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## Indoor and Outdoor Particulate Matter Concentrations in the Vicinity of Plastic Waste Processing Industries

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**Abstract.** While plastic recycling has gained conclusive acceptance by various stakeholders as a preferable products' end-of-life management, plastic waste processing industries may contribute to serious air pollutants emission and impair human health, especially if it is in uncontrolled conditions. Apart from toxic gas pollutants, this industry may also emit significant concentration of particulates matter or dust, notably via physical (shredding, sorting, and washing) and melt (re-granulation and reprocessing) processes. Meanwhile, in Sungai Petani, Kedah, Malaysia, public anguish is increasing in recent years due to mushrooming plastic waste recycling industries in its residential area. Thus, a study was conducted to analyse the day- and night-time ambient air PM<sub>10</sub> levels and their relationship with selected meteorological parameters (ambient temperature, relative humidity and wind speed) at two different locations (Cinta Sayang Resort Villa, CSRV and Metro Specialist Hospital, HM) in Sungai Petani, Kedah, Malaysia. The mean ambient PM<sub>10</sub> levels of Cinta Sayang Resort Villa (CSRV) and Metro Specialist Hospital (HM) were found exceeding the New Malaysia Ambient Air Quality Standard at 150 µg/m<sup>3</sup> (24-hours), which were 568.082 ± 266.441 µg/m<sup>3</sup> 615.046 ± 355.672 µg/m<sup>3</sup>, respectively. Distribution of PM<sub>10</sub> concentrations between day and night-time were found to be statistically insignificant at both sites. Meteorological parameters have also contributed to the trend of PM<sub>10</sub> concentrations at both sites especially at HM. Inverse correlation with PM<sub>10</sub> at CSRV was explained by the absence of moisture (or rain) at the site while the positive correlation observed at HM was due to the hot temperature-strong wind association at the site. Temperature was found to be the manipulating factor for PM<sub>10</sub> at HM, via linear regression model developed at  $PM_{10\text{out}} = -4352.426 + 170.557 \times T_h$  with  $F(1, 8) = 15.224$  at  $p < .005$ , accounting for 65.6% of the variation. Thus, proper attention should be given to the particulates matter emitted in Sungai Petani, believed to be influenced by the uncontrolled emission from the plastic recycling industries.



## 1. Introduction

Malaysia has experienced rapid industrial development and urbanization for the past years. As in many countries, air pollution has been associated with rapid industrialization, arising the public health and environmental concern in Malaysia. The development process has polluted the atmosphere despite that they have plenty of benefits on the economy [1]. The emission of pollutants to the atmosphere in 2017 were mainly contributed by mobile sources (70.4%) followed by power plant (24.5%), industrial (2.9%) and others (2.1%) [2]. Particulate matter (PM) is a general term to classify air pollutants comprising of suspended particles in air, varying in composition and size, resulting from various activities originating from human activities, such as industrial facilities, power plants, vehicles, incinerators, dust and fires [3]. PM consists of solid and/or liquid particles, entering the atmosphere by natural processes or by human intervention [4]. The particle size ranges between 2.5 $\mu\text{m}$  (PM<sub>2.5</sub>) and 10 $\mu\text{m}$  (PM<sub>10</sub>). PM is found substantially near the surface and its mechanism of development varies from gases [5]. Epidemiological studies suggest that mortality and morbidity are associated to PM in ambient air, particularly fine particles (with an aerodynamic diameter of less than 10  $\mu\text{m}$ ) that can penetrate more easily into the lungs and which are more expected to increase the incidence of respiratory and cardiovascular diseases [6]. PM can affect the reproductive system as it can lead to premature mortality in patients suffering from lung or heart disease, nonfatal heart attacks, aggravate asthma, reduced lung functionality, irritation in airways, coughing difficult breathing and many more [3].

In Malaysia, air pollution has become one of the common environmental problems due to urbanization and industrialization. The issues on air pollution have raised concerns which led to several studies on the characterization of the chemical and identification of the source of ambient air particulate matter [7 - 10]. The chemical composition of PM is a crucial component of data for evaluating its source and health impacts. Information of chemical composition makes it possible to identify the possible harmful impact of PM. The problem on air pollution at the location of the study, Sungai Petani, has become an issue for the past year. Sungai Petani is an industrial area in Kedah located at the northern of the peninsular Malaysia. Plastic waste recycling factories including illegal recycling plants operates in the area. The operations of the factories have cause discomfort among the residents in Sungai Petani. Public is concern on the mushrooming recycling factories operating in the region which is said to have been burning plastic waste in their compounds.

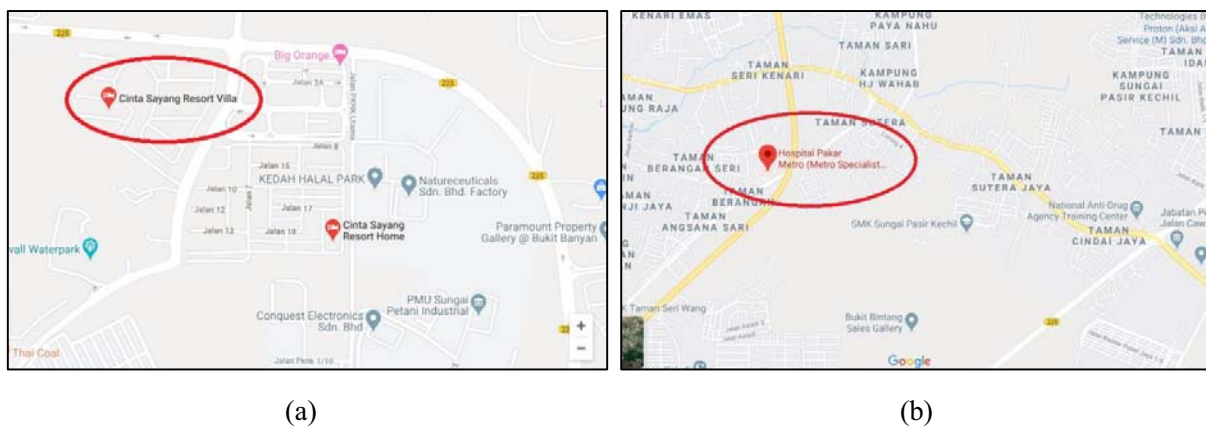
Plastics continue to benefit humans in countless ways. However, not all usage of plastics are practical and sustainable, as shown by common practice, unwanted human exposure to endocrine- disrupting bisphenol-A (BPA) and di-(2-ethylhexyl)phthalate (DEHP), issues arising from the large volumes of plastic being disposed of and the depletion of non-renewable petroleum resources as a consequence of the ever-increasing mass production of consumer plastic products [11]. Incineration of plastic waste in an open area contributes to emission of air pollution. 12% municipal solid waste comprising of plastics, are burnt, which will result in emission of toxic gases like dioxins, furans, mercury and polychlorinated biphenyls into the atmosphere [12]. Verma et al., (2016) found that the by-products of plastic incineration are airborne particulate emission (soot) and solid residue. Several studies have found that the soot and solid residual ash are most likely to cause health and environmental issues, particularly volatile organic compounds (VOCs), semi-VOCs, smoke (PM), heavy PM, polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzofurans (PCDFs) and dioxins [13].

## 2. Methodology

### 2.1. Sampling Plan

Two locations are selected at mixed industrial-residential area in Sungai Petani to study the temporal trends of PM<sub>10</sub> at mixed industrial-residential area in Sungai Petani. The locations chosen are Cinta Sayang Resort Villa and Metro Specialist Hospital. These sampling points covers the north and south part of Sungai Petani city. 24-hour sampling is conducted at the sampling points that have been selected. PM<sub>10</sub> samples were

collected for 10 weeks, once per week (from December 2019 to January 2020) at the sampling points. The samplers were location within 1–2 km radius from the identified sources of pollution. Figure 1 illustrated both sampling sites location and the plastic factories.



**Figure 1.** Sampling sites location (a) Cinta Sayang Resort Villa and (b) Metro Specialist Hospital.

### 2.2. Ambient $PM_{10}$ and Meteorological Parameters' Sampling

$PM_{10}$  samples were collected for 10 weeks, once per week at the sampling points at both sites for 24-hours exposure. Samples of  $PM_{10}$  were collected on 0.8  $\mu\text{m}$  pores size, 37mm diameter polycarbonate filters. The filters were placed into 37-mm 2-piece cassettes along with support pad for each cassette. One end of the cassette was attached to the pump (SKC AirChek XR5000) with a flexible tubing. Medium flow was used which is 1.8 L/min, in accordance with the sampling pump utilized. Before sampling was employed, the filters were pre-weighed using the electronic microbalance with resolution of 10 – 6 g. Filters to be used as blank were prepared at about the same time as sampling was begun. These blanks consist of unused filters and cassettes from the same as those used for sample collection. The blanks are managed in the same manner as the samples prepared previously to minimized and corrected the presence of systematic errors.

The meteorological factors monitored in this study are temperature, relative humidity (RH), wind speed and wind direction, measured by an automated weather station (AcuRite 01535M 5-in-1 Weather Station) equipped with weather sensors. The sensor provided various weather readings such as temperature with accuracy of  $\pm 2^\circ\text{C}$ , relative humidity with accuracy of  $\pm 4\%$  and wind speed ranging from 0 to 159 kph. The weather station was placed less than 100 meters of wireless range, on the rooftop of hospital building at Metro Specialist Hospital and a resident's dwelling in Cinta Sayang Resort Villa.

### 2.3. Sample Analysis

All samples ( $n = 20$ ) underwent gravimetric and statistical analyses. The filters were conditioned in a desiccator for at least 24 hours pre-and-post sampling prior to gravimetric analysis using a microbalance. Filters were placed in an environmentally controlled room of temperature at  $20^\circ\text{C}$  to  $23^\circ\text{C}$  and relative humidity of 30 – 40%. Each filter was weighted for six times before an average reading was taken. The final particulate concentration was obtained by dividing the average corrected particulate mass and divided by the total volumetric air flow passed through the filters. Throughout the study, the particulates concentrations are expressed in gravimetric unit ( $\mu\text{g}/\text{m}^3$ ). The average corrected particulate mass was obtained by using six additional filters designed as 'control' filters which were weighed along with the sample filter to compensate for any systematic error due to weighing. Variations for the 'control' filters observed were less than 2%.

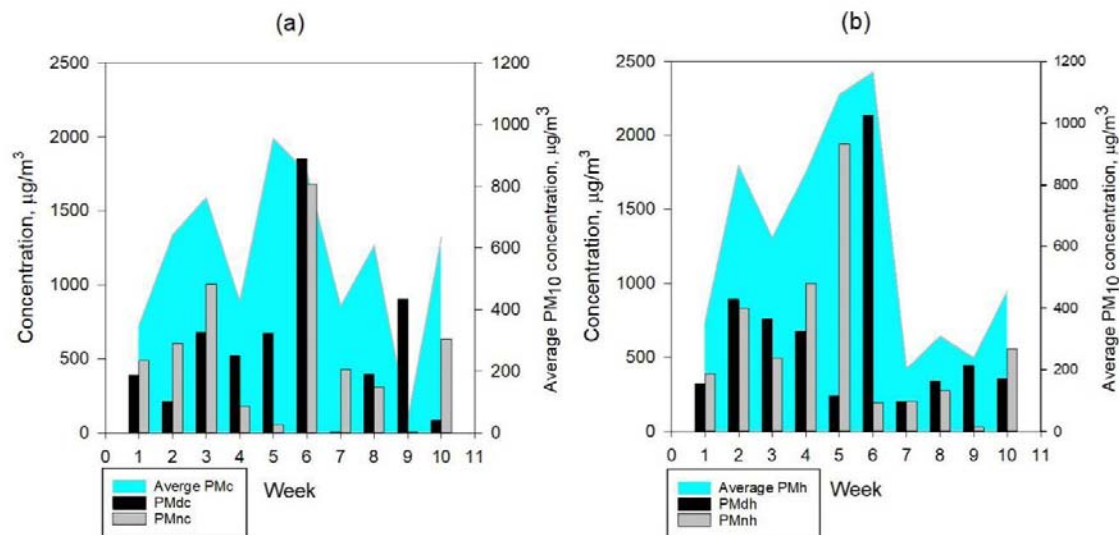
All data collected underwent series of statistical analyses. The Pearson product-moment correlation was used in the study particularly to determine the strength and direction of a linear relationship between continuous variables. While the multiple linear regression (MLR) models were developed to predict a continuous dependent variable ( $PM_{10}$  concentrations) based on multiple independent variables (meteorological or comfort parameters) for both outdoor and indoor  $PM_{10}$  at both sampling sites (CSRV and HM). Based on the MLR analysis, the overall fit (variance explained) of the model and the relative contribution of each of the predictors to the total variance explained can be determined. The model's performances and accuracies were then evaluated via performance indicators of coefficient of determination ( $R^2$ ), adjusted R (Adj R) and variance inflation factors (VIF).

### 3. Result and Discussion

#### 3.1. Day and Night Ambient $PM_{10}$ Concentrations

Weekly concentrations of  $PM_{10}$  at both Cinta Sayang Resort Villa (hereinafter CSRV) and Metro Specialist Hospital (hereinafter HM) are presented in Figure 2. In overall, it was observed that the mean concentration of  $PM_{10}$  for both sites were 10 to 12 times higher than the National Ambient Air Quality Standard (NAAQS) and the new Malaysia Ambient Air Quality Standard (MAAQS) of 24-hours exposure at  $150 \mu\text{g}/\text{m}^3$  and  $100 \mu\text{g}/\text{m}^3$ , respectively. Through the 10 weeks sampling, the mean concentration of  $PM_{10}$  in CSRV and HM were  $568.082 \pm 266.441 \mu\text{g}/\text{m}^3$  and  $615.046 \pm 355.672 \mu\text{g}/\text{m}^3$ , respectively. It was also observed that the highest readings were collected during the earliest to mid of months (week 2 – week 6), which were commenced during January 2020. During these times, there were no occurrences of rainfall recorded. Thus, it was believed that these might be the cause of immense atmospheric particulates pollution in Sungai Petani.

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the day and night  $PM_{10}$  concentrations at both sampling locations. Data are mean  $\pm$  standard deviation (table 1), unless otherwise stated. An outlier was detected at both CSRV and HM sites but did not reveal them to be extreme and they were kept in the analysis. The assumption of normality (table 2) was not violated for CSRV site, as assessed by Shapiro-Wilk's test ( $p = 0.063$  and  $p = 0.137$ ). However, normality test failed for the distribution of  $PM_{10}$  at HM site (Table 2). From both t-test results (Table 3)  $PM_{10}$  day concentrations at both sites were much higher (CSRV:  $572.667 \pm 530.208 \mu\text{g}/\text{m}^3$ ; HM:  $638.520 \pm 574.468 \mu\text{g}/\text{m}^3$ ) as opposed to night-time concentrations, but they were not statistically significant, for CSRV site,  $t(9) = 0.219$ ,  $p = 0.831$ , and for HM site,  $t(9) = 0.168$ ,  $p = 0.870$ . This could infer that a single source might be responsible in contributing to higher concentration of ambient  $PM_{10}$  in CSRV and HM. These single sources were believed to be operated during day and night-time.



**Figure 2.** Temporal variations of ambient PM<sub>10</sub> concentrations at (a) CSRV site, and (b) HM site.

**Table 1.** Descriptive statistics of day and night PM<sub>10</sub> concentrations at Cinta Sayang Resort Villa (CSRV) and Metro Specialist Hospital (HM).

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Day PM CSRV	572.667	10	530.208	167.667
	Night PM CSRV	539.334	10	499.044	157.812
Pair 2	Day PM HM	638.520	10	574.468	181.663
	Night PM HM	591.574	10	559.746	177.007

**Table 2.** Normality tests of day and night PM<sub>10</sub> concentrations at Cinta Sayang Resort Villa (CSRV) and Metro Specialist Hospital (HM).

	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Day PM CSRV	0.220	10	0.186	0.853	10	<b>0.063</b>
Day PM HM	0.231	10	0.139	0.719	10	0.001
Night PM CSRV	0.226	10	0.159	0.882	10	<b>0.137</b>
Night PM HM	0.226	10	0.158	0.835	10	0.039

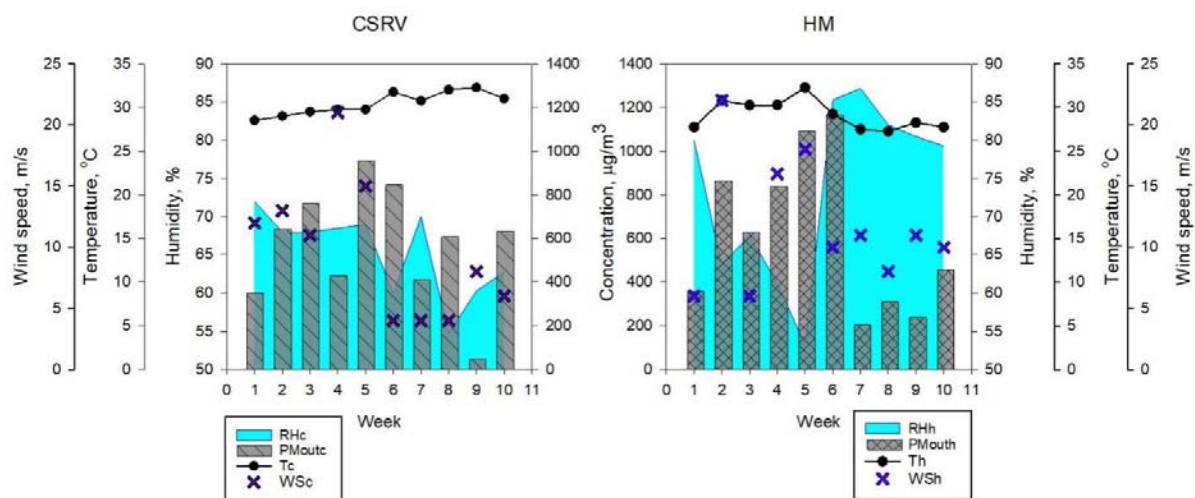
a. Lilliefors Significance Correction

**Table 3.** Student's t-test for Samples Collected at Cinta Sayang Resort Villa (CSRV) and Metro Specialist Hospital (HM).

	Paired Samples Test							
	Paired Differences							
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Day PM CSRV - Night PM CSRV	33.333	480.485	151.943	-310.385	377.051	0.219	9	<b>0.831</b>
Day PM HM - Night PM HM	46.946	883.541	279.400	-585.101	678.993	0.168	9	<b>0.870</b>

### 3.2. The Relation between Concentration of Ambient $PM_{10}$ and Meteorological Parameters

Through the 10 weeks sampling, in which the sampling was commenced from December 2019 until February 2020, 10 samples of meteorological parameters were obtained for each temperature, relative humidity and wind speed. Those readings were then analyzed to investigate their relationships and influences towards  $PM_{10}$  concentrations at both CSRV and HM sites. The highest concentration at CSRV was recorded during week 5 (January 2020) at  $954.63 \mu\text{g}/\text{m}^3$  at temperature of  $29.75^\circ\text{C}$ . It was also observed that the relative humidity recorded at 69% and wind speed of 15 m/s were among the highest out of 10 weeks monitoring. While at HM site, the highest concentration was observed ( $1164.35 \mu\text{g}/\text{m}^3$ ) during week 6 (January 2020), in which the humidity was also among the highest recorded (85.25%) at almost similar temperature of  $29.25^\circ\text{C}$ .



**Figure 3.** Weekly variations of average  $PM_{10}$  ( $PM_{outc}$ ) at CSRV and HM with meteorological parameters. Note that RH refers to relative humidity, T is temperature and WS is the wind speed. Small letters c and h are referring to CSRV and HM sites, respectively. MAAQS refers to the standard 24hrs  $PM_{10}$  of Malaysia Ambient Air Quality Standard.

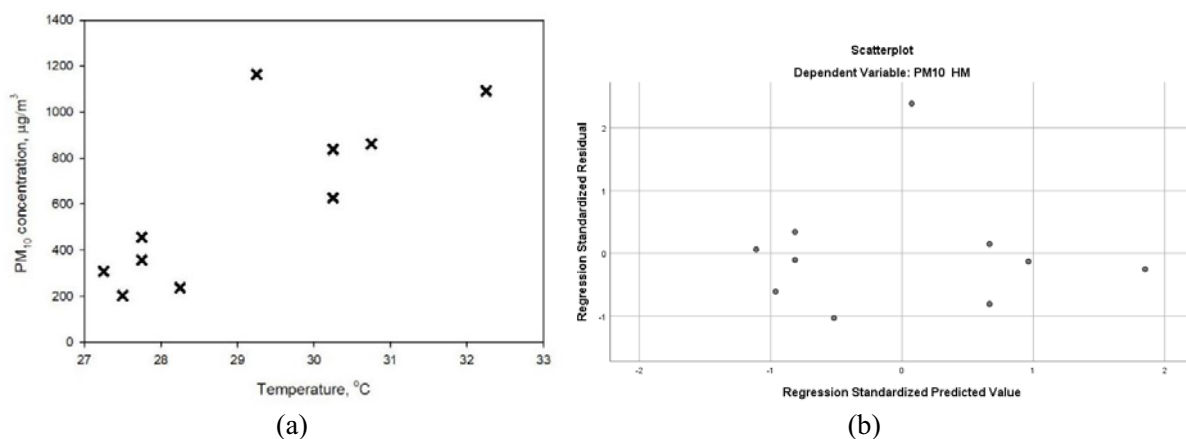
Higher humidity might cause discomfort to human. At  $25^\circ\text{C}$  condition of higher humidity, it may feel as  $28^\circ\text{C}$  surrounding temperature. At HM site, the effect was also proved via Pearson correlation analysis as tabulated in table 4. From the analysis, all meteorological parameters showed no significant relationship with  $PM_{10}$  at CSRV, while there were moderate to strong significant correlations observed at HM for all meteorological parameters studied. At all cases, relative humidity (RH) showed direct inverse relationship with temperature. Hot or warm air bears more capacity to hold more water as compared to cooler air. If there is no moisture added to the air, the amount of moisture in air over maximum amount that can be present will decrease when temperature increases. The synergistic effect of relative humidity and  $PM_{10}$  was also observed somewhere [14–16], in which higher humidity with higher  $PM_{10}$  could lead to visibility reduction and formation of haze. Moderate inverse correlation between  $PM_{10}$  at HM with RH implies that decrement in  $PM_{10}$  was influenced by incremental value of RH. This is attributed to mass accumulation of moist air adhered to the particulates leading to accretion of dry deposition rate to the ground.

**Table 4.** Pearson's product-moment correlation of PM<sub>10</sub> concentrations (PM<sub>out</sub>) with temperature (T), relative humidity (RH), and wind speed (WS) at (a) CSRV (subscript c) and (b) HM or (subscript h).

(a)				(b)			
	T <sub>c</sub>	RH <sub>c</sub>	WS <sub>c</sub>		T <sub>h</sub>	RH <sub>h</sub>	WS <sub>h</sub>
PM <sub>outc</sub>	<b>-0.181</b> <i>0.616</i>	<b>0.0079</b> <i>0.983</i>	<b>0.0152</b> <i>0.967</i>	PM <sub>outh</sub>	<b>0.81</b> <i>0.00453</i>	<b>-0.588</b> <i>0.0736</i>	<b>0.53</b> <i>0.115</i>
T <sub>c</sub>		<b>-0.865</b> <i>0.00122</i>	<b>-0.676</b> <i>0.0318</i>	T <sub>h</sub>		<b>-0.904</b> <i>0.000327</i>	<b>0.669</b> <i>0.0346</i>
RH <sub>c</sub>			<b>0.585</b> <i>0.0755</i>	RH <sub>h</sub>			<b>-0.657</b> <i>0.0391</i>

Note: bold values refer to correlation coefficient and italic values refer to the p-values.

Among all meteorological parameters studied, temperature was observed to influence PM<sub>10</sub> concentrations the most at all sites. Strong correlation was inspected between PM<sub>10</sub>-temperature at HM site. Therefore, the linear regression analysis was performed to determine how much of the variation in the PM<sub>10</sub> concentration at HM is explained by the temperature and understand the direction and magnitude of the relationship. Visual inspection of these two plots indicated a linear relationship between the variables (Figure 4a). There was homoscedasticity and normality of the residuals (figure 4b). The prediction equation was determined as  $PM_{outh} = -4352.426 + 170.557 \times T_h$  (as shown in table 5 and 6). Average temperature statistically significantly predicted PM<sub>10</sub> concentration with F-test of  $F(1, 8) = 15.224$  at  $p < .005$ , accounting for 65.6% of the variation in PM<sub>10</sub> concentration with adjusted  $R^2 = 61.2\%$ , a strong size effect according to Cohen (1988). Meanwhile the PM<sub>10</sub> magnitude at HM site was also contributed by the velocity of wind (figure 3). Higher winds, in the range of 10 – 20 m/s coupled with hot and less humid conditions increased the concentrations of PM<sub>10</sub>, in the sense that it induced the resuspension of particulates in ambient air.

**Figure 4.** Relationship of PM<sub>10</sub> with temperature at HM.

**Table 5.** Model summary of linear regression analysis for PM<sub>10</sub> at HM with its ambient temperature.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.810 <sup>a</sup>	0.656	0.612	221.41301	2.619

a. Predictors: (Constant), Temperature HM

b. Dependent Variable: PM<sub>10</sub> HM**Table 6.** ANOVA result for linear regression analysis of PM<sub>10</sub> at HM with its ambient temperature.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	746332.184	1	746332.184	15.224	0.005 <sup>b</sup>
	Residual	392189.783	8	49023.723		
	Total	1138521.968	9			

a. Dependent Variable: PM<sub>10</sub> HM

b. Predictors: (Constant), Temperature HM

#### 4. Conclusion

A particulate matter (PM<sub>10</sub>) concentration study has been conducted at two sampling locations located in the vicinity of plastic recycling industries in Sungai Petani, Kedah, Malaysia. Both sites are located within 1 – 2 km radius of the sources. The sites selected are the residential area of Cinta Sayang Resort Villa (CSRV) and a commercial building of Metro Specialist Hospital (HM), selected based on the report received from the residents nearby. It was observed that at almost all times the PM<sub>10</sub> concentrations have violated the 150 µg/m<sup>3</sup> for 24-hr exposure. The mean concentration for all 10 weeks sampling period were 568.082 ± 266.441 µg/m<sup>3</sup> at CSRV site and 615.046 ± 355.672 µg/m<sup>3</sup> at HM site, which are triple than the permissible limit. When investigating the day and night-time concentrations, it was found that both sites were possibly polluted by the similar source or sources of PM<sub>10</sub> pollutants operated day and night. This finding was proved via statistical mean values comparisons in which resulted to insignificant values between day- and night-time concentrations. The influence of meteorological conditions has also contributed to the particulate's pollution in the area especially during high ambient temperature and intense wind speed. The reversed influenced of relative humidity was observed at CSRV in which higher PM<sub>10</sub> concentration was contributed during higher relative humidity condition. This was believed to be the reason of reduced visibility in the investigated area. However, at CSRV site, the inverse relationship between relative humidity and PM<sub>10</sub> may signify the dry deposition process resulting from the mass accumulation process happened in absence of access moisture or rainfall effect. Among the meteorological parameters studied, temperature has been witnessed as the most contributing factor towards PM<sub>10</sub> trend in HM site as observed from the statistical analysis of linear regression and correlation study. In conclusion, the increment of PM<sub>10</sub> investigated in Sungai Petani may be contributed to the existing plastic waste recycling industry coupled with the dry and hot conditions. Further study is needed to further investigate the possible fingerprints of the PM<sub>10</sub> pollution.

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