Effect of indoor fine particulate matter (PM$_{2.5}$) associated in Petaling Jaya LRTs

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Abstract. This study was conducted to determine indoor PM$_{2.5}$ concentration, which was measured at indoor settings in three different Light Rail Transits in Petaling Jaya. The selected locations were LRT Kelana Jaya, LRT Ara Damansara and LRT Glenmarie. This study focused on determining the indoor fine particulate matter (PM$_{2.5}$) associated with samples collected from the three LRTs using Model 8532 DustTrak$^\text{TM}$ II Aerosol Monitor (DustTrak) at each LRT from 19:00 to 21:00 three times in a month from July till October 2018. Total of 33 mass concentrations were collected and 176 respondents were recorded from questionnaire given with information on health which was adapted from The American Thoracic Society, “Questionnaire ATS-DLD-C WHO (1982)”. Results were analyzed and compared with US Environmental Protection Agencies (EPA) and World Health Organization (WHO) standards and guidelines. LRT Glenmarie (37.64 µg/m$^3$) was determined higher than US EPA (35 µg/m$^3$) and WHO (25 µg/m$^3$). More than 50% of the survey respondents were affected from the respiratory disease. Therefore, it is necessary to improve the ventilation in LRTs in order to provide a healthier indoor environment.

1. Introduction

Fine particulate matter is commonly known as PM$_{2.5}$, accommodates the size of small particles up to 2.5 µm in aerodynamic diameter [1]. It is also known as inhalable and secondary particles. PM$_{2.5}$ can be freely perforate into the human’s respiratory system and can lead to health problems and most probably death. These particles generally found from an impenetrable composition of chemical substances directly liberated from sources and even by-product gases to its conversion processes [2]. With an increase of 10% in fine particulate matter (PM$_{2.5}$) in the atmosphere, there is also an increase of 10% in the systems of deterioration in human respiratory system such as cough and asthma [3].

Particulate matter (PM) is regulated by the particle’s size and thickness. The size of particles with non-uniform shapes and their aerodynamic reaction is communicated in terms of the diameter of a unit sphere which is a direct material that is associated to their possibilities of resulting health problems. There are two principal classes of aerodynamic diameter dissemination which are about 2.5 µm and about 10 µm and they are usually categorized as fine and coarse particles respectively [4]. Indoor PM is an air pollutant that enters inside the building before entering into human’s respiratory system. The particulate matter can be either PM$_{10}$ or PM$_{2.5}$ which are the main pollutants that deliberated in the atmosphere. In general, indoor environment is where human occupies most of their moment, either in house or workplaces. It started to bring attention of the scientists when human are committed with outdoor particulate matter (PM) together with some indoor air pollutants such as
carbon dioxide (CO$_2$), nitrogen oxide (NO) and unstable organic compound [5]. This is because indoor particulate matter is becoming very prestigious around the world by deteriorating human’s health. Indoor PM$_{2.5}$ found to be more deeply penetrating into human respiratory system compared to PM$_{10}$ and causing acute health consequences in human health [6]. The higher the particulate matter level of absorptions, the higher the rate of disease and death in a population which may causes short-term and long-term vulnerability towards maximum level of particulate matter [7].

The continuous development of Light Rail Transits (LRT) in Petaling Jaya till now had raised the important role of fine particulate matter in the indoor environment. This created potential health risk to the nearby residents. This is because the increase rate of death and disease is interconnected with outstanding variability in particulate matter vulnerability which causes the increase in lung disease and cardiovascular diseases among the residences. Even though human frequently travel out, but they prefer to spend their time indoor which far more affected than the outdoor environment [3] and indoor air quality level will increase from time to time [8].

In Malaysia, based on the Air Pollutant Index (API), Selangor has been recorded as unhealthy level due to 5 different areas such as Banting (172), Port Klang (163), Kuala Selangor (146), Shah Alam (146) and Petaling Jaya (142). In general, if the API reading between 0 and 50 is consider as good, 51 to 100 is moderate, while 100 to 200 is unhealthy, whereas 200 to 300 as very unhealthy and more than 300 is hazardous. Petaling Jaya has been recognized as unhealthy area in 2015 due to haze.

Therefore, this study will concentrate on the effect of indoor air pollutant, especially fine particulate matter (PM$_{2.5}$) at three different LRT stations and emphasize on determination the effect of PM$_{2.5}$ which associated both from outdoor and indoor of the environment to feature the present status of the indoor air quality in Petaling Jaya LRTs.

2. Materials and Methods

2.1. Material
The equipment used for this study was the TSI, Inc. Model 8532 DustTrak™ II Aerosol Monitor (DustTrak). This DustTrak is a handheld battery-operated and real-time sampler to determine the mass concentration of particulate matter [9] by engaging with light scattering technology [10]. Besides that, questionnaires was used which was adopted and adapted from The American Thoracic Society, “Questionnaire ATS-DLD-C WHO (1982)”. This questionnaire is a preliminary test and 10% of the sample area is used as the total respondents for the preliminary test [11].

2.2. Method

2.2.1. Description of the sites. Fine particulate samples were collected from three different locations in Petaling Jaya from July till October 2018. Kelana Jaya is a suburban in Petaling Jaya and situated on the south side of the Petaling Jaya. Kelana Jaya site is a township area full of infrastructure, facilities and resource to recreational, commercial, industrial and institutional conveniences. It is a low density of residential area and LRT Kelana Jaya station in Petaling Jaya selected as Station 1 (S1).

The second station (S2) is within the Petaling Jaya, which is located at LRT Ara Damansara station. Ara Damansara is a wealthy residential township in Petaling Jaya. LRT Ara Damansara is also location on the south side of Petaling Jaya. Station 3 (S3), LRT Glenmarie is near Kelana Jaya in Subang, Selangor as shown in Figure 1.
2.2.2. Questionnaires. A questionnaire with information on health was used which was adopted and adapted from the American Thoracic Society, “Questionnaire ATS-DLD-C WHO (1982)”. Respondents were requested to complete a time-activity questionnaire to obtain information on activities that would influence the health of people in measuring the indoor fine particulate matter (PM$_{2.5}$) level in three different locations during the sampling period.

2.2.3. Statistical analysis. In order to determine fine particulate matter (PM$_{2.5}$) concentration at three different stations, some statistical analyses were conducted to determine the dispersal of PM$_{2.5}$ concentrations using bivariate correlation analysis, multivariable linear regression and one-way ANOVA. The whole statistical assessment was carried out using Statistical Package for Social Sciences (SPSS) to determine any significant differences between the mean concentrations of fine particulate matter (PM$_{2.5}$) of three different stations.

2.2.4. Meteorology in Petaling Jaya. The climates of Petaling Jaya were equatorial and tropical due to hot weather with the temperature range between 26°C and 28°C and seldom reach to 29-35°C. The relative humidity was also high in Petaling Jaya. So, meteorological parameters such as temperature, precipitation, humidity as well as wind speed and direction were collected and summarized in the result to examine targeted data.

3. Results and discussion
This chapter discussed the results and findings to predict the concentration profile of indoor PM$_{2.5}$ associated in Petaling Jaya LRTs.
3.1. Mass distribution of indoor PM$_{2.5}$

Data collected from LRT Kelana Jaya, LRT Ara Damansara and LRT Glenmarie in Petaling Jaya is summarized in Table 1, while the result on mass distribution of PM$_{2.5}$ is presented in Table 2. LRT Glenmarie recorded the highest concentration of indoor PM$_{2.5}$ which is 37.64 µg/m$^3$, followed by LRT Ara Damansara 36.45 µg/m$^3$ and LRT Kelana Jaya 23.64 µg/m$^3$. The comparison of mean, median and mode showed that all the sampling locations incline towards normal distribution. However, the dwarf standard deviation (1.37) is equated in LRT Ara Damansara, which exhibits the highest value compared to LRT Glenmarie (1.36) and LRT Kelana Jaya (1.12). Besides that, the kurtosis and skewness also resulted that LRT Ara Damansara has the highest value but based on the overall indoor PM$_{2.5}$ mass concentrations, LRT Glenmarie and LRT Ara Damansara from July to October were found to be higher than National Ambient Air Quality Standards (NAAQS) standard of US EPA (35 µg/m$^3$) and World Health Organisation (25 µg/m$^3$).

Table 1. Summary of sampling schedule and mean mass together with meteorological parameters of PM$_{2.5}$.

| Location | Month       | No. of Sample | Mean ± SD | Relative Humidity (%) | Precipitation (mm) | Temperature (°C) | Wind direction (°) |
|----------|-------------|---------------|-----------|-----------------------|--------------------|------------------|-------------------|
| Kelana Jaya | July 4-6 2018 | 3 | 23.33 ± 1.53 | 69.6 | 3.4 | 28.4 | 176.7 |
|            | August 8-10 2018 | 3 | 24.00 ± 1.00 | 66.8 | 0.0 | 28.9 | 120.0 |
|            | September 5-7 2018 | 3 | 23.67 ± 1.53 | 76.5 | 2.7 | 27.3 | 210.0 |
|            | October 4-5 2018 | 2 | 23.50 ± 0.71 | 72.9 | 4.4 | 28.7 | 185.0 |
| Ara Damansara | July 11-13 2018 | 3 | 36.00 ± 1.00 | 71.1 | 0.0 | 29.0 | 170.0 |
|            | August 15-17 2018 | 3 | 35.67 ± 1.53 | 64.3 | 1.6 | 30.0 | 240.0 |
|            | September 12-14 2018 | 3 | 37.00 ± 1.73 | 74.3 | 10.7 | 27.6 | 250.0 |
|            | October 11-12 2018 | 2 | 37.50 ± 0.71 | 83.3 | 19.6 | 26.7 | 300.0 |
| Glenmarie | July 18-20 2018 | 3 | 38.00 ± 0.71 | 66.3 | 0.0 | 29.7 | 203.0 |
|            | August 22-24 2018 | 3 | 38.00 ± 1.00 | 65.0 | 1.6 | 28.9 | 240.0 |
|            | September 19-21 2018 | 3 | 38.33 ± 1.15 | 78.0 | 13.0 | 26.8 | 230.0 |
|            | October 18-19 2018 | 2 | 35.50 ± 0.71 | 73.9 | 7.4 | 26.9 | 290.0 |

Table 2. Basic distribution parameters indoor PM$_{2.5}$ in three different sampling locations in Petaling Jaya.

| LRTs         | Kelana Jaya(N=11) | Ara Damansara(N=11) | Glenmarie(N=11) |
|--------------|-------------------|---------------------|-----------------|
| Minimum      | 22.00             | 34.00               | 35.00           |
| Maximum      | 25.00             | 38.00               | 39.00           |
| Mean         | 23.64             | 36.45               | 37.64           |
| Median       | 24.00             | 37.00               | 38.00           |
| Mode         | 23.00             | 37.00               | 39.00           |
| Std. Deviation | 1.12             | 1.37                | 1.36            |
| Std. Error   | 0.34              | 0.41                | 0.41            |
| Kurtosis     | -1.22             | -0.89               | -0.44           |
| Skewness     | -0.16             | -0.46               | -0.64           |

The overall decreasing order of indoor PM$_{2.5}$ mass concentration at three different locations were LRT Glenmarie > LRT Ara Damansara > LRT Kelana Jaya. These show that concentration of indoor PM$_{2.5}$ is higher at LRT Glenmarie in Petaling Jaya when the construction and demolition activities and automobile emission increases at that station. This statement supported by Sara et al [12], saying that automobile is one of the main contributors of air pollution where the vehicles move from one place to
another place resulting the emission of gases to be higher and form in the mode of nucleation because of directly emitted and accumulation mode because of early emission. So, all these reasons might cause the contribution of indoor PM$_{2.5}$ to increase in LRT Glenmarie in Petaling Jaya.

3.2. Monthly concentration of indoor PM$_{2.5}$

The statistics for indoor PM$_{2.5}$ concentrations at three distinct stations in Petaling Jaya from the month of July to October 2018 is shown in Figure 2. The monthly mean concentrations of indoor PM$_{2.5}$ at LRT Glenmarie were 38.00 ± 0.71 µg/m$^3$ in July, 38.00 ± 1.00 µg/m$^3$ in August, 38.33 ± 1.15 µg/m$^3$ in September and 35.50 ± 0.71 µg/m$^3$ in October respectively with the overall ranged from 1.00 to 2.00 µg/m$^3$ and the overall mean concentration of 37.64 µg/m$^3$ in Petaling Jaya. The kurtosis and skewness in LRT Glenmarie station was found to be the highest among all LRTs station such as -0.44 and -0.64, respectively.

In contrast, the monthly mean concentration of indoor PM$_{2.5}$ at LRT Ara Damansara were 36.00 ± 1.00 µg/m$^3$ in July, 35.67 ± 1.53 µg/m$^3$ in August, 37.00 ± 1.73 µg/m$^3$ in September and 37.5 ± 0.71 µg/m$^3$, respectively with an overall ranged from 1.00 to 3.00 µg/m$^3$ and the overall mean concentration of 36.45 µg/m$^3$ followed by the monthly mean concentration of PM$_{2.5}$ at LRT Kelana Jaya were 23.33 ± 1.53 µg/m$^3$ in July, 24.00 ± 1.00 µg/m$^3$ in August, 23.67 ± 1.53 µg/m$^3$ in September and 23.5 ± 0.71 µg/m$^3$ in October, respectively with an overall ranged from 1.00 to 3.00 µg/m$^3$ and overall mean concentration of 23.64 µg/m$^3$. The kurtosis and skewness in LRT Ara Damansara were -0.89 and -0.46 followed by LRT Kelana Jaya with -1.22 and -0.16, respectively.

The LRT Glenmarie station is located between roads towards highway at Petaling Jaya where it connects between the to-and-from roads of Shah Alam. Therefore, traffic intensity plays significant role. Besides, there is also a few construction projects going on and some industrial dispersal as the industrial area is closely located, around 5 km away from LRT Glenmarie station. So, all these contribute to higher concentration of PM$_{2.5}$ at LRT Glenmarie station. Although the LRT Ara Damansara is 2 m away from LRT Glenmarie, the socioeconomic activities around this station have partial role for high concentration of indoor PM$_{2.5}$ but there might have some positive influence from the LRT Glenmarie as well as construction area too. Since LRT Kelana Jaya that is 35 km away from LRT Glenmarie and LRT Ara Damansara is found to have less anthropogenic activities, this station is considered as background due to lower indoor PM$_{2.5}$.

Moreover, the relative humidity in October for LRT Ara Damansara is found higher (83.3%) compared to the other months whereas for LRT Kelana Jaya and Glenmarie, the reason behind their highest relative humidity in September is unpredictable due to hazy period during this month.
Therefore, relative humidity plays one of the important roles of indoor PM$_{2.5}$ in Petaling Jaya.

In addition, in the two stations at Petaling Jaya such as LRT Ara Damansara and LRT Glenmarie, the indoor PM$_{2.5}$ concentrations ranged from 35.67 to 38.33 µg/m$^3$ and were notable higher than the US Environmental Protection Agency (USEPA) daily NAAQS for a 24 hours period. The highest indoor PM$_{2.5}$ concentration was seen in September at LRT Glenmarie station. At these stations, daily activities released notable amounts of oily fumes and gases as well as particulate pollutants. These pollutants are remarkable to be the main pollutant sources in Petaling Jaya environment. The lowest indoor PM$_{2.5}$ concentrations were resulted in the LRT Kelana Jaya station, which is within the USEPA daily National Ambient Air Quality Standards and World Health Organization (WHO) guideline.

3.3. Influence of indoor/outdoor sources
The concentration of three different stations such as LRT Kelana Jaya, LRT Ara Damansara and LRT Glenmarie were affected by both indoor and outdoor sources. Fine particulate matter (PM$_{2.5}$) concentration showed considerable temporal fluctuations during sampling period. Since there was no reading of coarse particulate matter (PM$_{10}$) concentration taken, indoor sources in these cases include any kind of human activities during working hours, with most important being the re-suspension of indoor particles. Majority of the research have already marked that the contribution from outdoor sources to indoor sources and mass concentration. Generally, indoor particles for both number and mass concentration data observed temporal fluctuations similar to the outdoor observations.

3.4. Study data population from the questionnaire
Based on the questionnaire, there are few numbers of people travelled and signed at three different stations such as LRT Kelana Jaya, LRT Ara Damansara and LRT Glenmarie as shown in Figure 3. LRT Glenmarie reported to be the highest number of people compared with LRT Ara Damansara and LRT Kelana Jaya. 41% number of passengers travel led using the LRT Glenmarie as their daily routine, while 31% passengers used LRT Ara Damansara and 28% passengers used LRT Kelana Jaya. Passengers prefer to use LRT rather than other public transport because it is convenient and practically safe to consume.

![Figure 3. Number of passengers travelled at three different LRTs in Petaling Jaya.](image)

3.5. General respiratory symptoms among studied population from the questionnaire
A total of 176 passengers signed a consent form in the questionnaire survey in Table 3 The age of adults ranged between 18 to 42 years, and for children between 1 and 15 years old. More than half of the passengers were employed (56.3%) and 73.2% of passengers were staying far away from the stations whereas there were 62 passengers were unemployed and 26.8% of passengers were staying
nearby the stations. Based on the questionnaires adopted from American Thoracic Society “Questionnaire ATS-DLD-C WHO” (1982), there was four variables were evaluated in this study, where the symptoms were asked based on cough, phlegm, wheezing and chest tightness experienced by passengers either adult or children. Table 3 shows that most passengers who declared for phlegm (24.6% of them) were from the adult studied group (80.7%) compared to 20(58.8%) of them from children group. The other symptom such as wheezing randomly occur among adult passengers in this study group (24 (16.9%)) and children (15 (44.1%)). Cough and chest tightness were also another common symptom found among the adults (25 (17.6%)) and children (7 (20.6%)) during this survey. Hence, it showed that more than 50% passengers including adults and children were affected during consumption of these LRT stations.

### Table 3. General Respiratory Symptoms Among the Passengers in Petaling Jaya.

| Variables       | Respiratory Symptoms |
|-----------------|----------------------|
|                | Total (%)            |
|                | Adults (n=142) | Children (n=34) |
| Cough          |                     |
| Yes            | 25 (17.6)     | 7 (20.6)       |
| No             | 117 (82.4)    | 27 (79.4)      |
| Phlegm         |                     |
| Yes            | 35 (24.6)      | 20 (58.8)      |
| No             | 107 (75.4)    | 14 (41.2)      |
| Wheezing       |                     |
| Yes            | 24 (16.9)      | 15 (44.1)      |
| No             | 118 (83.1)    | 19 (55.9)      |
| Chest tightness|                     |
| Yes            | 25 (17.6)      | 7 (20.6)       |
| No             | 117 (2.4)     | 27 (79.4)      |

### 3.6. Statistical Analysis

#### 3.6.1. Bivariate Correlation Analysis.
IBM Statistical Package Social Science (SPSS) Version 22 software package (IBM Corp., Armonk, NY, USA) was used to determine the correlation coefficients among the meteorological data such as relative humidity, precipitation, temperature and wind with indoor PM$_{2.5}$ concentrations at three sampling areas separately. Pearson correlation analysis method was used for present study. The significantly higher correlation was found between wind-relative humidity and wind-precipitation ($p<0.05$) as well as moderately high correlation was found between precipitation-relative humidity. The study of these highly correlated variables recommends that similar type of source may present together for their existence of mass of indoor PM$_{2.5}$.

#### 3.6.2. Multivariate Linear Regression Analysis.
The interaction between indoor concentration of PM$_{2.5}$ and its impacting variables were analyzed using multivariate linear regression analysis. The indoor PM$_{2.5}$ concentrations were set as dependent variables while the impacting variables as independent variables. The result of partial coefficient ($\beta$) for independent variables designated that high indoor PM$_{2.5}$ concentration occurred when relative humidity low and vice versa.

#### 3.6.3. One-way ANOVA.
ANOVA was used to compare between the temperature and relative humidity in order to predict which factor act as an influence. The significance level is 0.05. From one-way ANOVA analysis, relative humidity played an important role for indoor fine particulate matter at
three different stations such as LRT Kelana Jaya, LRT Ara Damansara and LRT Glenmarie in Petaling Jaya.

4. Conclusion
The aim of this study is to determine indoor fine particulate matter (PM$_{2.5}$) concentration in three different locations in Petaling Jaya which is LRT Kelana Jaya, LRT Ara Damansara and LRT Glenmarie, by assessing the effect of seasonal variation of indoor fine particulate matter and investigating the health risk associated at three sampling locations in Petaling Jaya. The samples were collected from three distinct sampling stations (LRT Kelana Jaya, LRT Ara Damansara and LRT Glenmarie). Indoor PM$_{2.5}$ samples were collected from July until October 2018. Mean concentrations of indoor PM$_{2.5}$ were 23.64 ± 1.12 µg/m$^3$, 36.45 ± 1.37 µg/m$^3$ and 37.64 ± 1.36 µg/m$^3$ for LRT Kelana Jaya, LRT Ara Damansara and LRT Glenmarie stations, respectively. The mean concentration of indoor PM$_{2.5}$ at LRT Glenmarie was greater than USEPA daily NAAQS (35 µg/m$^3$) and WHO guideline (25 µg/m$^3$).

From 176 respondents, more than 50% of the respondents including adults and children were affected by respiratory disease at all three different stations in Petaling Jaya. They were having phlegm severely before upgraded to cough, chest tightness and wheezing. Statistical analysis revealed that relative humidity played an important role as a seasonal variation at three different stations in Petaling Jaya. Long-term monitoring of indoor concentration should be conducted in the future to further understand the seasonal effects of indoor PM$_{2.5}$ and its determinants.

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