ORIGINAL ARTICLE

Assessment of the Inhalable Particulate Matter ($PM_{2.5}$ and PM_{10}) at Petrol Stations in Johor, Malaysia

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ABSTRACT

Introduction: Inhalable particulate matters (PM), particularly $PM_{2.5}$ and PM_{10}, are hazardous to health. Motor vehicle emissions are among the primary sources of PM. A large number of motor vehicles at the petrol station may contribute to the hazardous air quality, which may affect the health of the petrol station workers. This study aimed to explore the trends and characteristics of the PM in the petrol station environment. **Methods:** The study was conducted where 44 petrol stations from a chosen petrol station brand were sampled. PM concentrations were measured using Lighthouse® handheld 3016-IAQ particle counter for 9 hours from 0800H until 1700H. Data were then analysed using IBM SPSS software using univariate and multivariate analysis. **Results:** The mean (SD) of PM concentrations measured at petrol stations in Johor were 12.93 (7.09) μg/m³ and 42.02 (11.32) μg/m³ for $PM2_{.5}$ and PM_{10}, respectively. One-way Repeated Measured ANOVA showed that there were significant reductions of PM concentrations from morning to afternoon and evening for both $PM_{2.5}$ [$F(1.2, 52.6) = 95.587$, $p<0.001$] and PM_{10} [$F(1.2, 53.3) = 158.294$, $p<0.001$]. PM2.5 showed significant correlation with PM10 ($r = 0.898$, $p<0.001$), temperature ($r = 0.556$, $p<0.001$) and relative humidity ($r = -0.370$, $p = 0.014$). **Conclusion:** This study showed that PM concentrations at petrol stations were highest in the morning and significantly correlated with relative humidity and temperature. A further confirmatory study should be done to determine the exposure to PM and its effect on the health of petrol station workers.

Keywords: Air pollutants; Coarse particulate; Fine particulate; Gas stations; Pump attendant

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INTRODUCTION

Inhalable particulate matter (PM) is one of the major air pollutants, especially in urban cities. Alongside other pollutants like carbon monoxide (CO), ground-level ozone (O_3), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), they are the major air pollutants that government agencies use to quantify the air quality using the air quality index (AQI). PM is not a single pollutant but rather a mixture of chemical or biological components that form a mixture of solid and liquid particles suspended in the air. Inhalable PM refers to types of PM that can be inhaled through the respiratory system and are often described as fine PM ($PM_{2.5}$) and coarse PM (PM_{10}) based on their diameter.

Yu et al. reported that globally, the mean annual population-weighted $PM_{2.5}$ concentration between 2000 and 2019 was 32.8 μg/m³ where only 0.18% of the global land area and 0.001% of the world population had an annual exposure to $PM_{2.5}$ at concentrations lower than the World Health Organization (WHO) limit of 5 μg/m³ annually (1). In South East Asia, the regional mean monthly population-weighted $PM_{2.5}$ exceeded 90 μg/m³ even though it decreased in trend (2). As for Malaysia, the mean annual population-weighted PM in cities showed an increasing trend in 2021 to 15 μg/m³ and 23 μg/m³ for $PM_{2.5}$ and PM_{10}, respectively (3). Due to its varying components, exposure to PM is known to cause various detrimental health effects, especially for the cardiovascular and respiratory systems. Based on the Global Burden of Disease Study 2019, compared to other major air pollutants and other health risk factors, ambient PM is the leading risk factor of poor health where it is attributed to 4.14 million deaths and 118.22 million disability-adjusted life years (DALYs) due to respiratory diseases, which are mainly contributed by chronic obstructive pulmonary disease (COPD) (4).

The PM source in Malaysia was mainly the motor vehicle emissions from road traffic, especially in the cities (5). With the increasing number of registered motor vehicles in Malaysia, the demand for fuel increased, causing more petrol stations to be built (6). Being the place for many motor vehicles to stop for fuel refuelling and other activities, the PM concentrations in petrol stations environment are high and hazardous, especially for the petrol station workers and those susceptible to PM-related health effects like underlying cardiovascular diseases and respiratory diseases (7). It was evidenced by a study at petrol stations in Nigeria whereby a continuous area sampling for 11 hours showed the mean concentration of $PM_{2.5}$ was 30.75 μg/m^3 and PM_{10} was 100.50 μg/m^3 in which, both of them exceeding the WHO 24 hours standards (8). To the best of the researcher's search, there were very limited studies that measured the PM concentrations at petrol stations in Malaysia. A study by Alias measuring personal exposure to PM_{10} among 31 petrol station workers found that the mean personal exposure to PM_{10} was 1.85 μg/m^3, which was lower than the personal exposure limit (9). However, this study only recruited pump attendants that were working at 12 petrol stations located along the highways and was done more than ten years ago, which may not represent the current situation.

Furthermore, various studies showed that there were significant health impacts of PM among petrol station workers. For example, in a meta-analysis of 26 studies of lung function parameters among petrol stations workers, the pooled standard difference of forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1), and FEV_1/FVC, as compared to the control group, were −1.08 L (95% CI: −1.38, −0.78), −0.92 L (95% CI: −1.15, −0.69) and −0.65 (95% CI: −1.01, −0.30) respectively (10).

Meteorological factors, such as temperature, wind, radiation, atmospheric pressure, precipitation, and relative humidity, were known to influence PM concentrations (11). This was demonstrated by a study conducted in Makkah, Saudi Arabia, which found a significant correlation between the $PM_{2.5}$ concentration and temperature (r = 0.27), wind speed (r = 0.12), and relative humidity (r = -0.17). Furthermore, the PM_{10} concentration followed a similar trend which showed a significant correlation with temperature (r = 0.24), wind speed (r = 0.19), and relative humidity (r = -0.30) (12).

In view of the potential health effects of PM exposure on petrol station workers, many countries have implemented a self-service policy where the consumer does the refuelling activity instead of petrol station workers. The same initiative was introduced in Malaysia in 1996, and due to not being legally bound, the self-service policy in Malaysia was not fully implemented, especially in the urban area where the petrol station owners still hired pump attendants to accelerate the refuelling activity process. Furthermore, in Malaysia, apart from the general safety and health guidelines, there are no guidelines or programmes specifically tailored for petrol station workers' safety and health.

Despite all the potential hazards of PM, this study was carried out in view of very limited studies done in Malaysia regarding the concentration of PM at petrol stations and the need to justify further confirmatory studies such as personal exposure monitoring among petrol station workers. This study aimed to explore and determine the mean concentrations of $PM_{2.5}$ and PM_{10} at petrol stations and their trends and variations over different periods of the day. The study also examined the correlation between PM and meteorological factors (temperature and relative humidity).

MATERIALS AND METHODS

Study design and study population

This study involved 44 petrol stations from a chosen petrol brand in Johor. The study was carried out from January to December 2022. The inclusion criterion for this study was a petrol station with a convenience store, while mini petrol stations and portable container systems were excluded from this study. The required sample size was 44 and calculated using estimates of the single mean formula where a study from Chaurasia and Tiwari was used as a reference (13). The list of all petrol stations from a chosen brand was obtained, and 44 petrol stations were sampled using a proportionate stratified random sampling based on the ten districts in Johor, namely Tangkak, Muar, Segamat, Batu Pahat, Mersing, Kota Tinggi, Kluang, Kulai, Pontian and Johor Bahru. All the petrol stations that were sampled were within 50 metres from the state or federal main roads. Figure 1 shows the general layout of the petrol stations in Malaysia (14). The petrol station company and the owners of the selected petrol stations granted permission for the study after being briefed on the purpose of the study.

Sampling instruments

A portable, lightweight particulate counter, Lighthouse® handheld 3016-IAQ, was used to measure PM concentrations ($PM_{2.5}$ and PM_{10}). It measured particles with a size range from 0.3 to 10 μm at a flow rate of 0.1 CFM (2.83 L/min). This instrument was produced by Lighthouse Worldwide Solutions from Oregon, United States of America, and is also capable of measuring temperature and relative humidity through its attachable environmental probe (15). It was set to automatically convert PM measurements to mass concentration in μg/m^3 for density estimates. Temperature and relative humidity were measured using metric units, namely Celsius (°C) for temperature and percentage (%) for humidity.

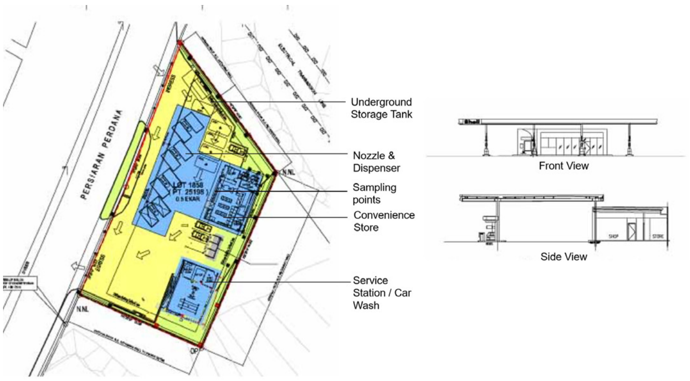

Figure 1 : The general layout of petrol stations in Malaysia.

Sampling methods
The instrument was mounted using a tripod approximately 1 metre from the ground and at least 0.5 metres from any wall. The sampling points were approximately similar for every petrol station where it was placed in front of the petrol station's convenience store. The instrument was carefully placed at least two metres from the convenience store's door and was not obstructing customers or disturbing the daily activities of petrol station workers (16). Measurements of PM, relative humidity and temperature were taken in a day for each 44 petrol station starting from 0800H to 1700H for 9 hours. The surrogates sampling method was applied, where the instrument was set to automatically measure the PM concentrations hourly for 30 minutes each cycle.

Statistical analyses
All the PM, temperature, and relative humidity data were extracted from the instrument using LMS Xchange Software Version 2.3.21 before being exported to Microsoft Excel format. Subsequently, all data were analysed using Statistical Package for the Social Sciences (SPSS) Version 26.0 software after data checking and cleaning. Initially, descriptive analysis was done to determine the mean concentrations of PM. Subsequently, the differences in mean concentrations of PM between the different periods of the day were obtained using one-way repeated measures ANOVA for both $PM_{2.5}$ and PM_{10}. In this study, the mean concentrations of PM were divided into three periods: morning, afternoon, and evening. The mean concentration of PM for the morning was the average from 0800H until 1000H, the afternoon was from 1100H until 1400H, and the evening was from 1500H until 1700H. A post hoc test was done to determine which periods had a significant difference in the mean concentrations of PM using a Bonferroni correction. Apart from that, Pearson correlation analyses were used to determine the correlation between PM ($PM_{2.5}$ and PM_{10}) and meteorological factors (temperature and relative humidity).

RESULTS

Mean concentrations of particulate matter at petrol stations in Johor
From a total of 69 petrol stations from the chosen petrol station brand that fulfilled the inclusion and exclusion criteria, 44 petrol stations were sampled using proportionate stratified random sampling. The mean (SD) concentrations of PM at petrol stations in Johor were 12.93 (7.09) μg/m^3 for $PM_{2.5}$ and 42.02 (11.32) μg/m^3 for PM_{10}. The mean concentrations of PM based on the districts were tabulated in Table I, where for both $PM_{2.5}$ and PM_{10}, Johor Bahru was the highest, and Pontian was the lowest. The same pattern showed for the individual petrol stations, where the highest concentrations of PM were recorded at a petrol station in the Johor Bahru districts, while the lowest were recorded at a petrol station in the Pontian districts.

The trends and variations of particulate matter at petrol stations in Johor
Figure 2 shows the trends of mean PM concentrations over 10 hours from 0800H until 1700H. The trends of the mean concentration of $PM_{2.5}$ and PM_{10} were similar, where it peaked at 0800H to 0900H, followed by a sharp decline until 1200H and gradually declined until 1700H. The highest mean

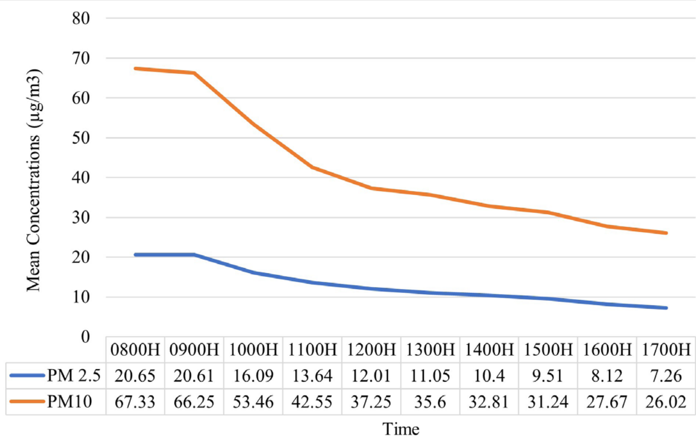

Figure 2 : 9-Hours trends of the mean concentration of $PM_{2.5}$ and PM_{10} at petrol stations in Johor.

Table I : Mean concentrations of particulate matter (µg/m³) in the petrol station environment based on districts (n = 44)

District	n	$PM_{2.5}$			PM_{10}		
		Mean (SD)	Min	Max	Mean (SD)	Min	Max
Johor Bahru	16	20.14 (6.64)	5.71	31.20	51.58 (8.93)	35.59	66.20
Kulai	2	12.40 (1.61)	11.27	13.54	51.29 (1.33)	50.35	52.23
Kota Tinggi	3	7.32 (0.89)	6.65	8.33	35.43 (1.91)	33.76	37.51
Pontian	4	4.84 (0.80)	3.88	5.76	26.06 (3.13)	22.19	29.59
Kluang	3	9.52 (0.52)	9.11	10.10	37.37 (5.11)	33.33	43.11
Mersing	1	9.31 (0.00)	9.31	9.31	35.40 (0.00)	35.40	35.40
Batu Pahat	8	11.60 (0.85)	10.14	12.63	44.04 (6.11)	36.18	54.26
Muar	5	7.20 (0.69)	6.25	7.82	29.87 (3.20)	27.00	33.32
Tangkak	1	7.21 (0.00)	7.21	7.21	32.26 (0.00)	32.26	32.26
Segamat	1	6.85 (0.00)	6.85	6.85	29.06 (0.00)	29.06	29.06
TOTAL	44	12.93 (7.09)	3.88	31.20	42.02(11.32)	22.19	66.20

concentrations of both PM were at 0800H, and the lowest were at 1700H. One-way repeated measures ANOVA revealed that there was a significant time effect on the mean concentration of $PM_{2.5}$, where it was highest in the morning, followed by afternoon and evening [Greenhouse-Geisser univariate test, F (1.2, 52.6) = 95.587, p < 0.001]. The mean differences between each period were found to be significant in the post hoc test (Table II). The same result was also seen for the mean concentration of PM_{10}, which was highest in the morning, followed by the afternoon and evening. There were significant differences in the mean concentration of PM_{10} over time [Greenhouse-Geisser univariate test, F (1.2, 53.3) = 158.294, p < 0.001], and the post hoc test revealed that the mean differences were significant for each period (Table III).

Table II: Comparison of mean $PM_{2.5}$ concentration (µg/m³) at petrol stations at a different period of the day (n = 44)

Period	Adjusted Mean (95% CI)*	F-stat (df)	p-value**
Morning	19.12 (15.90, 22.33)		
Afternoon	11.78 (9.71, 13.84)	95.587 (1.2, 52.6)	< 0.001
Evening	8.30 (6.83, 9.77)		

*Posthoc test with Bonferroni adjustment shows significant differences between all periods. Mean difference (µg/m³): Morning – Afternoon (7.34), Morning – Evening (10.82), Afternoon – Evening (3.48); p < 0.001

**Greenhouse-Geisser correction applied

Table III: Comparison of PM_{10} concentration (µg/m³) at petrol stations at a different period of the day (n = 44)

Period	Adjusted Mean (95% CI)*	F-stat (df)	p-value**
Morning	62.35 (56.27, 68.42)		
Afternoon	37.05 (33.75, 40.35)	158.294 (1.2, 53.3)	< 0.001
Evening	28.31 (26.13, 30.49)		

*Posthoc test with Bonferroni adjustment shows significant differences between all periods. Mean difference: Morning – Afternoon (25.30), Morning – Evening (34.04), Afternoon – Evening (8.74); p < 0.001

**Greenhouse-Geisser correction applied

Correlation between particulate matter and meteorological factors

Table IV shows the correlation between PM and meteorological factors. $PM_{2.5}$ was positively correlated with PM10 (r = 0.898, p < 0.001) and temperature (r = 0.556, p < 0.001), while it was negatively correlated with relative humidity (r = -0.370, p = 0.014).

Table IV : Pearson correlation between $PM_{2.5}$, PM_{10}, temperature, and relative humidity (n = 44)

Parameters	$PM_{2.5}$ (μg/m^3)	PM_{10}(μg/m^3)	Temperature (°C)	Relative humidity (%)
$PM_{2.5}$ (μg/m^3)	-			
PM_{10} (μg/m^3)	0.898**	-		
Temperature (°C)	0.556**	0.629**	-	
Relative humidity (%)	-0.370*	-0.274	-0.220	-

** $p < 0.001$ level

*$p < 0.05$ level

For PM10, it was positively correlated with temperature ($r = 0.629$, $p < 0.001$). However, the correlations between humidity with PM_{10} and temperature were found to be not significant.

DISCUSSION

The mean concentrations for both $PM_{2.5}$ and PM_{10} at petrol stations in Johor did not exceed the 24-hour WHO and Malaysian NAAQS standards (17,18). However, the in-depth analyses revealed that 3 (6.8%) and 13 (29.5%) individual petrol stations exceeded the standards for $PM_{2.5}$ and PM_{10}, respectively. The mean PM concentrations in this study may be underestimated because the sampling duration was only 9 hours instead of 24 hours. Nevertheless, they were comparable with the findings from the previous studies done in Jakarta, Indonesia, and Ibadan, Nigeria (19,20). Interestingly, several studies reported higher mean PM concentrations at the petrol stations in their study locations. For example, the mean PM concentrations of the petrol stations at Ile-Ife, Nigeria, were 30.75 μg/m^3 for $PM_{2.5}$ and 100.5 μg/m^3 for PM_{10} (8). Higher concentrations were found at the petrol stations in Saudi Arabia, where the mean PM concentrations were 344 μg/m^3 and 710 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively (21). The huge differences in the mean PM concentrations between these studies may be attributed to the differences in the background ambient PM concentrations, climates, and study methodologies. The variations in PM concentrations due to climates were demonstrated based on the evidence that supports a seasonal variation of PM concentrations. The variation was mediated by meteorological factors like temperature, wind direction, wind velocity, relative humidity, and rainfall (11,22). In terms of study methodologies, the mean PM concentrations will be affected by the sampling duration, instrument, sampling method, and sampling location at the petrol stations. In this study, Johor Bahru recorded the highest mean PM concentrations as compared with other districts for both $PM_{2.5}$ and PM_{10}. These findings were expected as Johor Bahru had the highest background ambient concentration of PM due to its being densely populated alongside major industrialisation (23).

This study found that the trends of PM concentrations at petrol stations were similar to the ambient concentration of PM, suggesting that the major source of PM in these environments was the same, which was most likely from vehicle emissions and traffic volume (24). The trends of both $PM_{2.5}$ and PM_{10} in this study showed similar diurnal variations of ambient PM concentrations in Malaysia, which were bimodal patterns with peaked concentrations in the morning and night (25). Various factors were attributed to the trends, mainly environmental and human factors. Few studies suggested the morning peak was due to the morning rush hours causing an increase in traffic as well as industry activities (26,27). The subsequent reduction of PM concentration in the afternoon and evening was primarily due to increased mixing layer height (MLH). The MLH can influence the formation and dissipation of air pollutants via its influence over the vertical diffusion of atmospheric pollutants and water vapour concentrations (28). However, Norazian et al. also postulated that lesser human activity during the afternoon and evening might play a role in causing the decrease in the mean PM concentrations (29). As for the second peak at night, it is due to reduced wind speed and MLH alongside the increasing traffic in the late evening due to people commuting back from work and school (25). The bimodal pattern of diurnal variation of PM was not only seen in Malaysia but also has been demonstrated in other countries like China, Bangladesh, Serbia, Indonesia, Thailand, and the United States of America (30–35). One-way Repeated Measures ANOVA showed a significant time effect over the mean PM concentrations, which are highest in the morning as compared to the afternoon and evening. The same finding was found in a study by Oni and Ana, where 19 out of 20 petrol stations in Ibadan, Nigeria, showed significantly higher mean PM_{10}

concentration in the morning as compared to the afternoon ($p < 0.05$) (19).

The concentrations of $PM_{2.5}$ and PM_{10} at the petrol stations were highly correlated. This finding was similar to a study by Basahi et al. in 15 petrol stations in Jeddah, Saudi Arabia (21). In their study, the mean concentration of $PM_{2.5}$ was moderately correlated with the mean concentration of PM_{10} ($r = 0.34$, $p < 0.01$). The correlation between PM2.5 and PM_{10} may suggest that there was a single primary source of PM in the petrol station's environment, as suggested by Wambebe et al. (36). The most probable primary source of PM in petrol stations' environment is vehicle emissions due to petrol stations usually located just beside the main road with much traffic, and a lot of the traffic stop at petrol stations for refuelling, resting, or going to the toilet or convenience store. Meteorological factors are known to influence the ambient concentrations of PM. This study revealed that the same influence was also seen in the petrol stations' PM concentrations, which positively correlated with temperature and negatively correlated with relative humidity. These findings were corroborated by a study at Johor Bahru, Malaysia, where the PM_{10} concentrations were significantly correlated positively with temperature ($r = 0.185$, $p < 0.05$) and negatively with relative humidity ($r = 0.299$, $p < 0.05$) (37). These meteorological factors were able to influence the formation of secondary aerosols that form PM. However, this study did not measure several other meteorological parameters that may influence the PM concentrations in the atmosphere, like wind speed, wind direction, rainfall, and solar radiation (25).

Risk assessments, especially the exposure assessment, need to be done in detail to quantify the exposure level of PM among petrol station workers. This is important as high exposure will lead to detrimental health effects. Any effort to reduce the ambient PM, such as policies on green energy, carpooling campaigns and industrial regulations, will more likely significantly reduce the PM concentrations at the petrol station due to similar trends and sources.

CONCLUSION

The mean concentrations of $PM_{2.5}$ and PM_{10} at petrol stations did not exceed the WHO and Malaysian NAAQS standards and were highest in more populated and industrialised districts like Johor Bahru. The trends of PM concentrations in petrol stations were similar to those of ambient PM for both $PM_{2.5}$ and PM_{10}, which peak in the morning followed by a decline in the afternoon and evening, suggesting it is highly attributed to environmental factors like MLH and human activities factors. The highly correlated concentrations of $PM_{2.5}$ and PM_{10} at petrol stations indicate that there was a single primary source of PM at the petrol stations, most probably from vehicle exhaust emissions.

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