



COMPARATIVE ANALYSIS OF PM₁₀ CONCENTRATIONS BETWEEN SEMI-ENCLOSED AND ENCLOSED STATIONS OF MASS RAPID TRANSIT IN KLANG VALLEY, MALAYSIA

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Abstract

Urban air quality is a growing concern in rapidly developing regions, where the physical structure of public spaces often dictates the level of pollutant exposure. Within this urban landscape, public transport systems like the Mass Rapid Transit (MRT) serve as critical environments where commuters are frequently exposed to varying levels of particulate matter such as PM₁₀. The concentration of pollutants in these spaces is largely determined by station design. This study investigates PM₁₀ concentrations in semi-closed and enclosed stations of MRT in Klang Valley, Malaysia to determine the influence of specific station designs and ventilation systems towards the indoor air quality. The results show that there are significant differences in PM₁₀ concentrations between these two types of stations ($t=-35.805$, $df=142.00$, $p<0.05$). These variations indicate that semi-enclosed stations often experience higher PM₁₀ accumulation due to the influence of external ambient air, where concentrations fluctuate based on nearby traffic density and local wind patterns. Conversely, enclosed stations are depending more on the ventilation conditions and occupancy levels. These findings highlight the need to give extra consideration to station design and ventilation in managing PM₁₀ exposure, as different station designs can lead to varying air quality levels that directly impact commuters' health.

Keywords: Indoor Air Quality, Railway Station, Particulate Matters, Ventilation Systems, Transportation Management, Sustainable Transport

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INTRODUCTION

Railways, often described as the “lifeline of urban development,” connect city regions, reduce road congestion, and serve as hubs for commerce and public activity (Reche et al., 2017). With the continuous improvement of the urban railway system, people’s daily travel patterns have become increasingly diverse. Transit-oriented developments (TODs) gradually emerging as a new model for urban growth, leveraging railway accessibility to shape cities more efficiently (Abdullah et al., 2023). The railway system can alleviate surface traffic pressure, make full use of underground or above-ground space, and is considered an efficient and sustainable form of public transportation (Papa & Bertolini, 2015; Ramlan et al., 2021). As a result, an increasing number of people are relying on railways as their primary mode of travel (Azizan et al., 2021). Compared with cars and buses, railways primarily use electric power, contributing to improved urban air quality (Zheng et al., 2019).

While railways provide significant benefits for urban mobility and air quality, the internal environment of railway station platforms is relatively confined. Such confinement can result in the accumulation of air pollutants, particularly particulate matter, which may pose health risks to commuters. In recent years, particulate matter (PM) has attracted increasing attention from the public and researchers due to its potential toxicity and its role in transmitting pathogenic agents (Thangavel et al., 2022). The airborne particulates are designated as Group I carcinogen by International Agency for Research on Cancer (IARC) (Loomis et al., 2013). In fact, no matter short-term or long-term exposure of the relatively high PM concentrations, people may suffer from the particle-related diseases (Kloog et al., 2013). Megido et al. (2017) assessed the toxicity of PM with an aerodynamic diameter less than 10 µm (PM₁₀) and found that 40.2% of total studied particles would be deposited in respiratory tract through inhalation, leading to respiratory diseases.

During the daily operation of trains, a certain amount of airborne PM is generated from the friction between the railway and the wheel brake system (Martins et al., 2015). At the same time, the piston effect produced by the movement of the trains also brings outdoor pollutants into the platform, which affects the air quality of the railway platform (Wang et al., 2016). In addition, different types of ventilation systems in the station will also have corresponding impacts on PM₁₀ concentrations. In semi-enclosed stations, natural ventilation is more commonly used. The concentrations of PM₁₀ are more susceptible to the influence of outdoor air quality (Pan et al., 2019). However, in enclosed stations, more mechanical ventilation is used. PM₁₀ concentrations are often influenced by human flow, as high commuters’ density and movement were seen to have associated with the increase of airborne particulate levels (Beanabed and Boulbair, 2022). Kim et al. (2019) also reported that physical parameters, such as

air temperature (AT), relative humidity (RH), and air movement (AM) give significant contribution to the airborne particulates in the indoor environments.

Therefore, this study aims to compare PM₁₀ concentrations and identify the key factors influencing air quality in two different types of railway stations. The findings can reveal critical factors controlling PM₁₀ accumulation and support strategies to enhance the safety and comfort of station environments. Ultimately, these insights can inform strategies for the sustainable management of air quality within railway stations.

RESEARCH METHODOLOGY

Study Area

The study was conducted along the Putrajaya Line, the second mass rapid transit line in the Klang Valley region of Malaysia. The line serves a corridor with an estimated population of approximately two million people, extending from Kwasa Damansara in the northwest of Kuala Lumpur to Putrajaya in the south. The 57.7km-long Putrajaya Line, consisting of 44.2km of elevated tracks and 13.5km underground tunnels. The line has 36 operational stations, consisting of both elevated and underground stations (Md Zin et al., 2025). For this study, a total of six stations were selected. Among them, three stations are semi-enclosed stations, which are UPM station (S1), Kuchai station (S2), and Sungai Besi station (S3). In addition, this study also selected three enclosed stations, which are Raja Uda (UTM) station (E1), Tun Razak Exchange (TRX) station (E2) and Titiwangsa station (E3). (Table 1).

Table 1: Details of the selected MRT stations

Code	Station	Size of Area (m ²)	Type of Station	Category of Station
S1	UPM	1069.76	Semi-enclosed	Educational
S2	Kuchai	1065.65		Commercial
S3	Sungai Besi	2179.71		Interchange
E1	Raja Uda (UTM)	1247.18	Enclosed	Educational
E2	Tun Razak Exchange	1647.24		Commercial
E3	Titiwangsa	1127.28		Interchange

The stations were selected based on their surrounding land-use characteristics, representing educational, commercial, and interchange station environments. S1 and E1 were selected to represent educational areas, while S2 and E2 were chosen as commercial stations. S3 and E3 were included as interchange stations, reflecting locations where multiple lines intersect and commuter transfers are frequent. Selecting stations from different functional categories enables the analysis of how PM₁₀ levels vary with station type.

Data Collection

Data monitoring in this study was conducted during peak periods, specifically from 7:00 to 9:00 a.m., 12:00 to 2:00 p.m., and 5:00 to 7:00 p.m., when higher numbers of commuters are reported due to work-related travel and lunchtime activities (Zhang et al., 2023). These times were chosen because PM₁₀ concentrations are expected to be higher due to increased movement and crowding, providing a clear understanding of air quality under typical peak conditions. Data were monitored at 5-minute intervals, corresponding to the train frequency during peak hours. Data collected at each station throughout the weekdays, with each measurement representing the PM₁₀ concentration during its corresponding 5-minute monitoring period. Therefore, each observation was treated as an independent measurement representing a distinct time interval. PurpleAir Flex Air Quality, which operates using a built-in sampling system with an approximate flow rate of 0.1 L min⁻¹ was used to monitor PM₁₀, while a Kestrel 4500 Weather Meter was used to monitor physical parameters i.e. AT, RH and AM. Both equipment were installed at the passenger waiting area on the platform of each station. To minimize the influence of nearby structures on airflow and particle dispersion, the equipment were mounted on a tripod, at least 1 meter away from any obstruction with the inlets of the monitors positioned at a height between 75 cm and 120 cm, preferably 110 cm from the floor, to represent the typical breathing zone of a person (DOSH, 2010).

Data Analysis

The collected data were analyzed using statistical methods to examine the variations in PM₁₀ concentrations and their potential influencing factors. Descriptive analysis was first conducted to summarize the PM₁₀ concentrations, the number of occupants, and the measured physical parameters, i.e. AT, RH and AM in enclosed and semi-closed stations. Descriptive analysis mainly describes the mean, standard deviation, as well as the maximum and minimum values of different parameters. This analysis provides a clear overview of the main characteristics of a dataset and helping to identify patterns or trends (MacFarland & Yates, 2020; Xu et al., 2025). The independent samples t-test is commonly used to determine whether there is a significant difference in the mean values between two independent groups (Pallant, 2020). In this study, the test was applied to examine whether there is a significant difference in the mean PM₁₀ concentrations between semi-enclosed and enclosed stations, which were the main groups in this study. PM₁₀ concentrations were measured at 5-minute intervals, with each measurement representing a separate monitoring interval. Although measurements were collected from multiple stations within each station type, the analysis focused on comparing the overall mean PM₁₀ concentrations between the two station types rather than differences among individual stations. Therefore, the independent-samples t-test was considered appropriate for

comparing the two independent groups. The analysis was conducted at a 95% confidence level ($\alpha = 0.05$). A p-value of less than 0.05 indicates that there is a statistically significant difference in PM₁₀ concentrations between the two station types (Xu et al., 2024). According to Field (2024), the test may perform well even without normal distributions in practice, particularly when sample sizes are sufficiently large as the test is considered robust to moderate violations of the normality assumption. In addition, Pearson correlation analysis was applied to evaluate the relationships between PM₁₀ concentrations and the number of occupants as well as the measured physical parameters. The results of the Pearson correlation analysis are categorized into three main types which are no correlation, positive correlation, and negative correlation. Schober et al. (2018) highlighted that the correlation coefficient (r) closer to -1 and 1, indicate a strong negative and positive relationship, respectively. Meanwhile, values near 0 indicate little or no relationship between variables. The strength of the correlation coefficients can be interpreted based on Table 2.

Table 2: Pearson correlation coefficient and its strength

Correlation Coefficient Size	Strength of Coefficient
0.91 to 1.00 or -0.91 to -1.00	Very strong positive or negative correlation
0.71 to 0.90 or -0.71 to -0.90	Strong positive or negative correlation
0.51 to 0.70 or -0.51 to -0.70	Medium positive or negative correlation
0.31 to 0.50 or -0.31 to -0.50	Weak positive or negative correlation
0.01 to 0.30 or -0.01 to -0.30	Very weak positive or negative correlation
0.00	No correlation

Source: Antonov (2019)

ANALYSIS AND DISCUSSION

Descriptive Analysis of Semi-enclosed and Enclosed stations

Table 3 and Figure 1 present the descriptive statistics and temporal trends of PM₁₀ concentrations measured at both semi-enclosed and enclosed stations. The mean PM₁₀ concentrations for all semi-enclosed stations were observed to be almost similar with the highest mean PM₁₀ concentrations was recorded at S1 ($58 \pm 4 \mu\text{g}/\text{m}^3$), followed by S3 ($56 \pm 3 \mu\text{g}/\text{m}^3$) and S2 ($49 \pm 3 \mu\text{g}/\text{m}^3$). This observation is further supported by the temporal trend graph, which demonstrates consistent PM₁₀ patterns among the semi-enclosed stations throughout the monitoring period. This is due to comparable station designs and ventilation conditions. Semi-enclosed stations allow greater interaction with the outdoor environment, enabling particulate matter to disperse more easily through natural airflow. As a result, PM₁₀ concentrations in such stations are often influenced by ambient outdoor air and tend to show less variation between stations with similar structural characteristics (Pang et al., 2020). In contrast, the enclosed stations exhibited more significant differences in mean PM₁₀ concentrations between

stations. E2 was recorded the highest, followed by E1 and E3 with mean PM₁₀ concentrations of $72 \pm 9 \mu\text{g}/\text{m}^3$, $28 \pm 5 \mu\text{g}/\text{m}^3$ and $8 \pm 2 \mu\text{g}/\text{m}^3$, respectively.

Table 3: Descriptive Statistics of Semi-Enclosed and Enclosed Stations

Parameters	N total	Mean $\pm$ SD	Min	Max	N total	Mean $\pm$ SD	Min	Max
Semi-Enclosed Stations					Enclosed Stations			
S1					E1			
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	72	58 ± 4	51	66	72	28 ± 5	16	46
AM (m/s)	72	0.27 ± 0.15	0.04	0.64	72	0.00 ± 0.00	0.00	0.02
AT ($^{\circ}\text{C}$)	72	29.2 ± 1.9	26.2	31.6	72	22.8 ± 0.3	22.5	23.8
RH (%)	72	68 ± 8	58	81	72	60 ± 2	57	63
No. of occupants	72	28 ± 14	5	52	72	30 ± 15	5	60
S2					E2			
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	72	49 ± 3	44	57	72	72 ± 9	56	89
AM (m/s)	72	0.41 ± 0.22	0.04	0.97	72	0.00 ± 0.00	0.00	0.03
AT ($^{\circ}\text{C}$)	72	28.2 ± 2.0	25.8	31.6	72	27.0 ± 0.2	26.6	27.3
RH (%)	72	72 ± 9	57	81	72	67 ± 1	64	69
No. of occupants	72	42 ± 25	8	98	72	340 ± 232	85	802
S3					E3			
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	72	56 ± 3	49	64	72	8 ± 2	4	11
AM (m/s)	72	0.04 ± 0.05	0.00	0.27	72	0.00 ± 0.00	0.00	0.00
AT ($^{\circ}\text{C}$)	72	29.6 ± 1.6	27.3	32.2	72	21.8 ± 0.4	21.1	23.1
RH (%)	72	68 ± 7	56	77	72	66 ± 1	63	68
No. of occupants	72	121 ± 65	23	221	72	148 ± 86	20	297
Overall					Overall			
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	72	54 ± 2	50	58	72	36 ± 4	29	43
AM (m/s)	72	0.24 ± 0.12	0.06	0.54	72	0.00 ± 0.00	0.00	0.01
AT ($^{\circ}\text{C}$)	72	29.0 ± 1.8	26.4	31.6	72	23.9 ± 0.2	23.5	24.7
RH (%)	72	69 ± 8	59	79	72	65 ± 1	62	65
No. of occupants	72	63 ± 34	16	117	72	173 ± 105	47	365

*S1: UPM station; S2: Kuchai station; S3: Sungai Besi station; E1: Raja Uda (UTM) station; E2: Tun Razak Exchange station; E3: Titiwangsa station

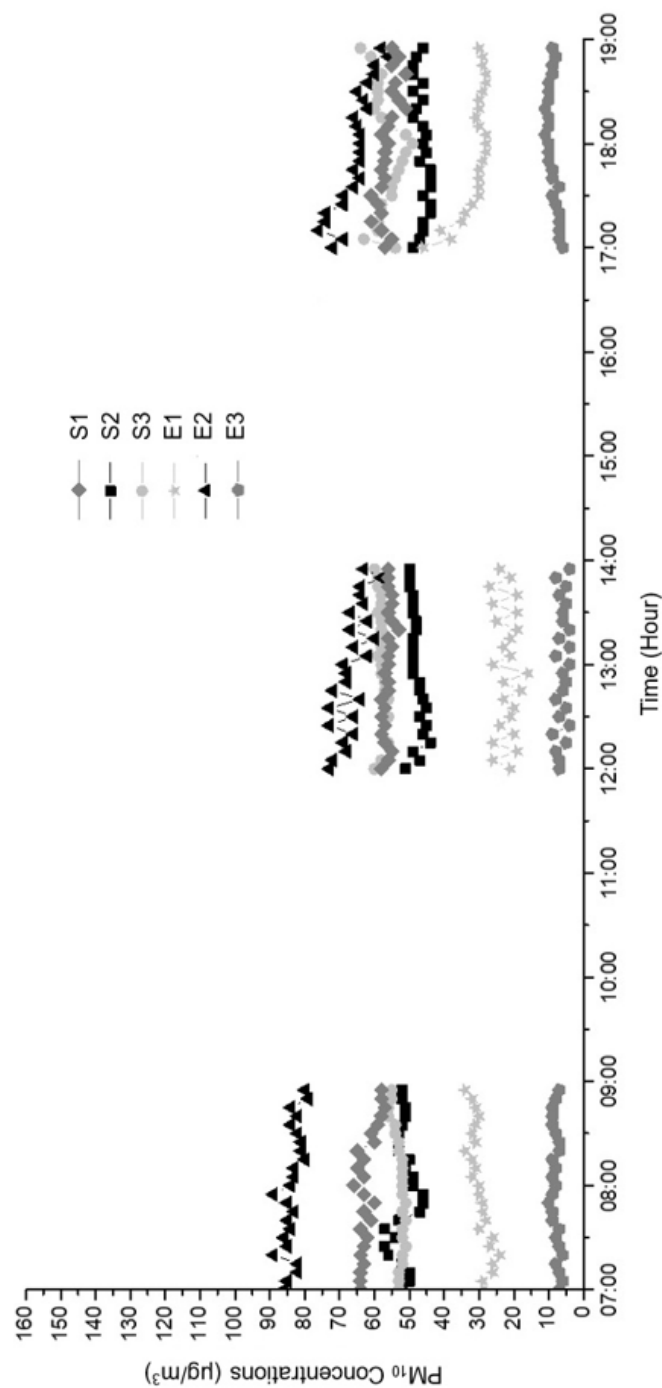


Figure 1 Temporal trend of PM₁₀ concentrations at semi-enclosed and enclosed stations

The elevated PM₁₀ concentrations at E2 were attributed to its fully enclosed design combined with its location in close proximity to a busy commercial and business hub, resulting in higher occupant density and increased external particulate influx. Frequent occupant activity within the station may also contribute to the resuspension of settled particles. In comparison, the lower concentrations observed at E1 and especially E3 suggest lower occupancy levels and/or more effective airflow conditions that facilitate particle dispersion within the station environment (Wang et al., 2023). To provide a reference for interpreting the measured PM₁₀ concentrations, the results were compared with the acceptable limit for respirable particulates of 150 µg/m³ specified in the Malaysian Industry Code of Practice on Indoor Air Quality (ICOP) 2010 (DOSH, 2010). All PM₁₀ concentrations in both semi-enclosed and enclosed stations were below this guideline value. However, because the ICOP 2010 limit is based on an 8-hour time interval, the comparison is intended to provide context for the measured concentrations rather than to demonstrate regulatory compliance.

Although the mean PM₁₀ concentration was highest at S1, S2 recorded the highest, AM and RH with the mean values of 0.41 ± 0.22 m/s and $72 \pm 9\%$, respectively. The higher AM observed at S2 may have contributed to lower PM₁₀ concentrations, as increased airflow can enhance the dispersion and dilution of particulate matter. Previous studies have reported that ventilation and air movement play an important role in reducing the accumulation of particulate matter in railway stations and other indoor transport environments (Moreno et al., 2014). Meanwhile, AM was observed to be stagnant across all enclosed stations. Limited air movement reduces the dispersion of particles, which may increase exposure risks during periods of high occupancy or activity (Yang et al., 2023).

Higher AT and number of occupants were recorded at S3. Similar trend was observed at E2. The elevated occupancy level was observed to be the factor that influencing the PM₁₀ concentrations through the resuspension of settled particles caused by occupant movement and activities (Zainordin et al., 2022). In addition, human presence can influence indoor thermal conditions, leading to higher air temperatures within the station environment (Beanabed and Boulbair, 2022).

Overall, it was observed that mean PM₁₀ concentrations in semi-enclosed stations were higher than enclosed stations. This trend may be attributed to the greater influence of outdoor air and resuspension from passenger movement in semi-enclosed stations, which allows more particulate matter to enter and circulate on the platform compared with enclosed stations where airflow is more restricted (Wang and Li, 2025).

Independent Samples T-Test between Semi-enclosed and Enclosed station

The results of the independent t-test analysis (Table 4) indicated a significant difference in PM₁₀ concentrations between semi-enclosed and enclosed stations ($t = -35.805$, $df = 142.00$, $p < 0.05$). This significant difference is largely due to the higher PM₁₀ concentrations observed in semi-enclosed stations compared to enclosed stations, suggesting that station design and ventilation characteristics strongly influence particulate matter levels. Semi-enclosed stations, which are more exposed to outdoor air, may experience greater PM₁₀ intrusion from ambient sources, leading to elevated concentrations despite the absence of major indoor particle emissions. This aligns with previous research indicating that higher ventilation and air exchange rates can increase indoor PM concentrations by outdoor particles rather than merely recirculating indoor air (Ben-David et al., 2018).

Table 4: Independent Samples T-Test of PM₁₀ Concentrations between Semi-enclosed and Enclosed Station

t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
				Lower	Upper
-35.805	142.00	.000	-18.50	-19.52140	-17.47860

Moreover, studies have consistently shown that indoor PM concentrations are often dominated by outdoor sources, particularly in spaces with limited indoor emissions, emphasizing the importance of considering both outdoor air quality and station design when assessing particulate matter exposure (Liao et al., 2004; Li et al., 2005; Massey et al., 2012).

Pearson Correlation of Semi-enclosed and Enclosed Stations

The result from Pearson correlation analysis is presented in Table 5. The findings indicate that in semi-enclosed stations, PM₁₀ concentrations were correlated with all measured physical parameters ($P < 0.05$) except for the number of occupants. Meanwhile, in enclosed stations, PM₁₀ concentrations showed correlations with all parameters ($P < 0.01$) except for AM. In semi-enclosed stations, the correlation coefficients (r) between PM₁₀ concentrations and AM, air temperature (AT), and relative humidity (RH) were -0.269 , -0.376 , and 0.294 , respectively. However, these parameters demonstrated very weak to weak relationships with PM₁₀ concentrations. Both AM and AT showed weak negative correlations with PM₁₀ concentrations, while RH indicated a very weak positive correlation with PM₁₀ concentrations. The weak negative correlations between PM₁₀ concentrations and both AM and AT suggest that increased airflow and higher

temperatures may contribute to the dispersion of particulate matter in semi-enclosed stations (Avdakovic et al., 2016). Greater AM can enhance particle dilution, reducing the accumulation of PM₁₀ within the platform environment. Meanwhile, RH may slightly influence particle suspension in the air. This may be due to absorption of moisture by airborne particles, which increases particle size and contributes to higher PM₁₀ levels (Tai et al., 2010). However, no significant correlation was observed between PM₁₀ concentrations and the number of occupants. This may be due to the semi-enclosed station design, which allows continuous air exchange with the outdoor environment, thereby reducing the impact of passenger activities on PM₁₀ levels (Pang et al., 2020).

For enclosed stations, AT, RH and number of occupants showed positive medium to strong relationship with PM₁₀ concentrations with the correlation coefficients (*r*) of 0.749, 0.572, 0.821, respectively. This indicates that higher commuters' density and warmer indoor conditions may contribute to increased PM₁₀ concentrations in enclosed stations, likely due to particle resuspension from human activities and the accumulation of particulate matter in confined environments (Abdul Shakor et al., 2020). According to Yuan et al. (2023), warmer indoor conditions may enhance particle suspension and reduce deposition rates, allowing PM₁₀ to remain airborne for longer periods. Meanwhile, the positive relationship with RH may be associated with the hygroscopic growth of particles, where higher humidity levels can cause particles to absorb moisture, increase in size, and alter their behavior in indoor environments (Qiu et al., 2024).

In enclosed stations, no significant relationship was observed between PM₁₀ concentrations and AM. This is likely because AM was recorded at very low and almost stagnant levels across these stations, limiting its ability to disperse particulate matter. In such confined environments, the effects of airflow on PM₁₀ concentrations are minimal, and particle behavior is instead primarily influenced by occupancy levels, air temperature, and relative humidity. Choi et al. (2022) highlighted that when airflow or ventilation is very low or nearly stagnant, indoor particulate matter levels tend to remain elevated due to limited dispersion and removal, emphasizing the critical role of adequate airflow in controlling PM concentrations.

The findings from this study indicate that PM₁₀ concentrations in railway stations are influenced by occupancy levels, indoor environmental conditions such as temperature and humidity, and ventilation or air movement. These findings highlight the importance of considering both human activity and built-environment characteristics, such as station enclosure, ventilation design, and platform layout, in managing air quality and reducing potential health risks for commuters. Despite temporal variability in the measured concentrations, consistent differences between station types remain evident, supporting the

comparison of PM₁₀ concentrations between semi-enclosed and enclosed railway stations and reinforcing the influence of built-environment design on indoor particulate exposure in transit environments.

Table 5: Pearson Correlation Analysis of Semi-Enclosed and Enclosed Stations.

Table 3. Pearson Correlation Analysis of Semi-Enclosed and Enclosed Stations.										
Parameters	Semi-Enclosed Stations					Enclosed Stations				
	PM ₁₀ (µg/m ³)	AM (m/s)	AT (°C)	RH (%)	No. of occupants	PM ₁₀ (µg/m ³)	AM (m/s)	AT (°C)	RH (%)	No. of occupants
PM ₁₀ (µg/m ³)	1	-.269*	-.376**	.294*	.023	1	-.071	.749**	.572**	.821**
Pearson Correlation										
Sig. (2-tailed)		.022	.001	.012	.845		.555	.000	.000	.000
AM (m/s)		1	.859**	-.841**	-.793**		1	-.049	-.140	-.200
Pearson Correlation										
Sig. (2-tailed)			.000	.000	.000		.684	.241	.092	.092
AT (°C)			1	-.986**	-.803**		1	.455**	.614**	.614**
Pearson Correlation										
Sig. (2-tailed)				.000	.000			.000	.000	.000
RH (%)				1	.851**			1	.715**	.715**
Pearson Correlation										
Sig. (2-tailed)					.000				.000	.000
No. of occupants					1					1
Pearson Correlation										
Sig. (2-tailed)										

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

CONCLUSION

The findings from this study provide a comprehensive understanding of factors influencing PM₁₀ concentrations in railway stations. This study highlights that PM₁₀ concentrations in railway stations are influenced by a combination of environmental conditions, ventilation, and commuter activity. Descriptive analysis revealed variations in PM₁₀ levels across stations and highlighted the influence of environmental parameters such as air temperature, relative humidity, and air movement, as well as number of occupants. Independent t-test results confirmed significant differences in PM₁₀ concentrations between different station types, emphasizing the role of station design and ventilation in particle accumulation. Pearson correlation analysis further identified that PM₁₀ concentrations were associated with all the measured parameters depending on the station types. Collectively, these findings indicate that both human activity and indoor environmental conditions are critical drivers of particulate matter exposure, providing essential insights for the related stakeholders to implement effective air quality management strategies that protect commuters' health and promote sustainable transit environments.

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