SUBURBAN ATMOSPHERIC $PM_{2.5}$ DISTRIBUTION IN SOUTHERN REGION OF PENINSULAR MALAYSIA

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Abstract - Air pollution is one of the crucial factors that causes premature death and health problems. Excessive inhalation of fine particulate matter, particularly $PM_{2.5}$, has high association with adverse health effects due to its capability to penetrate deep into human respiratory system. This paper aims to investigate the analysis and interpretation of monthly and seasonal cycles of 24–h average $PM_{2.5}$ mass concentrations, recorded in a suburban area in southern region of Peninsular Malaysia. The meteorological variables and $PM_{2.5}$ data were recorded via Grimm Environmental Dust Monitor continuously from August 2017 to January 2018. This study found that the highest $PM_{2.5}$ 24-h average pollutant in the suburban area is 44.6 $\mu g/m^3$, with an average value of 21.85 $\mu g/m^3$ throughout southwest monsoon through northeast monsoon season. Almost half of the total percentage, which is 43.33% of the $PM_{2.5}$ pollutant exceeded the 24-h World Health Organization Guideline, 8.33% of the $PM_{2.5}$ distribution concentration exceeded the 24-h Malaysia Ambient Air Quality Standard. The variation of PM_{10} level is revealed to be constantly 1.09~1.90-fold the level of $PM_{2.5}$ mass concentration, indicating that $PM_{2.5}$ mass is consistently 52-92% of PM_{10} mass concentration. On a seasonal scale, the variations of particulate matter (PM) concentration value is influenced by meteorological factors such as wind speed (WS), rainfall, temperature and relative humidity (RH), as well as primary emissions and local anthropogenic activities.

Index Terms - Atmospheric $PM_{2.5}$, Meteorological Influence, Particulate Matter

I. INTRODUCTION

Particulate matter (PM) can alter climate, atmospheric chemistry and also has the ability to affect human health [1]. World Health Organization (WHO) mentioned that 1/8 premature deaths are caused by the airborne pollution. WHO also reported that more than 3 million premature deaths every year is caused by the exposure to the pollution of ambient air [2]. This statement is parallel with the epidemiological study that reported the correlation between the PM pollution and adverse effects of human health [3]. The airborne pollution has strong correlations with cancer, premature mortality that is related to heart attack, as well as respiratory diseases [4]. Reference [5] too reported, in a study conducted in Hong Kong, that PM pollution has high association with respiratory diseases. Atmospheric particles of different size ranges exhibit wide chemical composition and characteristics [6].

$PM_{2.5}$ is particulate matter that has the aerodynamic diameters of less than 2.5 micrometer, and is known to be toxic to mankind. These particles have the ability to deteriorate local and regional air quality, as well as atmospheric visibility [8]. In addition, $PM_{2.5}$ pollution is associated with health diseases such as lung cancer and cardiopulmonary mortality as it was reported that an increase of 10 $\mu g/m^3$ resulted in a 1.5% increase in the total daily mortality, estimated increment of a 6% risk of cardiopulmonary problems and 8% risk of lung cancer mortality [9]. Most study shows the adverse effects of fine particles ($PM_{2.5}$) to human health is much worse than coarser particles [10]. Previous studies showed that $PM_{2.5}$ has high association with morbidity and mortality [11, 12]. Meanwhile, a different study from nine European countries reported a finding that risks of lung cancer disease increase up to 18% with every increment of 5 mg/m^3 in atmospheric $PM_{2.5.}$ The toxicity of smaller size particulates is greater as it can penetrate into human respiratory system easily as the inhalation can be distributed in the respiratory tract along the bronchial tree and the deep alveolar region [13, 14]. They have the capacity to adsorb carcinogenic elements due to their great surface area [15]. These particulates contain toxic elements such as hydrocarbons from combustion, and heavy metals from polluted environment. WHO International Agency for Research on Cancer (IARC) categorized diesel engine exhaust as carcinogenic to humans (Group 1) ([16, 17]. Different particle size intervals are of different sources, chemical characteristics and health problems [18]. In addition, both of the size fraction particles also are different in terms of sources, removal processes and also chemical compositions [19]. Furthermore, there are a few factors that could influence the concentration of particle mass which are the earth topography, emission sources and the meteorological parameters itself. This is because, these variables affect pollution concentration, as well as the removal, transportation and dispersion of the airborne particles [20]. Monsoon seasons and meteorological parameters (relative humidity, wind speed, temperature), as well as local activities are the factors that strongly affect the pollution level [21-23].

Due to industrialization, use of vehicles, and expansion of suburban areas into close proximity with industrial areas, the particle pollution in ambient environment is increasing [24]. Skudai or sometime is known as Iskandar Puteri, is a rapidly growing town and has various types of industries that could worsen the pollution level, as well as the health of the human population. However, there are limited studies that focuses on the temporal variation of particulate matter in this expanding suburban region. Hence, the aim of this study is to determine and analyze the variation and correlations of $PM_{2.5}$ mass concentration and meteorological influence in Southern region of Peninsular Malaysia, over a 6-month period.

II. METHODOLOGY

Fig. 1 and Fig. 2 show the location of the monitoring site, together with the zoomed-in map. The location is selected at southern part of Malaysian Peninsula with coordinates,

A. Monitoring Site

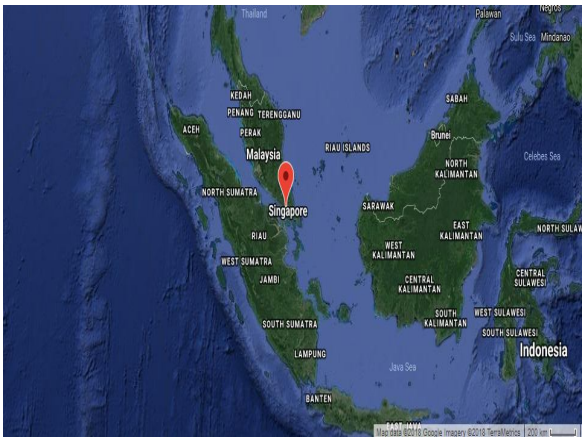


Figure 1: Monitoring Location (Map)

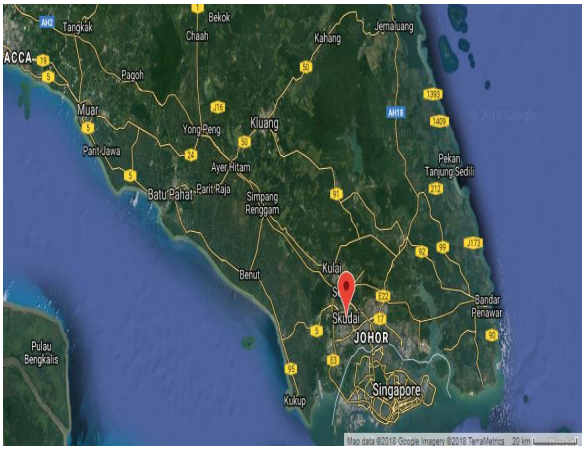


Figure 2: Monitoring Location (Zoom In)

1°33'56.7"N 103°38'21.5"E, located at Universiti Teknologi Malaysia (UTM) Skudai, Johor Bahru for continuous sampling of aerosols in order to study the ambient air quality. The sampler was placed on the roof top of N12 building, Faculty of Chemical Engineering. The study area, UTM Skudai has a population of 29,319 inside the campus only, with an increasing population growth rate especially after the expansion of Skudai suburban town into Iskandar Puteri developed region. The sub-urban area is surrounded by woods, dense residential cum commercial areas and literally sandwiched among different types of areas in the circumference of 30 km. Local background activities of the study area include being located 3 km to 5 km away from residential areas of Taman Universiti, Taman Sri Pulai, Taman Teratai, Taman Sri Pulai Perdana and Taman Sri Skudai,; 5 km away from industrial areas of Johor Technology Park and Taman Universiti, 5 km to 10 km away from Skudai and Senai Highway with frequent heavy vehicular traffic volume, 20 km away from Nusajaya and Iskandar Puteri developed regions, 20 km away from Johor Bahru city centre, and 30 km away from Pasir Gudang. Traffic congestion is quite common around the area due to the sampling site being 5 km away from queuing vehicles at Skudai toll plaza. On top of that, the location itself has intense human activity and heavy traffic flow due to great population and vehicle numbers in the premier education centre of 3020 acres. With the rapid urbanization, industrialization, development, transportation, economic and population growth rate around the campus area as well as the Skudai region, the particle mass concentration is expected to be around the ambient level of National Ambient Air Quality Standards of Malaysia.

B. Monitoring Device

The data collection of atmospheric $PM_{2.5}$ as well as meteorology parameters such as wind speed, temperature, relative humidity and rain volume were monitored via Grimm Environmental Dust Monitor (GRIMM Enviro EDM 164). GRIMM was programmed to run automatically at an air flow-rate of 1.2 L/min to collect $PM_{2.5}$ and meteorological parameters, continuously for 24 h. The parameters are monitored for half a year, which is from August 2017 to January 2018. The sampler is placed approximately 30 m above ground level, while the inlet is set to be at 2 m above roof surface. Careful consideration of the emission source distribution and dispersion patterns are taken when selecting the site. Ideally, the sampler is placed in such way that the inlet is not too closed with interferences and disturbances [25].

III. RESULTS AND DISCUSSIONS

$PM_{2.5}$ Mass Concentration and Meteorological Variables

Fig. 3 shows the daily diurnal trends of $PM_{2.5}$ mass concentrations which is monitored within 24-h time resolution, in order to ensure that the variation of

particulate daily pattern remain obscure in most cases [26]. PM_{10} mass concentration is plotted in the graph as well in the graph as a comparison study. 60-day data is represented for a 6-month trend; S1-S10: Day 1- Day 10 in August 2017; S11-S20: Day 1- Day 10 in September 2017; S21-S30: Day 1- Day 10 in October 2017; S31-S40: Day 1- Day 10 in November 2017; S41-S50: Day 1- Day 10 in December 2017; and S51-S60: Day 1- Day 10 in January 2018. Fig. 3 shows the particle mass concentration for both particle fractions of $PM_{2.5}$ and PM_{10} ($\mu g/m^3$).

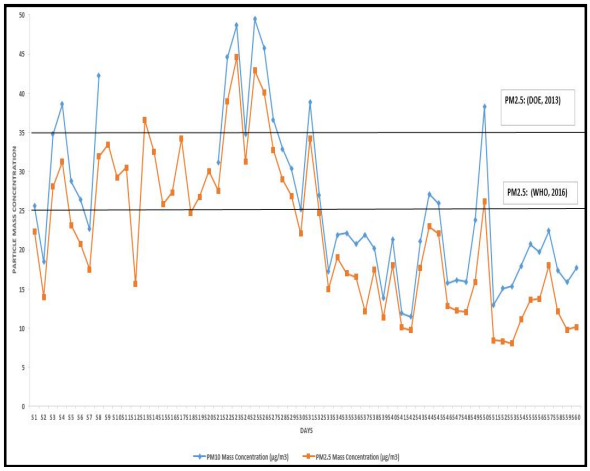


Figure 3: Daily Diurnal Trends of $PM_{2.5}$ and PM_{10} Mass Concentrations ($\mu g/m^3$)

The reference lines in Fig. 3 show the 24-h permissible value of $PM_{2.5}$ mass concentration according to World Health Organization Guideline and 2020 Malaysia Ambient Air Quality Standard. Some of the PM_{10} data in the graph are missing due to technical errors. However, the temporal variation in Fig. 3 indicates that the particle mass concentration of both $PM_{2.5}$ and PM_{10} have almost the same trend throughout the half a year plot. Assumptions that the PM_{10} findings are always almost of the same trend as the $PM_{2.5}$ data, and that the concentration value are always slightly greater than $PM_{2.5}$ data, are made. From the plot, it is observed that the PM_{10} level is uniformly 1.09~1.90-fold the level of $PM_{2.5}$ mass concentration. This also reveals that $PM_{2.5}$ mass concentration is consistently 52-92% of PM_{10} level. Normally, the re–suspended dust contribution to $PM_{2.5}$ is expected to be smaller compared to larger fraction of particulate matter [27]. The diurnal variations showed that both $PM_{2.5}$ and PM_{10} concentration variations are consistent with each other. However, the emission of PM_{10} tends to be generated constantly at a greater level than $PM_{2.5}$. The highest 24-h average pollutant contributions are 44.6 $\mu g/m^3$ and 49.44 $\mu g/m^3$ for $PM_{2.5}$ and PM_{10}, respectively. However, the lowest 24-h average mass concentrations for the suburban area are 8.06 $\mu g/m^3$ and 17.71 $\mu g/m^3$, for $PM_{2.5}$ and PM_{10}, respectively. The value of PM_{10} mass concentration ranges from 11.43 to 49.44 $\mu g/m^3$ throughout August 2017 to January 2018. The result of every 24-h mean concentration value of PM_{10} is under safe condition as the concentrations do not exceed the 24-h Malaysian Ambient Air Quality Standard (100 $\mu g/m^3$) [28], World Health Organization (50 $\mu g/m^3$) [2] and US National Ambient Air Quality Standard (150 $\mu g/m^3$) [29]. Meanwhile, the value of $PM_{2.5}$ mass concentration ranges from 8.06 to 44.6 $\mu g/m^3$ with 24-h average values of 26.80 $\mu g/m^3$, 26.08 $\mu g/m^3$ and 13.76 $\mu g/m^3$ for southwest monsoon, inter-monsoon, and northeast monsoon season, respectively. The average $PM_{2.5}$ mass concentration is 21.85 $\mu g/m^3$. The highest 24-h $PM_{2.5}$ mass concentrations exceeds the 24-h World Health Organization Guideline (25 $\mu g/m^3$) [2] and 2020 Malaysia Ambient Air Quality Standard (35 $\mu g/m^3$) [28]. Of the daily mean $PM_{2.5}$ pollutant variables, 43.33% exceed the 24-h World Health Organization Guideline, while 8.33% of them exceed the 24-h Malaysia Ambient Air Quality Standard and none of the pollutant concentration exceeded the 24-h Interim Target 1 and Interim Target 2 of Malaysia Ambient Air Quality Standard.

The time series plot in Fig. 3 shows that the two distinct peaks observed which spiked in August for both $PM_{2.5}$ and PM_{10} are probably due to strong seasonal variation, as well as local anthropogenic activities at the region of monitoring location. In the past years of 1997, 2005, 2013, and 2015, Malaysia and Singapore have experienced intensified haze episodes during Southwest monsoon seasons. However, in year 2017, there was no haze period occurred during this particular monsoon. The higher particulate mass concentration level at the site is probably due to motor vehicle activities and strong winds, besides the presence of dry atmospheric condition that re-suspended the road dust and soil particles. The graph displayed shows that Skudai region is not affected by any haze occurrence or regional biomass burning activities, which indicates that the level of pollutants are highly affected by other factors such as local motor vehicles and nearby industries [21], as well as prolonged dry season due to El-Nino's Southern Oscillation (ENSO) phenomenon [30]. A few researches second this particular statement with proofs such as in reference [31] which revealed that 30% of the total emission of fine particles ($PM_{2.5}$) is originated from transportation, while reference [32] reported motor vehicles and soil dust as main sources. Nevertheless, the particulate mass concentration plot starts to gradually decrease in December through January. The concentration of the pollutants start to reduce drastically as the wind flow patterns of the NE monsoon seasons change, indicating the beginning of a rainy seasons over Malaysia [33-35]. The intensity of rainfall during this season is high resulting the pollutants to be diminished from the atmosphere through wet deposition processes [36].

In Fig. 3 too, particle mass concentration from August through September is transported by the prevailing south-west wind during the south-west (SW) monsoon season as it is the dry season in Malaysia. On the other hand, the particle mass concentration from October to November is produced during inter-monsoon season while particle mass concentration generated during December to January is collected during north-east (NE) monsoon season as it is normally a wet season in Malaysia. During the SW monsoon season, the pollutants commonly come from the south-west quadrant of the Southeast Asia (SEA) region, which is Sumatra Island of Indonesia. Meanwhile, $PM_{2.5}$ and PM_{10} pollutants are usually carried by the prevailing NE wind from the Chinese mainland, Indochina region, and the Philippines, during the NE monsoon season. The source of the coarse particles (PM_{10}) are mainly primary particles which are directly originated from soil-related and organic carbon particles from the combustion of fossil fuels and biomass burning. Examples of soil-related particles include road dust, construction, and agriculture. Other sources of primary particles are volcanic eruptions, biomass burning, biological particles, and traffic related suspension such as brakes and tires, soil, mechanical processes and mineral dusts [37]. On the contrary, the fine particles ($PM_{2.5}$) are a mixture of primary and secondary particles that are produced in the atmosphere, such as sulfate and nitrate, which are derived from combustion-related sources such as industrial activities, combustion sources, automobile exhausts and heavy transportations [38-40].

These data agree well with a research previously reported by reference [24], as this study contributes a slightly higher level of daily average concentration of fine particles compared to his study which was also conducted in a suburban area, with $PM_{2.5}$ mass concentrations of 24.5 ± 12.0 μg/m^3 and 14.3 ± 3.58 μg/m^3, during pre-haze and post-haze, respectively. His findings are comparable with the result of this study due to the same type of sampling location. It was reported that 70% of the PM emission during non-haze period is originated from traffic activities [41]. On top of that, authors in reference [42] and [43], who conducted research in Istanbul and Helsinki, respectively, reported 24-h mean $PM_{2.5}$ mass concentration results of 20.8 μg/m^3 and 20.3 μg/m^3, respectively. For a haze occurrence period in the urban city of Kuala Lumpur, the concentration value is 61.2 ± 24 μg/m^3 [23]. Likewise, large cities such as Zhuhai and Hong Kong reported fine particle mean concentration of 59.3 μg/m^3 and 54.5 μg/m^3 [44]. Along with, the average levels of $PM_{2.5}$ mass concentration is also similar with those in Manila (44 μg/m^3), Bangkok (50 μg/m^3), Bandung (53 μg/m^3) and Chennai (46 μg/m^3) [45].

Fig. 4a shows the hourly distribution of the $PM_{2.5}$ mass concentration, one week of August to represent southwest (SW) monsoon, one week of November to represent inter-monsoon (IM), and another one week of January to represent northeast (NE) monsoon, while Fig. 4b plots the diurnal distribution of $PM_{2.5}$ mass concentrations (μg/m^3) and wind speed (m/s).

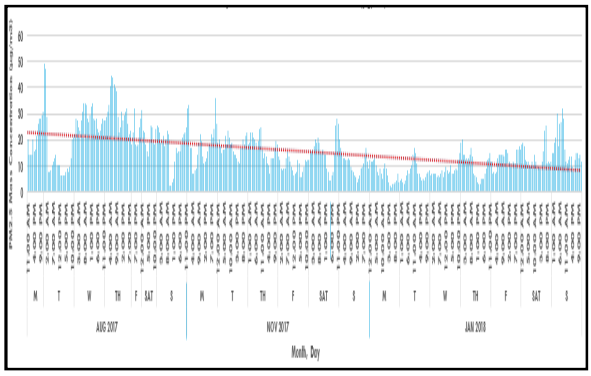


Figure 4a: Hourly Variation of $PM_{2.5}$ Mass Concentrations (μg/m^3)

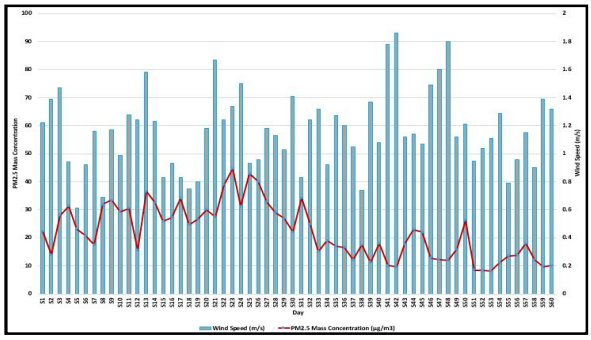


Figure 4b: Daily Distribution of $PM_{2.5}$ Mass Concentrations (μg/m^3) and Wind Speed (m/s)

Although the number of monitoring days is considered small to properly characterize the hourly plot, as well as weekday to weekend variation, but since the hourly extracted data is too abundant for half a year monitoring session, only a limited time frame is required to tabulate the graph. Therefore the 7-day hourly graph is plotted as in Fig. 4a. Fig. 4a use a-week data to represent each month, representing each season. The results of hourly $PM_{2.5}$ concentration value in Fig. 4a is obtained by adding the concentration value of each hour for the day in order to generate the accumulated number of mass concentration for the week. From Fig. 4a, it is clearly seen that the total of fine particulate matter mass concentration decreases significantly from August 2017 through January 2018. The graph states that the emission of this particular pollutant reduces according to the meteorological conditions. SW monsoon in August is usually dry season while NE monsoon in January is normally wet season. However, the value of $PM_{2.5}$ during weekends are not significantly different from those of weekdays, as there is only a slight decrease in the fine particulate mass concentration observed during the weekends, probably due to the less amount of primary particles being emitted into the ambient air. However, as reported by reference [46], despite the pollutant

sources, the level of PM concentration is almost stagnant in a region due to the meteorological factors enhancing the mixing of the lower atmosphere. Subsequently, during rainfall occurrence or wet season, the stagnant condition is reducing the efficiency of atmospheric dilution as the mixing height is much lower that during dry season. Rainfall occurrence during the study period results in slight increase in precipitation intensity, which act as a mechanism of washing-out and raining-out pollutants from the ambient air. This is due to the inhibition process that will eventually decrease the pollution level, as well as limiting the performance of particle precipitation from regional pollutant sources, as rain variable acts as an essential scavenging polluted atmosphere. Besides that, due to the geographical location and maritime exposure of southern region in Peninsular Malaysia too, the climate has uniform temperature and pressure, high humidity and abundant rainfall.

From Fig. 4b, the average wind speed readings for August, November and January are 1.076 m/s, 1.089 m/s and 1.09 m/s, respectively. Based on the figure, it is seen that the $PM_{2.5}$ mass concentrations is negatively influenced by the wind speed. This is because, as the magnitude of wind speed increases throughout the months, the level of particle mass concentration reduces significantly. Hence, the low level of PM concentration during NE season in January. This strong wind condition indicates clearer visibility of the atmosphere as the emission strength is reduced. This is because, strong convection, due to strong wind, has the capability to ventilate the daily boundary layer height [47]. On the other hand, the readings of wind speed during SW monsoon in August seems to be at a higher magnitude level, causing the reduction of dispersion process of the particulates. Thus, inducing the increase of $PM_{2.5}$ mass concentration values.

CONCLUSION

In conclusion, since the area is located in a non-busy city, the days are mostly clear days, although there are also some days that have $PM_{2.5}$ mass concentration that exceeded the permissible limit of $PM_{2.5}$ standards, and the level of $PM_{2.5}$ pollutant concentration varies according to the meteorological conditions throughout southwest monsoon to northeast monsoon seasons, with a range of 8.06 to 44.6 $\mu g/m^3$. In comparison with PM_{10} mass concentration, the PM_{10} concentration level is constantly consistent with $PM_{2.5}$ level (PM_{10} level is 1.09~1.90-fold the $PM_{2.5}$ mass concentration), revealing $PM_{2.5}$ mass concentration is 52-92% of PM_{10}., as well as is slightly greater than $PM_{2.5}$ level which contributes the highest 24-h mass concentration value of 49.44 $\mu g/m^3$.

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