non-smokers. Out of 3 restrictive diseases in workers, 2 (67%) belongs to smoking category and 1 (33%) from non-smoker category. Out of total of 11 mix lung diseases in workers, 3 (27%) belongs to smoker category and 8 (73%) from non-smokers category.

While the rest of 60% of workers shows normal lung functioning. The obstructive disease was most prevailing in Feed Manufacturing site with 8 (40%) workers having this disease, while 4 (20%) workers were diagnosed with mix lung diseases.

A study conducted by Yasmeen et al., 2020b in 18 controlled broiler houses in Raiwind and Kasur Road near Lahore, Pakistan to assess the respiratory problem in 79 poultry workers using spirometer. The results show that (68) 86% of workers have normal lung functioning and 11 (14%) show mild obstruction. The results are in align with the results revealed in the present study. Another study conducted by Hamid et al., 2018 conducted respiratory and health risk among 71 poultry-farm workers on eight poultry farms in Lahore and Sheikhpura, the spirometry results revealed that 65% workers show restrictive lung disease, 14% show obstructive diseases and 21% show normal lung functioning. The obstructive lung disease is in line with the present study while percentage of restrictive disease workers are greater than the present study. Another study conducted by Serya et al., 2023 on respiratory findings in Dairy farmworkers from the Nile delta region in Egypt through spirometer shows that out of 141 total dairy farmworkers, 97 (78.2%) workers show normal lung functioning, 24 (19.4%) workers show obstructive lung disease, 2 (1.6%) shows restrictive and one (0.8%) show mixed lung disease. The results support the finding of the present study.

Table 3. 4 Obstructive, Restrictive and Mix lung disease in all workers

| Department         |             | No. of workers | Obstruction | Restriction | Mix Lung Disease | Normal |
|--------------------|-------------|----------------|-------------|-------------|------------------|--------|
| COW                | Smokers     | 6              | 3           | 1           |                  | 2      |
|                    | Non-Smokers | 9              |             |             | 1                | 8      |
|                    | Total       | 15             | 3           | 1           | 1                | 10     |
| GOAT               | Smokers     | 3              |             | 1           |                  | 2      |
|                    | Non-Smokers | 13             |             |             | 2                | 11     |
|                    | Total       | 16             |             | 1           | 2                | 13     |
| Milk Extraction    | Smokers     | 4              | 2           |             |                  | 2      |
|                    | Non-Smokers | 4              | 1           |             |                  | 3      |
|                    | Total       | 8              | 3           |             |                  | 5      |
| Feed Manufacturing | Smokers     | 8              | 5           |             | 2                | 1      |
|                    | Non-Smokers | 12             | 3           |             | 2                | 7      |
|                    | Total       | 20             | 8           |             | 4                | 8      |
| Feed Dispatch      | Smokers     | 3              |             | 1           | 2                |        |
|                    | Non-Smokers | 8              | 2           |             | 2                | 4      |
|                    | Total       | 11             | 2           | 1           | 4                | 4      |
|                    | Grand total | 70             | 16          | 3           | 11               | 40     |

### 3.3.3. Comparison of Obstructive, Restrictive and Mix-lung diseases in Subject VS Control group

In subject group obstructive lung diseases are most common in majority of workers (22%), 16% have mix lung diseases, 13% have restrictive diseases while 50% workers have normal lung functioning. While in control group, obstructive diseases are prevailing and accounts for 20%, 10% show restrictive diseases, and 70% show normal lung functioning. In both the groups the normal lung functioning was dominant.

Table 3. 5 Obstructive, Restrictive and Mix lung disease in subject vs control group samples

| Parameters        | Subject (n=70) | Control Group (n=30) |
|-------------------|----------------|----------------------|
| Obstructive       | 15 (22%)       | 6 (20%)              |
| Restrictive       | 9 (13%)        | 3 (10%)              |
| Mix lung diseases | 11 (16%)       | 0                    |
| Normal            | 35 (50%)       | 21 (70%)             |

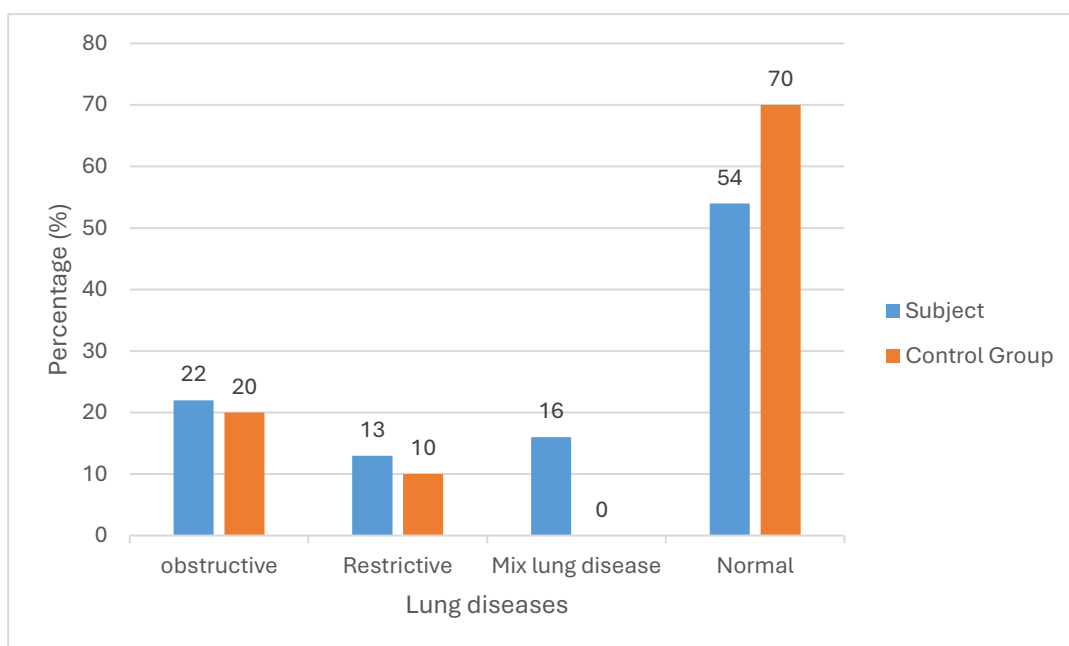


Figure 3. 1 Comparison of Obstructive, Restrictive and Mix-lung diseases in Subject VS Control group

### 3.3.4. Comparison of Lung diseases in smoker's vs non-smokers in subject and control group

In subject group, obstructive lung diseases are prevailing in both smokers and non-smokers workers. Obstruction is most common in majority of smokers (42%), 25% have restrictive diseases, 21% have mix lung diseases, while 12% workers have normal lung functioning. While in non-smokers, obstructive diseases accounts for 11%, mix lung disease accounts for 13%, while 70% shows normal lung functioning.

In control group, restrictive diseases are prevailing in smokers. In smokers' restrictive diseases accounts for 20%, 33% show obstructive diseases, and 72% show

normal lung functioning. While in non-smokers 20% show restriction, 7% show obstruction and 70% show normal lung functioning. In both the groups (smokers + non-smokers) the normal lung functioning was dominating and there are no mix-lung diseases recorded in control group.

Table 3. 6 Comparison of Lung diseases in smoker's vs non-smokers in subject and control

| Lung Function Pattern | Smokers (n=24) | Non-Smokers (n=46) | P-value      |
|-----------------------|----------------|--------------------|--------------|
| <b>Subject group</b>  |                |                    |              |
| Obstruction           | 10             | 5                  | <b>0.005</b> |
| Restriction           | 6              | 3                  | 0.054        |
| Mix-lung diseases     | 5              | 6                  | 0.493        |
| Normal                | 3              | 32                 | <0.001       |
| <b>Control group</b>  |                |                    |              |
| Lung Function Pattern | Smokers (n=15) | Non-Smokers (n=15) | P-value      |
| Obstruction           | 5              | 1                  | 0.169        |
| Restriction           | 3              | 0                  | 0.224        |
| Mix-lung diseases     | 0              | 0                  | N/A          |
| Normal                | 7              | 14                 | 0.014        |

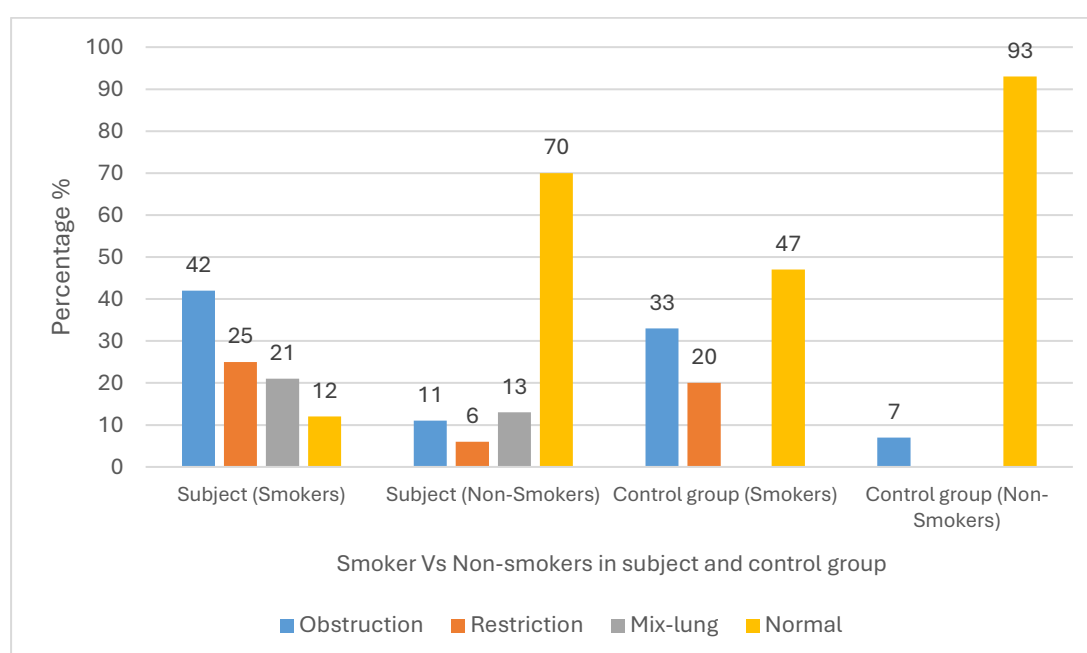


Figure 3. 2 Comparison of Lung diseases in smoker's vs non-smokers in subject and control group

### 3.4 PM<sub>2.5</sub> and PM<sub>10</sub> concentration in Air Samples

Table 3.7 summarizes the average concentrations ( $\pm$  standard deviation) of PM<sub>2.5</sub> and PM<sub>10</sub> detected in various departments of a dairy farm and animal feed manufacturing facility. For PM 2.5 the Cow Byre department exhibited the highest PM<sub>2.5</sub> concentration at  $149 \pm 27 \mu\text{g}/\text{m}^3$ , followed by Feed Dispatch at  $87 \pm 28 \mu\text{g}/\text{m}^3$ , Feed Manufacturing at  $76 \pm 15 \mu\text{g}/\text{m}^3$ , Milk Extraction at  $57 \pm 24.3 \mu\text{g}/\text{m}^3$ , and Goat Pen at  $27 \pm 9 \mu\text{g}/\text{m}^3$ . For PM<sub>10</sub>, the highest levels were also found in the Cow Byre department at  $191 \pm 23 \mu\text{g}/\text{m}^3$ , with subsequent concentrations in Feed Manufacturing ( $159 \pm 64 \mu\text{g}/\text{m}^3$ ), Goat Pen ( $99 \pm 29 \mu\text{g}/\text{m}^3$ ), Milk Extraction ( $80 \pm 33 \mu\text{g}/\text{m}^3$ ), and Feed Dispatch ( $53 \pm 22 \mu\text{g}/\text{m}^3$ ). Comparison to reference threshold values set by the World Health Organization indicates that all departments exceeded the recommended limits for PM<sub>2.5</sub> ( $5 \mu\text{g}/\text{m}^3$ ) and PM<sub>10</sub> ( $15 \mu\text{g}/\text{m}^3$ ) significantly. These high levels of particulate matter signal a considerable occupational health risk, particularly for respiratory issues, for workers subjected to these environments over extended time frames. Similar values of PM<sub>2.5</sub> and PM<sub>10</sub> concentration in cattle farms are reported by Kimanzi et al., 2022, Jamil et al., 2023, and Chotigawin, et al., 2024.

Another study conducted by Kimanzi et al., 2022 on Particulate Matter (PM<sub>10</sub> and PM<sub>2.5</sub>) exposure in ten selected animal feed processing facilities in Kiambu, Kenya shows mean concentration of PM<sub>10</sub>  $53.7 \mu\text{g}/\text{m}^3$  and PM<sub>2.5</sub>  $36.5 \mu\text{g}/\text{m}^3$  respectively. The mean concentration of PM<sub>10</sub> and PM<sub>2.5</sub> in Feed Manufacturing was  $49.13 \mu\text{g}/\text{m}^3$  and  $34.5 \mu\text{g}/\text{m}^3$  and grinding site was  $130.8 \mu\text{g}/\text{m}^3$  and  $82.6 \mu\text{g}/\text{m}^3$  respectively. The mean concentration of PM<sub>10</sub> and PM<sub>2.5</sub> in finished goods loading was  $39.30 \mu\text{g}/\text{m}^3$  and  $28.67 \mu\text{g}/\text{m}^3$  and in transport area was  $31.18 \mu\text{g}/\text{m}^3$  and  $22.56 \mu\text{g}/\text{m}^3$  respectively. The results are in lined with the concentration of heavy metals found in Feed Manufacturing site and feed dispatching sites of the present study. A study conducted by Prashanth R, 2025 on livestock air pollution show PM<sub>2.5</sub> observed range of 45-118 and PM<sub>10</sub> 72-165  $\mu\text{g}/\text{m}^3$ , which is similar to the results revealed in present study. While another study conducted by Jamil et al., 2023 on air quality of 10 livestock farm in District Kasur and Lahore measured air-borne levels of Particulate Matter show PM<sub>2.5</sub>  $3.29 + 1.82 \mu\text{g}/\text{m}^3$  in farm A (farm with no recent (2 years) disease outbreak) and PM<sub>2.5</sub>  $3.81 + 3.67 \mu\text{g}/\text{m}^3$  in farm B (farm with history of (2 years) disease outbreak), while PM<sub>10</sub>  $3.81 + 3.67$

$\mu\text{g}/\text{m}^3$  in farm A and  $\text{PM}_{10}$   $16.07 + 11.63 \mu\text{g}/\text{m}^3$  in farm B. The results are much lower than the current study. Another study conducted by Mushtaq et al., 2025 on ambient air quality in large (26-30 cows and buffalos) and small ruminant farms (18-26 goats and sheep) of Lahore and Pattoki was carried out, the results revealed the mean concentration of  $\text{PM}_{2.5}$   $224.4 \mu\text{g}/\text{m}^3$  and  $\text{PM}_{10}$   $577.4 \mu\text{g}/\text{m}^3$  in large farms and  $\text{PM}_{2.5}$   $193.7 \mu\text{g}/\text{m}^3$  and  $\text{PM}_{10}$   $456.7 \mu\text{g}/\text{m}^3$  in small farms. The results are much higher than the concentration of particulate matter found in the present study. Another study conducted by Chotigawin, et al., 2024 on air quality assessment of poultry farm houses in Chonburi, China, the results show  $\text{PM}_{10}$  concentration of  $146.5 \pm 29 \mu\text{g}/\text{m}^3$  and  $\text{PM}_{2.5}$  was way below than  $50 \mu\text{g}/\text{m}^3$  respectively. The findings are fairly same as the findings revealed in the present study.

Although ammonia is naturally released from animal manure, when it combines with air pollutants like Sulfur dioxide and nitrogen oxides, it can function as a precursor to the formation of fine particulate matter (Hristov, 2011; Lunghi et al., 2024). Inadequate waste management, frequent transportation, and poor farm upkeep and feeding methods might all be contributing factors to the elevated  $\text{PM}_{10}$  concentrations (Habib et al., 2022). In addition to the intrinsic particle emissions of farm activities, vehicle movements inside or near livestock farms can also result in excessive particulate matter (Roman et al., 2021). Farming systems are the source of higher particulate matter levels in rural and agricultural regions relative to urban areas (Spencer and Van Heyst, 2018). Accordingly, cattle farms contribute significantly to PM emissions (Pue and Buysse, 2020).

Table 3. 7 Particulate Matter concentration in Air Samples collected from each site

| Departments | AV $\pm$ S.D                                                          | COW             | GOAT        | Feed manufacturing | Feed Dispatch | ME               | TLV (TWA) $\mu\text{g}/\text{m}^3$            |
|-------------|-----------------------------------------------------------------------|-----------------|-------------|--------------------|---------------|------------------|-----------------------------------------------|
|             | <b>PM<sub>2.5</sub></b><br><b><math>\mu\text{g}/\text{m}^3</math></b> | 149 $\pm$<br>27 | 27 $\pm$ 9  | 76 $\pm$ 15        | 87 $\pm$ 28   | 57 $\pm$<br>24.3 | <b>5 <math>\mu\text{g}/\text{m}^3</math></b>  |
|             | <b>PM<sub>10</sub></b><br><b><math>\mu\text{g}/\text{m}^3</math></b>  | 191 $\pm$<br>23 | 99 $\pm$ 29 | 159 $\pm$ 64       | 53 $\pm$ 22   | 80 $\pm$<br>33   | <b>15 <math>\mu\text{g}/\text{m}^3</math></b> |

**Note:** TLV (TWA) for micro-occupational environment has not been specified by AGCIH/NIOSH. The commonly used TLV is derived from WHO guidelines (Backes, 2014), (Gagas, 2015).

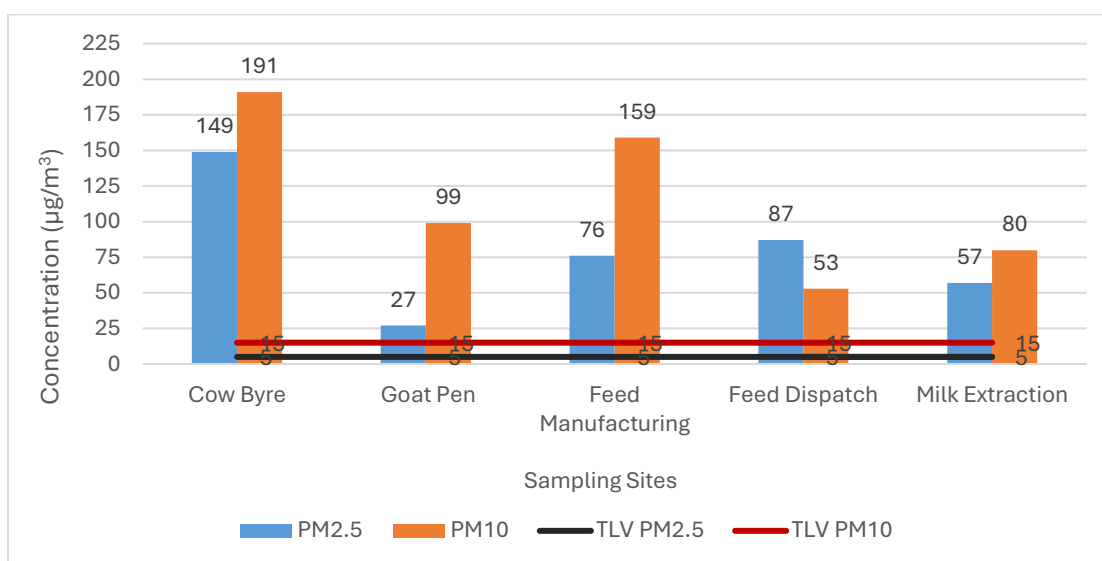


Figure 3. 3 PM2.5 and PM10 concentration in Air Samples collected from selected sites

### 3.5 Heavy Metal in Particulate Matter

The study investigated heavy metal concentrations in PM<sub>2.5</sub> and PM<sub>10</sub> samples from various departments, specifically focusing on Cu (Copper), Pb (Lead), Zn (Zinc), and Cd (Cadmium). The findings, presented in Table 3.8, the levels of all metals in all departments are however within the limits of occupational exposure limits (OELs) set by NIOSH and AGCIH (Sarwar et al., 2023).

For PM<sub>2.5</sub>, Lead was identified as the predominant metal, with the highest concentration in the Feed Manufacturing department at  $2.90 \pm 0.01$  ppm. Zinc concentrations peaked in the Cow Byre and Milk Extraction departments, reaching 2.17 ppm, while Copper had its highest measurement in the Goat Pen department at  $0.83 \pm 0.02$  ppm. In contrast, Cadmium levels remained relatively low and consistent across all tested departments.

In the analysis of PM<sub>10</sub>, Lead concentrations ranged narrowly from 2.82 to 2.89 ppm across various departments. The Feed Manufacturing department again exhibited the highest Zinc concentration at  $4.42 \pm 0.07$  ppm, potentially linked to feed processing

activities. Copper and Cadmium showed low concentrations throughout the departments.

Despite all heavy metal levels being within safe limits, the detection of these metals in airborne particulate matter underscores the importance of ongoing monitoring. Continuous occupational exposure could potentially lead to detrimental respiratory health impacts, necessitating vigilant oversight of air quality in workplace environments.

Zinc (Zn) was the most commonly found metal among the elements examined in both PM fractions. This finding is in line with other studies showing that because zinc is often used as a nutritional supplement in animal feed, it is frequently found in airborne dust in livestock and feed-processing environments (Suttle, 2010; Brugger and Windisch, 2015). According to studies, agricultural workers are constantly exposed to organic dust produced in livestock facilities, which contains elements obtained from feed, such as trace minerals (Basinas et al., 2015). Moreover, Zn is frequently detected in PM<sub>2.5</sub> and PM<sub>10</sub> fractions since it is known to occur mostly in tiny particle form in the atmosphere (ATSDR, 2005). Zn predominates the metal profile of dust particles, indicating its nutritional value, according to similar research by (Wei and Yang, 2010).

Another study conducted by Jamil et al., 2023 on air quality of 10 livestock farm in District Kasur and Lahore measured air-borne levels of Particulate Matter and potentially toxic trace elements through AAS in animal housing facilities and results show occurrence of trace metals as Pb>Zn>Ni. All metals mean values are below 1.5 ug/m<sup>3</sup>, the results of lead are in line with current study while the value of zinc was slightly lower than the current study. The present study results are in line with another study conducted by Pascu, et al., 2024 on animal husbandry in Timisoara (Romania). The result show that in PM<sub>2.5</sub> the concentration of heavy metals was Zn>Sr>Mn>Pb>Cr>Cu>As>Cd, while in PM<sub>10</sub> the concentration was Zn>Sr>Mn>Pb>Cu>As>Cd. The As, Cd, concentration was less than 0.5ppm, while Cu was below 1 ppm in both PM<sub>2.5</sub> and PM<sub>10</sub>, Zn concentration was 21ppm in PM<sub>2.5</sub> and 31 ppm in PM<sub>10</sub>, Pb was less than 1.5 ppm in PM<sub>2.5</sub> and greater than 2.5 ppm in PM<sub>10</sub> respectively. The concentration of As, Cd, Cu, was slightly greater than current study. The concentration of lead was less than the present study. While concentration of zinc was higher than the current study. Low concentration of As, Cd, Cu were also

reported in PM<sub>2.5</sub> in two cities of Vietnam, which was slightly higher as the current study, while the concentration of lead and zinc were much higher than the current study (Hien, et al. 2022).

*Table 3. 8 Heavy Metals concentration in PM<sub>2.5</sub> and PM<sub>10</sub> in Selected sites*

| Departement                        |                         | Cu (ppm)       | Pb (ppm)      | Zn (ppm)        | Cd (ppm)      |
|------------------------------------|-------------------------|----------------|---------------|-----------------|---------------|
| <b>Occupational exposure limit</b> |                         | <b>200 ppm</b> | <b>50 ppm</b> | <b>2000 ppm</b> | <b>2 ppm</b>  |
| <b>COW</b>                         | <b>PM<sub>2.5</sub></b> | 0.06 ± 0.1     | 2.83 ± 0.01   | 2.17 ± 0.10     | 0.016 ± 0.06  |
|                                    | <b>PM<sub>10</sub></b>  | 0.08 ± 0.01    | 2.89 ± 0.01   | 0.61 ± 0.01     | 0.011 ± 0.013 |
| <b>Goat</b>                        | <b>PM<sub>2.5</sub></b> | 0.83 ± 0.02    | 0.19 ± 0.03   | 0.19 ± 0.02     | 0.014 ± 0.012 |
|                                    | <b>PM<sub>10</sub></b>  | 0.10 ± 0.01    | 2.87 ± 0.07   | 1.53 ± 0.03     | 0.010 ± 0.09  |
| <b>Feed Manufacturing</b>          | <b>PM<sub>2.5</sub></b> | 0.01 ± 0.01    | 2.90 ± 0.01   | 0.87 ± 0.04     | 0.013 ± 0.08  |
|                                    | <b>PM<sub>10</sub></b>  | 0.05 ± 0.03    | 2.82 ± 0.12   | 4.42 ± 0.07     | 0.013 ± 0.04  |
| <b>Feed Dispatch</b>               | <b>PM<sub>2.5</sub></b> | 0.05 ± 0.01    | 2.75 ± 0.11   | 1.41 ± 0.01     | 0.011 ± 0.01  |
|                                    | <b>PM<sub>10</sub></b>  | 0.05 ± 0.002   | 2.86 ± 0.10   | 0.78 ± 0.1      | 0.015 ± 0.03  |
| <b>Milk Extraction</b>             | <b>PM<sub>2.5</sub></b> | 0.06 ± 0.01    | 2.83 ± 0.02   | 2.17 ± 0.02     | 0.016 ± 0.001 |
|                                    | <b>PM<sub>10</sub></b>  | 0 ± 0.001      | 2.86 ± 0.01   | 0.82 ± 0.01     | 0.013 ± 0.11  |

### 3.6 Pearson Correlation Between Heavy Metals and Human Lung functioning:

The study explores the Pearson correlation between airborne heavy metal concentrations (Copper, Lead, Zinc, and Cadmium) and pre-bronchodilator lung function parameters (FVC, FEV<sub>1</sub>, and PEF). The analysis revealed that Zinc emerged as the only heavy metal correlated with lung function, particularly with pre-bronchodilator FVC. This imply that elevated zinc levels could be detrimental to pulmonary capacity among workers exposed to it. Respiratory irritation, coughing, chest tightness, and metal fume fever—a flu-like illness frequently reported in work environments—have all been linked to inhaling zinc-containing particulate matter (Plum et al., 2010). In contrast, Copper, Lead, and Cadmium did not demonstrate significant correlations with any lung function parameters.

Table 3. 9 Pearson Correlation between Heavy metals vs human lung functioning

| Heavy Metals | FVC           | FEV1          | PEF    |
|--------------|---------------|---------------|--------|
| <b>Cu</b>    | -0.011        | 0.001         | 0.214  |
| <b>Pb</b>    | -0.043        | -0.025        | -0.255 |
| <b>Zinc</b>  | <b>-0.726</b> | <b>-0.425</b> | -0.243 |
| <b>Cd</b>    | <b>0.084</b>  | 0.126         | 0.302  |

### 3.7 Pearson Corelation Between Heavy Metals and Particulate Matter (PM<sub>2.5</sub> PM<sub>10</sub>) Concentration

The Pearson correlation analysis aimed to evaluate the relationships between heavy metal concentrations (copper [Cu], lead [Pb], zinc [Zn], and cadmium [Cd]) and particulate matter indicators (PM 2.5 and 10 concentrations across 15 observations).

#### 3.7.1 Correlation of PM<sub>2.5</sub> Concentration vs Heavy Metals:

Pearson correlations was conducted to evaluate relationship between PM<sub>2.5</sub> concentrations and heavy metals (copper (Cu), lead (Pb), zinc (Zn), and cadmium (Cd)) across different sampling sites. The findings revealed moderate positive correlations for Pb ( $r = 0.642$ ), Zn ( $r = 0.658$ ), and Cd ( $r = 0.196$ ) with PM<sub>2.5</sub> concentrations as shown in table 3.10. These correlations imply that higher PM<sub>2.5</sub> levels are generally associated with increased concentrations of lead and zinc, indicating a potential link between these metals and particulate matter emissions in the studied environments. . Lead is a well-known neurotoxic that damages the central nervous system, resulting in neurological dysfunction and cognitive decline. Lead and Zinc exposure through inhalation of particulate matter has been associated with adverse health effects, including impaired lung function, airway inflammation, respiratory irritation, coughing, chest tightness, and other respiratory symptoms, highlighting their potential impact on occupational respiratory health (Kim et al., 2018; Plum et al., 2010).

Chronic exposure is also linked to respiratory issues, such as impaired lung function and inflammation of the airways, particularly when particulate matter is breathed (Kim et al., 2018). Respiratory irritation, coughing, chest tightness, and metal fume fever—a flu-like illness frequently reported in work environments—have all been linked to inhaling zinc-containing particulate matter (Plum et al., 2010).

Conversely, copper displayed a moderate negative correlation ( $r = -0.631$ ) with  $PM_{2.5}$ , indicating that higher  $PM_{2.5}$  levels correspond to lower copper concentrations, which may reflect distinct sources or environmental behaviors for this metal in contrast to the others studied

A strong negative correlation was found between copper and lead ( $r = -0.999$ ), signifying a perfect inverse relationship, indicating that the sources of lead emissions may not be the same as those for copper within the research area. Zinc also exhibited a strong positive correlation with lead ( $r = 0.757$ ), implying a potential shared sources or similar mechanisms affecting their transport and deposition.

*Table 3. 10 Correlation between  $PM_{2.5}$  Conc VS Heavy Metals*

|                              | <b>PM<sub>2.5</sub> conc</b> | <b>Cu</b>     | <b>Pb</b>     | <b>Zn</b>     | <b>Cd</b> |
|------------------------------|------------------------------|---------------|---------------|---------------|-----------|
| <b>PM<sub>2.5</sub> Conc</b> | 1                            | <b>-0.631</b> | <b>0.642</b>  | <b>0.658</b>  | 0.196     |
| <b>Cu</b>                    | <b>-0.631</b>                | 1             | <b>-0.999</b> | <b>-0.730</b> | 0.027     |
| <b>Pb</b>                    | <b>0.642</b>                 | <b>-0.999</b> | 1             | <b>0.757</b>  | 0.017     |
| <b>Zn</b>                    | <b>0.658</b>                 | <b>-0.730</b> | <b>0.757</b>  | 1             | 0.493     |
| <b>Cd</b>                    | 0.196                        | 0.027         | 0.017         | 0.493         | 1         |

### 3.7.2 Correlation of $PM_{10}$ Conc vs Heavy Metals

The study analyzed the correlation between  $PM_{10}$  concentrations and heavy metals—copper (Cu), lead (Pb), zinc (Zn), and cadmium (Cd)—through Pearson correlation analysis across various sites.  $PM_{10}$  showed weak positive correlations with Cu ( $r = 0.369$ ), Pb ( $r = 0.062$ ), and Zn ( $r = 0.351$ ), indicating slight increases in these metals with rising  $PM_{10}$  levels as shown in table 3.11.

Conversely, a moderate negative correlation was found between Cd and  $PM_{10}$  ( $r = -0.503$ ), implying that higher  $PM_{10}$  levels were associated with lower Cd

concentrations. This relationship might be occurred from differences in sources, transport mechanisms, or the nature of particle-size associations for cadmium compared to other metals. Pb and Zn exhibited a strong negative correlation ( $r = -0.879$ ), indicating that higher lead concentrations corresponded to lower zinc levels. This indicates distinct emission sources or environmental processing for these metals.

Additionally, Cu showed a moderate positive correlation with Pb ( $r = 0.363$ ) and a moderate negative correlation with Cd ( $r = -0.651$ ). Overall, the analysis indicated that PM<sub>10</sub> concentrations had weak associations with the examined heavy metals but highlighted a significant inverse relationship between Pb and Zn.

Table 3. 11 Correlation of PM10 Conc VS Heavy Metals

|                 | <b>PM10<br/>conc</b> | <b>Cu</b>     | <b>Pb</b>     | <b>Zn</b>     | <b>Cd</b>     |
|-----------------|----------------------|---------------|---------------|---------------|---------------|
| <b>PM10conc</b> | 1                    | 0.369         | <b>0.062</b>  | 0.351         | <b>-0.503</b> |
| <b>Cu</b>       | 0.369                | 1             | 0.363         | 0.020         | <b>-0.651</b> |
| <b>Pb</b>       | <b>0.062</b>         | 0.363         | 1             | <b>-0.879</b> | -0.453        |
| <b>Zn</b>       | 0.351                | 0.020         | <b>-0.879</b> | 1             | <b>0.052</b>  |
| <b>Cd</b>       | <b>-0.503</b>        | <b>-0.651</b> | -0.453        | <b>0.052</b>  | 1             |

### 3.8 Health Risk Assessment of Heavy Metals on Workers

To evaluate the human health risk associated with the Particulate matter concentration, EC and HQ were calculated. The toxicity of heavy metals depends upon its daily intake. The EC was determined all metals and detected in all of the samples.

To assess non-carcinogenic risk from exposure to these metals, HQ values were calculated based on average metal concentration. A HQ value below one indicates no significant health risk, whereas values above one suggests possible adverse effects. The concentration of selected heavy metals (Cu, Pb, Zn, As, and Cd) associated with particulate matter fractions (PM<sub>2.5</sub> and PM<sub>10</sub>) across different departments (Cow, Goat, Feed Manufacturing (FM), Feed Dispatch, and Milk Extraction (ME)) is presented in the table below.

Exposure concentrations (EC) of all examined elements for PM<sub>2.5</sub> were usually low in all departments under study. Among the metals examined, lead (Pb) had the greatest exposure concentration, ranging from  $1.19 \times 10^{-3}$  in the Goat Pen to  $1.81 \times 10^{-3}$  in the Feed Manufacturing department. The Cow Byre had the greatest EC ( $1.36 \times 10^{-3}$ ), followed by Feed Dispatch ( $8.82 \times 10^{-1}$ ) and Feed Manufacturing ( $5.44 \times 10^{-1}$ ). Zinc (Zn) was the second most prevalent metal. Comparatively lower amounts of copper (Cu) were found; the Goat Pen had the highest value ( $5.2 \times 10^{-1}$ ). while cadmium (Cd) was only found at trace quantities, ranging from  $6.9 \times 10^{-1}$  to  $2.0 \times 10^{-1}$  as shown in table 3.12

In all occupational settings, PM<sub>2.5</sub>-associated metal exposure was mostly caused by Pb and Zn. Similar trends were seen for PM<sub>10</sub>, with Pb showing the greatest exposure amounts in all departments, ranging from  $1.76 \times 10^{-3}$  to  $1.81 \times 10^{-3}$ . The Feed Manufacturing department had higher zinc concentrations ( $2.76 \times 10^{-3}$ ), followed by the Goat Pen ( $9.57 \times 10^{-1}$ ), while the other departments had lower amounts. The amounts of copper stayed low, ranging from  $6.3 \times 10^{-3}$  in the Goat Pen to undetectable levels in Milk Extraction. While cadmium was found at trace levels ( $6.3 \times 10^{-1} - 9.4 \times 10^{-1}$ ). These results show that at the dairy farm under study, Pb and Zn were the main causes of metal exposure through coarse particulate matter.

The hazard quotient (HQ) values for all examined metals in both PM<sub>2.5</sub> and PM<sub>10</sub> fractions were significantly below the permitted threshold value of 1 in terms of non-carcinogenic health risk assessment. Cd ( $2.86 \times 10^{-1}$ ) and Zn ( $1.29 \times 10^{-1}$ ) had the greatest HQ values for PM<sub>2.5</sub>, whereas Pb showed HQ values between  $3.40 \times 10^{-1}$  and  $5.18 \times 10^{-1}$ . Similarly, Zn in the Feed Manufacturing sector had the greatest HQ for PM<sub>10</sub> ( $2.63 \times 10^{-1}$ ), followed by Cd ( $1.79 \times 10^{-1} - 2.68 \times 10^{-1}$ ), and copper as shown in table 3.13.

It is becoming significantly established that heavy metals like zinc (Zn) and lead (Pb) are carried by airborne particulate matter (PM), especially PM<sub>10</sub> and PM<sub>2.5</sub>, in cattle production systems, posing serious threats to occupational and environmental health. Recent research indicates that the metal load of particulate matter in dairy farm settings is influenced by both interior and outdoor air. Several heavy metals, including Zn and Pb, were found in airborne particles in research by Zhang et al. (2023) that assessed PM concentrations in dairy barns and found a good connection ( $R = 0.95$ )

between indoor and outdoor PM levels. This result emphasizes how indoor air quality is influenced by both farm-specific activities and ambient pollution sources like traffic and industrial pollutants.

Supporting evidence indicates that agricultural dust in livestock housing environments contains significant concentrations of heavy metals. Compositional analyses conducted in 2015 revealed zinc (Zn) and lead (Pb) as major constituents of respirable particulate matter, with specific concentrations of approximately 448 mg/kg for Zn and 4.77 mg/kg for Pb (Yang et al., 2015). Although the study is older, its findings continue to be referenced in contemporary reviews, which corroborate that the particulate matter in livestock systems is primarily derived from components such as feed particles, manure, animal dander, and soil resuspension. These particulates can bind trace metals and are characterized by fine fractions that exhibit high surface reactivity, allowing them to effectively adsorb and transport metals into the air, consequently affecting the respiratory health of exposed workers (Cambra-López et al., 2010).

The existence of particle emissions that can carry pollutants is further supported by more recent studies of cattle habitats. Livestock activities are major emitters of airborne particulate matter, as evidenced by research done in commercial feedlots that showed detectable emissions of PM<sub>2.5</sub> and PM<sub>10</sub> from cow production systems.

Research specifically focusing on air quality in animal feed manufacturing remains limited; however, existing studies reinforce the notion that Zn- and Pb-containing dust is prevalent in these environments. The processes involved in feed production—including grinding, mixing, and transportation—generate considerable amounts of airborne dust sourced from mineral premixes, contaminated raw materials, and various feed additives known to harbour heavy metals (Adamse et al., 2017; Kim et al., 2018).

The existence of particle emissions that can carry pollutants is further supported by more recent studies of cattle habitats. Livestock activities are major emitters of airborne particulate matter, as evidenced by research done in commercial feedlots that showed detectable emissions of PM<sub>2.5</sub> and PM<sub>10</sub> from cow production systems (Rahimian et al., 2023). These airborne particles can linger in the air and potentially

contribute to occupational exposure for workers in feed mills, with exposure mechanisms akin to those identified in livestock housing settings.

From the perspective of health risk assessment, workers in dairy farms and the feed industry are particularly concerned about occupational exposure to particulate matter containing zinc and lead. The main method of exposure is inhalation, which allows tiny particles (PM<sub>2.5</sub>) to reach the systemic circulation and deeply infiltrate the lung's alveolar area. Even at comparatively low concentrations, chronic lead exposure is linked to neurotoxicity, haematological damage, renal failure, and cardiovascular illnesses (World Health Organization, 2021; Agency for Toxic Substances and Disease Registry, 2020). Even though zinc is a necessary element, excessive inhalation can lead to metal fume fever and respiratory irritation, especially in work environments (Plum et al., 2010; Genchi et al., 2020).

Average daily dose (ADD), hazard quotient (HQ), and hazard index (HI) are common indices used in health risk assessment models to assess exposure. Research has demonstrated that HQ values for lead in particulate matter can surpass safe limits (HQ > 1), indicating possible non-carcinogenic health risks (United States Environmental Protection Agency, 2011; Li et al., 2015). Additionally, long-term exposure to dust containing metals has been linked to long-term respiratory disorders, such as obstructive lung illnesses and airflow restriction, especially in workplaces with high particulate matter concentrations (World Health Organization, 2021).

## EXPOSURE CONCENTRATION

Table 3. 12 . Exposure concentration of heavy metals calculated in selected samples site

|                         | METALS    |    | COW      | GOAT     | FM       | FEED<br>DISPATCH | ME       |
|-------------------------|-----------|----|----------|----------|----------|------------------|----------|
| <b>PM<sub>2.5</sub></b> | <b>Cu</b> | EC | 3.75E-05 | 0.00052  | 6.3E-06  | 3.1E-05          | 3.8E-05  |
|                         | <b>Pb</b> | EC | 1.77E-03 | 1.19E-04 | 1.81E-03 | 1.72E-3          | 1.77E-03 |
|                         | <b>Zn</b> | EC | 1.36E-03 | 3.12E-05 | 5.44E-04 | 8.82E-04         | 4.37E-05 |
|                         | <b>Cd</b> | EC | 1.0E-05  | 8.8E-06  | 8.1E-06  | 6.9E-06          | 2.0E-05  |
|                         |           |    |          |          |          |                  |          |
| <b>PM<sub>10</sub></b>  | <b>Cu</b> | EC | 5E-05    | 6.3E-05  | 3.1E-05  | 3.1E-05          | 0        |
|                         | <b>Pb</b> | EC | 1.81E-03 | 1.80E-03 | 1.76E-03 | 1.79E-03         | 1.79E-03 |
|                         | <b>Zn</b> | EC | 3.82E-04 | 9.57E-04 | 2.76E-03 | 4.88E-04         | 5.13E-05 |
|                         | <b>Cd</b> | EC | 6.9E-06  | 6.3E-06  | 8.1E-06  | 9.4E-06          | 8.1E-06  |

## HAZARD QUOTIENT

Table 3. 13 . Hazard quotient of heavy metals calculated in selected sample sites

|                         | METALS    |    | COW      | GOAT     | FM       | FEED<br>DISPATCH | ME       |
|-------------------------|-----------|----|----------|----------|----------|------------------|----------|
| <b>PM<sub>2.5</sub></b> | <b>Cu</b> | HQ | 2.68E-11 | 3.71E-10 | 4.47E-12 | 2.23E-11         | 2.68E-11 |
|                         | <b>Pb</b> | HQ | 5.06E-07 | 3.40E-08 | 5.18E-07 | 4.91E-07         | 5.06E-07 |
|                         | <b>Zn</b> | HQ | 1.29E-06 | 2.97E-08 | 5.18E-07 | 8.40E-07         | 4.16E-07 |
|                         | <b>Cd</b> | HQ | 2.86E-06 | 2.50E-06 | 2.32E-06 | 1.97E-06         | 2.86E-06 |
|                         |           |    |          |          |          |                  |          |
| <b>PM<sub>10</sub></b>  | <b>Cu</b> | HQ | 3.57E-11 | 4.46E-11 | 2.23E-11 | 2.23E-11         | 0        |
|                         | <b>Pb</b> | HQ | 5.16E-07 | 5.13E-07 | 5.04E-07 | 5.11E-07         | 5.11E-07 |
|                         | <b>Zn</b> | HQ | 3.63E-07 | 9.11E-07 | 2.63E-06 | 4.65E-07         | 4.88E-07 |
|                         | <b>Cd</b> | HQ | 1.97E-06 | 1.79E-06 | 2.32E-06 | 2.68E-06         | 2.32E-06 |

### 3.9 Lifetime cancer risk

The Lifetime Cancer Risk (LTCR) is the probability that an individual will develop or die from cancer over their course of their lifespan. LTCR assessment for cadmium (Cd) associated with PM<sub>2.5</sub> and PM<sub>10</sub> fractions reveals critical insights into potential health risks across various departments. LTCR values for Cd in PM<sub>2.5</sub> ranged from  $3.44 \times 10^{-5}$  to  $5.00 \times 10^{-5}$ , while those for PM<sub>10</sub> ranged from  $3.13 \times 10^{-5}$  to  $4.69 \times 10^{-5}$ . The highest LTCR for PM<sub>2.5</sub> was recorded in the Cow Byre and Milk Extraction departments (both  $5.00 \times 10^{-5}$ ), with the lowest observed in the Feed Dispatch department ( $3.44 \times 10^{-5}$ ). In contrast, the Feed Dispatch department exhibited the highest LTCR for PM<sub>10</sub> ( $4.69 \times 10^{-5}$ ), while the Goat department had the lowest ( $3.13 \times 10^{-5}$ ) as shown in table 3.14.

All LTCR values fell within the acceptable range of  $10^{-6}$  to  $10^{-4}$  as per the United States Environmental Protection Agency (USEPA), recommended a tolerable cancer risk. However, the proximity of the values to the upper limit raises concerns regarding the long-term carcinogenic potential of chronic occupational exposure to cadmium-containing particulates (Zheng et al., 2010). Continuous exposure

necessitates the implementation of occupational exposure control measures and routine environmental monitoring to mitigate health risks for workers.

The study focused solely on cadmium for LTCR calculations because it is classified as a carcinogenic heavy metal with a recognized inhalation cancer slope factor. Lifetime cancer risk assessments were not conducted for other metals such as copper (Cu), lead (Pb), or zinc (Zn) due to either the lack of detected concentrations, absence of carcinogenic classification for inhalation exposure, or unavailability of necessary cancer slope factor values for estimation. This targeted approach underscores the significance of cadmium as a health risk factor in occupational settings.

*Table 3. 14 Lifetime cancerous risk of cadmium calculated in selected sample sites*

| <b>Departement</b> | <b>LTCR</b> | <b>Cd PM<sub>2.5</sub></b> | <b>Cd PM<sub>10</sub></b> |
|--------------------|-------------|----------------------------|---------------------------|
| COW                | LTCR        | 5.0E-05                    | 3.44E-05                  |
| GOAT               | LTCR        | 4.38E-05                   | 3.13E-05                  |
| FM                 | LTCR        | 4.07E-05                   | 4.07E-05                  |
| FEED DISPATCH      | LTCR        | 3.44E-05                   | 4.69E-05                  |
| ME                 | LTCR        | 5.0E-05                    | 4.07E-05                  |

## **CONCLUSIONS:**

- Ambient air quality assessment showed significant variations in PM<sub>2.5</sub> and PM<sub>10</sub> concentrations, with the highest levels found in the Feed Manufacturing department, all exceeding WHO guideline values.
- Lung function evaluation indicated varied spirometric parameters (FVC, FEV<sub>1</sub>, PEF) across departments; obstructive lung diseases were found in exposed workers and mixed lung disease was exclusive to this group, suggesting adverse respiratory effects.
- Heavy metal analysis (Pb, Cd, Zn, Cu) in particulate samples met Occupational Exposure Limit standards, but a negative correlation was noted between zinc concentration and FVC, indicating possible impacts on pulmonary function from particulate-bound metals.
- Health risk assessment showed all Hazard Quotient values below permissible limits by the US EPA, indicating low non-carcinogenic risk, with Lifetime Cancer Risk values for cadmium also within acceptable ranges.

## RECOMMENDATIONS

- Regular monitoring of PM<sub>2.5</sub>, PM<sub>10</sub>, and heavy metal concentrations in selected dairy farm and feed manufacturing industry should be done to assess air quality and to ensure environmental, human and cattle health.
- Effective dust control measures, including proper ventilation systems, enclosure of feed processing units, and water spraying techniques, should be adopted to minimize particulate exposure.
- Personal protective equipment (PPE), such as face masks and protective clothing, must be obligatory for workers in high-exposure areas.
- Periodic medical check-ups, including spirometry testing, must be conducted for early detection of respiratory impairments among workers.
- Awareness and training programs should be organized to educate workers about occupational hazards, safe handling practices, and the importance of protective measures.
- Future research on dairy farms and feed manufacturing industries across various regions of Pakistan should be conducted that assessed site-specific particulate matter concentrations (PM<sub>10</sub> and PM<sub>2.5</sub>) and explicitly linked them with lung function results in dairy farm and feed sector workers.
- Additional contaminants that may cause respiratory impairment, such as bioaerosols, endotoxins, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and persistent organic pollutants (POPs), should be analyzed in order to fully characterize particulate matter.
- To evaluate the bioaccumulation and transfer of heavy metals from the workplace to employees and livestock products, biomonitoring investigations using blood, urine, hair, or milk samples should be carried out.
- Seasonal monitoring should be performed to determine how climatic factors such as temperature, humidity, wind speed, and farming activities influence particulate matter concentrations and worker exposure throughout the year.

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## ANNEX I

### Worker survey form for demographic information

| No. | Name | Age | Height<br>(foot) | Weight<br>(kg) | Smoker/<br>Non-<br>smoker | Total job<br>years | Dairy<br>Farm<br>workers | Cattle feed<br>Workers |
|-----|------|-----|------------------|----------------|---------------------------|--------------------|--------------------------|------------------------|
|     |      |     |                  |                |                           |                    |                          |                        |
|     |      |     |                  |                |                           |                    |                          |                        |
|     |      |     |                  |                |                           |                    |                          |                        |
|     |      |     |                  |                |                           |                    |                          |                        |
|     |      |     |                  |                |                           |                    |                          |                        |
|     |      |     |                  |                |                           |                    |                          |                        |
|     |      |     |                  |                |                           |                    |                          |                        |
|     |      |     |                  |                |                           |                    |                          |                        |

## ANNEX II

### Photographs taken during sampling



*Figure 1 Particulate Matter sampling at the feed dispatch site.*



*Figure 2 Particulate Matter sampling at feed manufacturing site.*



*Figure 3 Particulate Matter sampling at Cow Byre site.*



*Figure 4 Particulate Matter sampling at Goat Pen site.*



*Figure 5 Particulate Matter sampling at the milk extraction site.*

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Matches with in-text citation present, but no quotation marks

### Top Sources

- 11%  Internet sources
- 8%  Publications
- 10%  Submitted works (Student Papers)

### Integrity Flags

0 Integrity Flags for Review

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.