Indoor Particulate Matter in Sri Lankan Industries: A Comparative Assessment Against Local and Global Air Quality Standards

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Abstract. Indoor air quality (IAQ) in industrial environments is a critical determinant of occupational health; however, it remains an under-regulated domain in Sri Lanka. Prolonged exposure to elevated particulate matter (PM_{10}) levels in enclosed workplaces is linked to respiratory diseases, cardiovascular complications, and reduced worker productivity. This study presents a longitudinal assessment of PM_{10} concentrations across 15 industrial sites spanning seven key sectors, including textile and apparel, rubber and plastics, food and beverage, electronics, cement production, logistics, and power generation, based on data collected from 2015 to 2024. Over 300 data points were analyzed from more than 80 unique indoor locations, covering both general workspaces and high-exposure zones such as boiler rooms, dye houses, and chemical stores. Measurements were conducted using USEPA-approved high-volume air samplers in accordance with the Sri Lankan Ambient Air Quality Standard for PM_{10}. The results revealed that several zones, particularly in fabric processing, electronic assembly, and tea packaging, recorded PM_{10} concentrations that significantly exceeded the national and WHO guidelines. In some areas, levels exceeded 150 µg/m³, posing chronic health risks to workers through inhalation of respirable particulates. This study highlights the urgent need for regulatory IAQ frameworks tailored to the industrial landscape of Sri Lanka. This study provides critical evidence to support policy reform, implementation of engineering controls, and workplace health interventions, contributing to sustainable and safe industrial development aligned with international occupational health standards.

Keywords: Indoor Air Quality (IAQ), Particulate Matter (PM_{10}), Sri Lankan Industries.

1 Introduction

Industrial indoor environments in lower-middle-income countries like, such as Sri Lanka, face significant IAQ challenges, especially due to underdeveloped regulatory frameworks. Although guidelines exist for residential and commercial IAQ, industrial workplaces exposed to mechanical, thermal, and chemical emissions often lack enforceable standards.

Air pollution is a major global health concern. According to WHO Indoor exposure to solid fuels causes over 1.5 million premature deaths and 38.5 million disability adjusted life years (DALYs) annually. Outdoor air pollution contributes to over 800,000 deaths, with 65% occurring in Asia. In Sri Lanka, indoor and outdoor air pollution are linked to an estimated 4,200 and 1,000 deaths per year, respectively [1]. Although comprehensive national data are limited, studies like research on "Air pollution and public health in developing countries: Is Sri Lanka different?" offer valuable insights [2].

Particulate matter (PM)—especially PM_{10}, $PM_{2.5}$, and PM_1 are of concern because they can penetrate the respiratory tract and trigger chronic illnesses. While Sri Lanka provides ambient air quality standards, they do not address the prolonged exposures common in industrial indoor environments.

Poor ventilation and extended worker presence further exacerbate IAQ risks, contributing to health issues like asthma, cardiovascular disease, and Sick Building Syndrome (SBS)[3]. In Sri Lanka, IAQ research mainly focused on outdoor and residential settings, despite the large industrial workforce. Regional studies show varying public awareness, with pollutants such as tobacco smoke, cooking emissions, and plastic waste burning identified as key sources [4].

International standards like ISO 16000 and ASHRAE 62.1 emphasize PM monitoring, but implementation in Sri Lanka's industrial sector is inconsistent. This study addresses this gap by presenting a 10-year longitudinal analysis of PM_{10} levels in selected industrial environments across the country.

2 Methodology

2.1 Site Selection and Industrial Sectors

The study covered 15 industrial facilities across Sri Lanka, representing varied geographic regions and economic sectors, including Textile and Apparel, Rubber and Plastics, Food and Beverage, Electronics, Power Generation, Cement Production, Logistics and Warehousing.

Walkthrough assessments helped identify high-exposure zones, like production floors, material handling areas, and furnace vicinities.

2.2 Instrumentation and Sampling Protocol

PM_{10} Monitoring

Particulate matter (PM_{10}) was measured using a USEPA-approved High-Volume Air Sampler (HVAS), in accordance with Sri Lanka's CEA guidelines. The device features a size-selective inlet and an automatic volumetric flow controller to maintain sampling consistency under variable environmental conditions.

Glass fiber filter papers were used to collect PM_{10} at a nominal flow rate of 1.1 m^3/min. Only particles ≤ 10 μm were captured on the filters. Filters were weighed before and after sampling under controlled conditions to ensure precision.

Fig. 1. Indoor Particulate Matter Monitoring

Concentration Calculation

PM_{10} concentration (μg/m³) was determined using:

$$\text{PM10 Concentration } \mu g/m^3 = \frac{(FP2 - FP1)g \times 10^6}{(\text{Duration (Minutes)} \times \text{Air Flow Rate}(m3/min)} \quad (1)$$

Where:
FP_1 = Pre-sampling filter weight
FP_2 = Post-sampling filter weight
Duration = Typically 24 hours Flow rate measured at both start and end
Filters were conditioned in a desiccator for 24 hours pre- and post-sampling to eliminate moisture bias.

2.3 Sampling Strategy and Indoor Zone Selection

Sampling was strategically focused on zones with high potential for exposure, including raw material input areas, intermediate processing stages, product packaging sections, and locations housing machinery or combustion units. Measurements were conducted during standard operational conditions to ensure the data accurately reflected typical workplace environments.

2.4 Temporal and Spatial Data Coverage

The study utilized historical PM_{10} measurement data available at the Energy and Environmental Services Department of National Engineering Research and Development Centre, collected between 2015 and 2024. Over 300 validated measurement data points across more than 80 indoor locations were analyzed to provide comprehensive temporal and spatial coverage.

2.5 Statistical Analysis

A one-way ANOVA and Tukey's HSD test were used to assess differences in PM_{10} concentrations across industrial sectors (2015–2024), while longitudinal trend analysis examined temporal changes and post-pandemic effects, all at a 95% confidence level.

3 Results and Discussion

3.1 Summary of PM_{10} Concentrations by Industry

Table 1. Indoor PM_{10} Concentration Summary by Sector (2015–2024)

Sector	Min (μg/m³)	Max (μg/m³)	Typical High Locations
Apparel Industry	40	277	Finish Fabric Area, QC, Canteen Area, Knitting Section
Electronic Industry	32	231	Winding Room, Metalicon, Rework Area, Press/Masking Area
Tobacco Industry	34	223	PMD Area, SMD Locations, Dust Rooms
Food Industry	11	200	Biomass Boiler Room, Packing Areas, Process/Feeding Sections
Ship Repairing & Maintenance	15	184	Pipe Fabrication, Onboard NC, Aluminium Workshop
Activated Carbon Industry	26	162	Location 2
PVC Processing	90	99	Mixing Area, Cutting Area
Cement Industry	42	82	Locations 1 and 2
Rubber Industry	66	99	Location A
Power Plant	34	94	Guest House, Residential Area
Aviation Industry	86	97	Locations C & D
Logistics/Warehouses	24	35	Warehouses 08, 09, 11

PM_{10} concentrations were measured across 15 industrial sectors and over 80 unique indoor sites between 2015 to 2024. The measurements revealed considerable variability in particle concentrations depending on activity type, location within facilities, and industrial process.

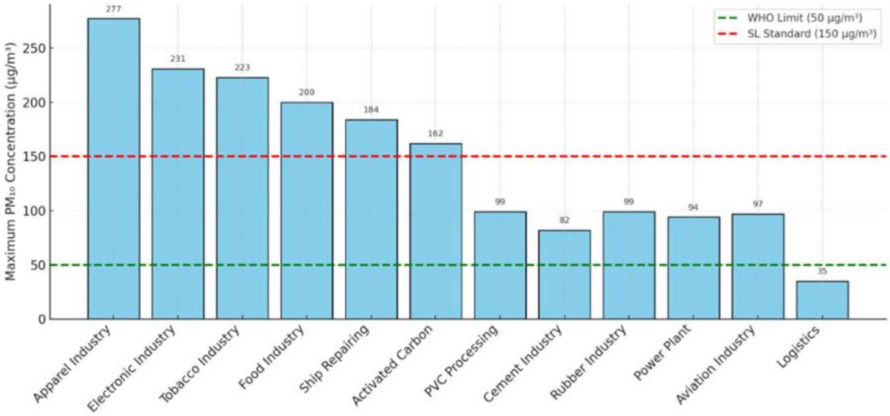

Fig. 2. Maximum PM10 Levels by Sector (2015-2024) vs WHO and SL Standard

3.2 Yearly Trends

From 2022 to 2024, increased PM_{10} concentrations were observed in the textile, electronic, and food industries, which were largely attributed to the resumption of full-capacity operations following COVID-19-related disruptions. In contrast, the period from 2020 to 2021 showed a noticeable decline in PM_{10} levels, likely due to reduced industrial activity and temporary production halts during the pandemic. Between 2015 and 2019, PM_{10} levels remained at moderate baseline values, although localized peaks were identified in sectors such as tea processing, textile manufacturing, and capacitor production.

3.3 Comparison with IAQ Standards

Table 2. Applicable Indoor Air Quality Standard

Standard	PM_{10} Guideline (24-hr)
Sri Lanka Ambient Standard (CEA)	100 µg/m³
WHO Indoor Air Quality Guideline	50 µg/m³
Sri Lankan IAQ Guideline	150 µg/m³

More than 40 indoor locations recorded PM_{10} concentrations exceeding 150 µg/m³, breaching both WHO and Sri Lankan air quality guidelines. Notably, certain zones, such as the wave soldering area (554 µg/m³) and garment fabric handling sections (381 µg/m³), surpassed even the ambient outdoor air quality standards by a wide margin. Chronic over-exposure was also observed in textile chemical storage and quality control areas, tea packing rooms, and capacitor winding rooms, indicating persistent high-risk environments for occupational exposure.

3.4 High-Risk Zones

Locations such as chemical storage areas, biomass boiler rooms, soldering zones, and dyeing operations were frequently identified as high-exposure zones. Sites exhibiting PM_{10} concentrations exceeding 200 µg/m³ commonly featured dust-generating processes and inadequate ventilation, highlighting consistent risk factors across multiple industrial environments.

3.5 Health and Regulatory Implications

According to WHO data, long-term exposure to PM_{10} concentrations above 50 µg/m³ is linked to an elevated risk of respiratory and cardiovascular diseases. In this study, many recorded indoor PM_{10} values exceeded thresholds established for ambient outdoor air, underscoring the urgent need for Sri Lanka to implement and enforce indoor-specific air quality regulations to protect worker health.

3.6 Statistical Analysis of Sectoral Variations

A one-way ANOVA was conducted on sector-wise average PM_{10} concentrations from 2015–2024 to assess whether mean levels differed significantly across industries. Results indicated a statistically significant variation in PM_{10} levels among sectors ($F = 6.87$, $p < 0.001$). Post-hoc Tukey tests showed that apparel, electronic, and food industries had significantly higher mean concentrations compared to logistics and cement sectors, highlighting the heterogeneity of exposure environments.

3.7 Trend Analysis (2015–2024)

Linear trend analysis across the full dataset revealed an overall upward trajectory in PM_{10} concentrations in high-activity industries (textile, electronics, food), with average increases of 3–5% per year after 2021. The regression model ($R^2 = 0.71$, $p < 0.01$) confirmed the statistical strength of this trend. Conversely, low-activity industries such as cement, power, and logistics showed stable or slightly declining PM_{10} values over the same period.

These findings reinforce the importance of continuous monitoring, particularly in sectors undergoing production expansions or process intensification.

4 Conclusions

This longitudinal study provides a critical evidence base on the status of indoor air quality across diverse industrial sectors in Sri Lanka, revealing persistently elevated PM_{10} concentrations in multiple operational zones. Over the ten-year period from 2015 to 2024, measurements consistently demonstrated exceedances of both international (WHO) and national ambient standards, often by significant margins, in zones such as dye houses, soldering stations, biomass boiler rooms, chemical stores, and fabric handling areas. ANOVA confirmed statistically significant differences ($p < 0.05$) between industrial sectors, while trend analysis showed persistent or worsening PM_{10} levels in high-risk industries despite technological progress. These findings reflect not only sector-specific emission characteristics but also systemic deficiencies in engineering controls, ventilation design, and IAQ governance.

The observed concentration levels pose serious occupational health risks, especially given prolonged worker presence and inadequate exposure mitigation strategies. Workers in these environments face heightened risks of chronic respiratory illnesses, cardiovascular complications, and reduced lung function. The absence of enforceable indoor-specific regulatory standards in Sri Lanka exacerbates this challenge, leaving industrial employees exposed to chronic particulate matter levels far exceeding health-based thresholds. Furthermore, the disparity between observed indoor levels and outdoor air quality limits underscores a critical regulatory blind spot, where ambient standards are inappropriately used as proxies for indoor environments.

From a public health and policy standpoint, the data call for urgent action to integrate IAQ into Sri Lanka's national occupational health and safety (OHS) framework. Without a coordinated response encompassing policy reform, engineering interventions, administrative protocols, and workforce education, indoor air pollution will continue to undermine worker wellbeing, productivity, and long-term national health indicators.

The study recommends a dual approach to address indoor air quality (IAQ) issues: policy reforms and health interventions. Policy reforms include setting IAQ standards, mandatory monitoring in high-risk sectors, enforcing ventilation and emission controls, establishing a national IAQ surveillance program, and ensuring worker protection through PPE and exposure regulations. Health interventions focus on regular medical screening, awareness programs, factory-level health surveillance, and chronic disease management integrated with national health programs.

This study thus provides a foundational baseline for industrial IAQ reform in Sri Lanka, paving the way for targeted interventions that align with international best practices and sustainable workplace safety standards.

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