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Short-term Monitoring of Indoor Particulate Matter (PM) Using Low-cost Sensors in a Residential Environment in Bengaluru, India

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ABSTRACT

Indoor air quality is an important factor in maintaining a healthy living environment. In this study, indoor particulate matter concentrations (PM_1, $PM_{2.5}$ and PM_{10}) were monitored in a residential living room in Bengaluru, India which is naturally ventilated, using a low-cost SmileDrive air quality sensor. Measurements were taken at hourly intervals over three consecutive days from 18 to 20 March 2025, along with temperature and relative humidity. The results showed that particulate matter concentrations varied throughout the day, with PM_{10} recording higher values than $PM_{2.5}$ and PM_1. The daily mean concentrations ranged from 10.47–12.24 μg m^{-3} for PM_1, 14.26–16.76 μg m^{-3} for $PM_{2.5}$, and 16.21–19.24 μg m^{-3} for PM_{10}. Overall, the measured concentrations indicated relatively good indoor air quality during the monitoring period. Temperature and relative humidity also showed normal daily fluctuations. An analysis of the relationship between relative humidity and particulate matter concentrations revealed that the strength of the correlation varied across the three days, with stronger associations observed on 19 and 20 March 2025. The study demonstrates that low-cost sensors can be effectively used for short-term indoor air quality monitoring and can give useful information on the behaviour of particulate matter in residential environments.

Keywords: Indoor Air Quality; Low-Cost Sensors; Particulate Matter; Relative Humidity (RH); Correlation; Temperature; PM Concentration; Naturally Ventilated; Monitoring; Residential Environment.

1.0. Introduction

The indoor environment has particulates as one of the major air pollutants (PM). The particulate matter is a mixture of solid and/or liquid particles suspended in the air and is composed of organic compounds, ammonium, nitrates, sulphates, metals, and other ions [1]. PM can be classified according to its size into PM_{10}, $PM_{2.5,}$ and PM_1; however, the two main concerns deal with the fine particulate sizes of particles ($PM_{2.5}$ & PM_1) that are able to penetrate deeply into the lungs and, in some circumstances, enter the bloodstream [2]. The outdoor PM in cities in India is highly elevated because of road dust, construction activities, traffic, and other sources of outdoor pollution, which can dramatically deteriorate the quality of indoor air and lead to an increase in the amount of PM in places of residence through natural ventilation and building leakage [3]. The poorly ventilated indoor spaces rapidly accumulate dangerous thresholds of finer particles, and adaptation of mechanical ventilation thereby improves the indoor air quality [4, 5].

In addition, indoor activities such as cooking, using incense or burning candles, smoking, cleaning, and moving around the house will affect the concentration of indoor PM [6]. Many studies reported that exposure to indoor PM have serious health effects, including asthma, Chronic Obstructive Pulmonary Disease (COPD), cardiovascular disease, and lung cancer [7]. Therefore, the study of indoor air quality for public health becomes important as majority of an individual's time is spent indoors [8]. Hourly monitoring is therefore helpful for understanding the variation in PM levels. The use of standard instruments for measuring indoor PM levels is limited by their high cost, despite their precision. Low-cost PM sensors have become an alternative option for monitoring indoor air quality, and when used properly, they provide temporal patterns in PM concentration [9].

This study aims to evaluate the hourly variation in indoor PM_{10}, $PM_{2.5}$, and PM_1 concentrations in a residential living room in Bangalore over three consecutive days using a low-cost sensor. The results provide insight into short-term indoor particulate matter behaviour in an urban Indian residential setting and contribute to the limited database on indoor air quality in Indian homes.

1.1. Objectives

1) To monitor indoor concentrations of PM_1, $PM_{2.5}$ and PM_{10} in a residential living room in Bengaluru using a low-cost air quality sensor.
2) To examine the hourly variation of indoor particulate matter concentrations during the monitoring period.
3) To determine the daily mean concentrations of PM_1, $PM_{2.5}$ and PM_{10} and compare them with recommended air quality guidelines.
4) To monitor indoor temperature and relative humidity and evaluate their variation during the study period.
5) To study the relationship between relative humidity and indoor particulate matter concentrations.

2.0. Materials and Methods

2.1. Study Area

The study was conducted in a residential living room located in Bengaluru, Karnataka, India (12.931965° N, 77.558627° E). The study area is situated away from major roads and heavy traffic zones, thereby reducing the direct influence of vehicular emissions on indoor air quality. The living room measured approximately 3.66 m × 4.88 m (20.8 m^2) and was occupied by six residents. The room was naturally ventilated through windows and a main door, allowing regular exchange of indoor and outdoor air. Two bedrooms were located adjacent to the living room, contributing to normal indoor human activity and airflow interactions within the household.

2.2. Instrumentation

Air quality in the building was measured using a SMILEDRIVE portable air quality monitor (Version 1.0). This equipment is low-cost and detects particulate matter concentrations, including PM_{10}, $PM_{2.5}$, and PM_1, as well as indoor parameters such as temperature and humidity. The instrument operates on the principle of an optical light-scattering sensor in the monitor, which uses light to detect airborne particles and provides real-time measurements through a digital display.

2.3. Monitoring Procedure

Monitoring was conducted continuously for three days under normal residential conditions, without altering the occupants daily activities. The particulate matter concentrations (PM_1, $PM_{2.5}$, and PM_{10}) and meteorological parameters, such as temperature and relative humidity (RH), were recorded at 1-hour intervals throughout the monitoring period.

The air quality detector was positioned at a height of approximately 4 ft (1.2 m) above floor level, corresponding to the average human breathing zone. The instrument was placed at a suitable indoor location, away from direct

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airflow from windows or doors and from local emission sources, to measure only indoor particulate matter concentrations.

2.4. Data Collection and Analysis

Hourly measurements of PM_1, $PM_{2.5}$, and PM_{10} concentrations, along with the parameters -temperature and RH, were recorded and tabulated for further analysis. The collected data were examined to study the hourly and daily variations in indoor particulate matter levels and the relationship between PM concentration and RH during the study period. Graphical representations and statistical methods were used to interpret temporal trends in indoor PM concentrations in residential environments.

2.5. Limitations of the Study

The study was conducted over a short monitoring duration in a single residential setting; therefore, the results may not represent long-term indoor air quality conditions in all residential environments. In addition, low-cost sensors may show slight variations in accuracy compared to reference-grade instruments; however, they are useful for short-term monitoring and trend analysis of indoor particulate matter levels.

3.0. Results and Discussion

3.1. Hourly Variation of Indoor PM_1, $PM_{2.5}$, and PM_{10} Concentrations

Indoor PM_1, $PM_{2.5}$, and PM_{10} concentrations measured at 1-hour intervals over three consecutive days are shown in Figure 1. The results indicate substantial temporal variation in concentrations of particulate matter throughout the study period and demonstrate that indoor air quality (in residential settings) is dynamic.

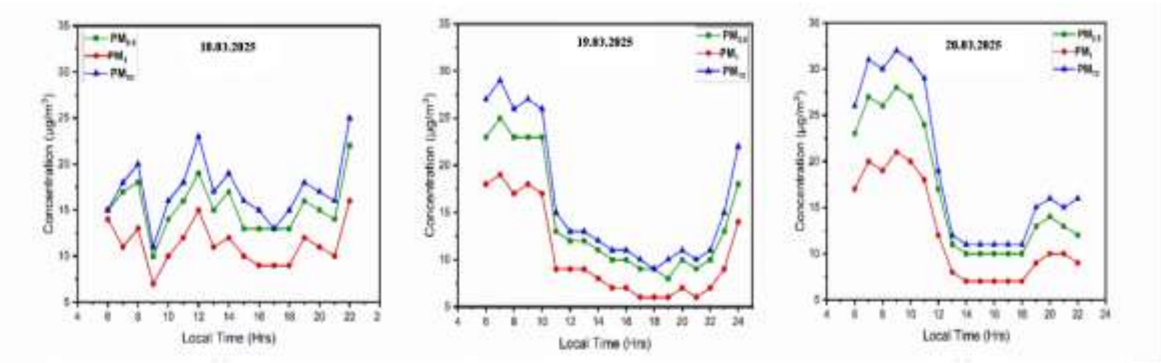

Figure 1. Hourly variation of indoor PM_1, $PM_{2.5}$ & PM_{10} on (a) 18.03.2025 (b) 19.03.2025 & (c) 20.03.2025.

In all three monitoring days, PM_{10} concentrations consistently exceeded those of $PM_{2.5}$ and PM_1, following the order $PM_{10} > PM_{2.5} > PM_1$. This pattern suggests a predominance of coarse particles in the indoor environment, likely due to the resuspension of settled dust by occupant movement and household activities. Comparable findings have been documented in residential indoor environments, where human activities have been shown to significantly influence coarse particulate matter concentrations [10, 11].

The hourly plots indicated that particulate matter concentrations were generally high in the morning and evening and low in the afternoon. The high PM levels in the morning might be linked to routine household activities such as cleaning, occupant movement, and cooking emissions. Evening peaks may similarly be linked to increased indoor occupancy and reduced ventilation conditions. Previous studies have reported that indoor PM concentrations are strongly influenced by occupant activities, ventilation characteristics and indoor emission sources within residential buildings [12, 13]. The observed reduction in PM concentrations during the afternoon may be attributed to reduced indoor activity and enhanced natural ventilation through windows and doors, which promotes the exchange of indoor and outdoor air and helps to dilute indoor pollutants. The increased PM concentration during afternoon hours on 18.03.2025 is due to an increase in the number of occupants and cooking activities.

On 18.03.2025, throughout the monitoring period, moderate fluctuations in PM concentrations were observed, with gradual increases in the late evening hours. On 19.03.2025, relatively lower PM levels were measured compared to the other two monitoring days, indicating comparatively stable indoor conditions and improved dilution of indoor pollutants. On the other hand, the measurements from 20.03.2025 showed comparatively higher PM concentrations, especially in the evening, which may indicate increased indoor particulate generation or reduced ventilation efficiency that day.

The temporal variation observed in this study demonstrates that indoor particulate matter concentrations vary markedly over short time scales and are influenced by indoor occupancy patterns, ventilation conditions, and routine residential activities. The results further indicate that low-cost portable sensors can effectively capture hourly variations in indoor PM concentrations and serve as useful tools for short-term indoor air quality assessment.

3.2. Daily Mean Concentration of Indoor Particulate Matter

Figure 2 displays the daily mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} measured during the course of the three-day monitoring period. The study shows that particulate matter levels in residential living rooms vary noticeably on a daily basis. For all particulate matter fractions, the lowest values were observed on March 19, 2025, whereas the highest daily mean concentrations were observed on March 20, 2025, among the three monitoring days.

The daily mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} recorded during the study period ranged from 10.47–12.24 µg m^{-3}, 14.26–16.76 µg m^{-3}, and 16.21–19.24 µg m^{-3}, respectively. The observed concentration levels indicate relatively good indoor air quality within the monitored residential environment, with only minor day-to-day variations.

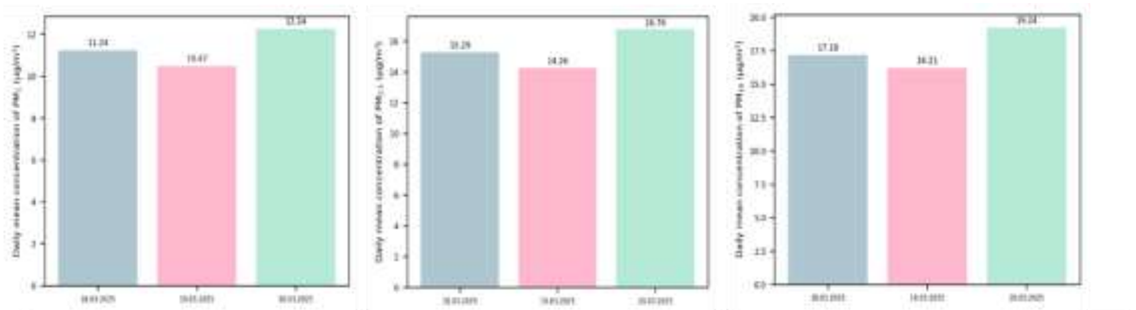

Figure 2. Daily Mean Concentration of PM_1, $PM_{2.5}$ and PM_{10} in Residential Living Room for 3.

The measured $PM_{2.5}$ concentrations, when compared with the World Health Organisation (WHO) 2021 Air Quality Guidelines, remained close to the recommended 24-hour guideline value of 15 µg m^{-3}, with only slight exceedances observed on certain days. Although the WHO does not provide a guideline value for PM_1, recorded PM_1 concentrations were consistently lower than those of $PM_{2.5}$ and PM_{10}. Similarly, measured PM_{10}

concentrations were well below the WHO 24-hour guideline value of 45 μg m^{-3}. These relatively low concentrations of PM_1, $PM_{2.5}$, and PM_{10} are likely attributable to the monitored residence's location away from major traffic roads, which minimises contributions from direct vehicular emissions. Indoor activities may have played a dominant role in influencing the measured particulate matter levels. Similar findings have been reported in previous studies investigating indoor particulate matter dynamics in naturally ventilated residential environments [14].

3.3. Variation of Indoor Temperature and Relative Humidity

Indoor temperature and relative humidity exhibited normal diurnal variations during the three-day monitoring period and are shown in Figure 3. The temperature was generally lower in the morning and increased gradually in the afternoon, while relative humidity showed the opposite trend, with higher values during cooler periods and lower values during warmer periods. The variations observed in temperature and relative humidity levels were indicative of the impact of natural ventilation and the current atmospheric conditions outside buildings. In general, throughout the study period, the temperature and relative humidity inside the buildings were moderate, which were good conditions for measuring particulate matter levels throughout multiple time frames.

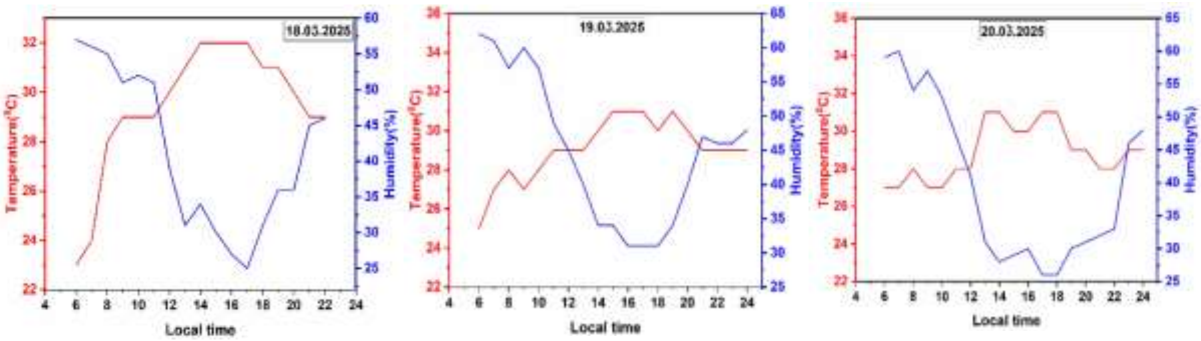

Figure 3. Hourly Variation of Indoor Temperature and Relative Humidity During (a) 18.03.2025 (b) 19.03.2025 (c) 20.03.2025.

3.4. Relationship Between Relative Humidity and PM Concentrations

The relationship between relative humidity (RH) and indoor particulate matter concentrations was examined using scatter plots for the three monitoring days, as shown in Figure 4. The results showed that the strength of the relationship between RH and particulate matter varied from day to day.

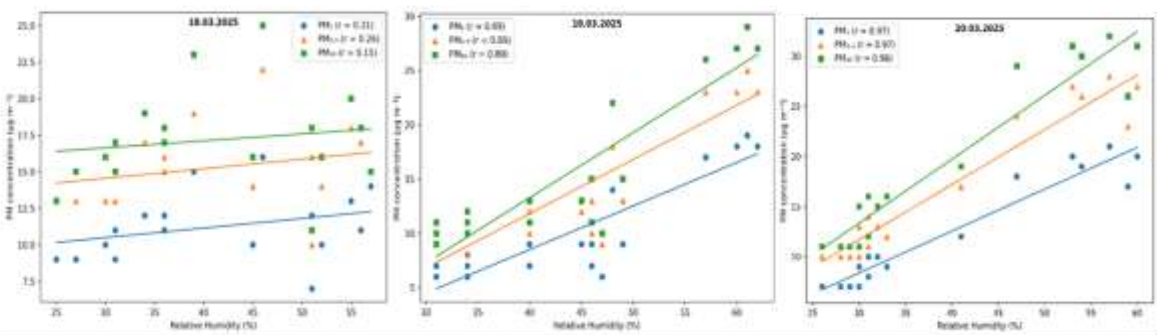

Figure 4. Scatter plot of PM_1, $PM_{2.5}$, and PM_{10} against relative humidity for (a) 18.03.2025 (b) 19.03.2025 (c) 20.03.2025.

From the figure, it is clear that a weak positive correlation was observed between RH and PM concentrations on 18 March 2025, with correlation coefficients of 0.31, 0.26, and 0.15 for PM_1, $PM_{2.5}$, and PM_{10}, respectively. This indicates that relative humidity had only a limited influence on particulate matter levels on that day. In contrast, strong positive correlations was observed on 19 March 2025, with correlation coefficients of 0.89 for PM_1, $PM_{2.5}$ and PM_{10}. A similar trend was observed on 20 March 2025, with very strong positive correlations of 0.97, 0.97, and 0.96 for PM_1, $PM_{2.5}$, and PM_{10}, respectively. These results indicate that particulate matter concentrations generally increased as relative humidity increased over these two days. The stronger correlations observed on 19 and 20 March suggest that humidity played an important role in influencing indoor particle concentrations during these periods. Higher humidity can promote the growth of airborne particles by increasing their moisture content, resulting in higher measured particulate matter concentrations. However, the weaker relationship observed on 18 March suggests that factors such as ventilation, occupant activities, and indoor air movement may also have influenced the PM levels.

Previous studies have reported a negative correlation between PM_1 concentration and RH, as these particles absorb moisture and agglomerate into larger particles, reducing their number in the air [15]. The researcher also studies that $PM_{2.5}$ has a positive correlation with RH, whereas PM_{10} has a negative correlation with RH **[16]**. The study also reported that by maintaining indoor RH at around 50% or higher can help reduce the concentration of some particulate matter components **[17].** Thus, the results suggest that relative humidity had a noticeable effect on indoor particulate matter concentrations, particularly during periods of higher humidity. However, indoor PM levels were influenced by a combination of environmental and indoor factors rather than humidity alone.

4.0. Conclusion

This study evaluated indoor particulate matter levels in a residential living room in Bengaluru using a low-cost air quality sensor over three consecutive days. The measurements showed that PM_1, $PM_{2.5}$ and PM_{10} concentrations varied throughout the day, with PM_{10} consistently recording higher values than $PM_{2.5}$ and PM_1. However, the overall particulate matter levels remained relatively low during the monitoring period, indicating satisfactory indoor air quality within the residence.

The results also showed that temperature and relative humidity changed throughout the day and influenced indoor environmental conditions. A relationship between relative humidity and particulate matter concentrations was observed, particularly on 19 and 20 March 2025, with higher humidity associated with higher PM concentrations. This suggests that humidity may affect indoor particle behaviour.

Overall, the study demonstrates that low-cost sensors can be effectively used for short-term indoor air quality monitoring. The findings provide useful information on indoor particulate matter levels in naturally ventilated residential environments and highlight the importance of considering environmental factors such as relative humidity when assessing indoor air quality.

5.0. Future Recommendations

This study was conducted in one residential living room for a short monitoring period of 3 days. Further studies with longer monitoring periods over different seasons can help to better understand the changes in particulate matter concentrations indoors. Monitoring in various rooms and houses can also provide a better insight into the indoor air quality. Moreover, investigation of the influence of factors such as occupancy, ventilation practices and activities in households would be helpful in identifying the major sources affecting the indoor particulate matter levels.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not–for–profit sectors.

Competing Interests Statement

The authors declare no competing interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors conceptualized the study, performed data analysis, and prepared the manuscript.

Availability of data and materials

Authors are willing to share data and material on request.

Ethical Approval

Not applicable for this study.

Institutional Review Board Statement

Not applicable for this study.

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