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Investigation of Relationship between Particulate Matter ($PM_{2.5}$ and PM_{10}) and Meteorological Parameters at Roadside Area of First Penang Bridge

Muhammad Arieff Mat Shukri[1], Mahani Yusoff[2*], Norrimi Rosaida Awang[1], Musfiroh Jani[1], Zairah Ab Kadir[1], Bawani Selvam[1], Muhammad Azwadi Sulaiman[2], Mohammed Abdus Salam[3]

[1]Faculty of Earth Science, Universiti Malaysia Kelantan, Jeli Campus, 17600 Jeli, Kelantan, Malaysia.
[2]Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Jeli Campus, 17600 Jeli, Kelantan, Malaysia.
[3]Department of Environmental Science, Independent University, Bangladesh.

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☒*Corresponding author:
Dr. Mahani Yusoff
Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Jeli Campus, 17600 Jeli, Kelantan, Malaysia.
Email: mahani@umk.edu.my

Abstract

Present study was focusing to characterize the particulate matter ($PM_{2.5}$ and PM_{10}) at the roadside of First Penang Bridge and the associated meteorological parameters influence such as precipitation, temperature, and relative humidity. The study was conducted by focusing on the roadside area of First Penang Bridge (N05°21.375'; E100°23.584'). A total of 12 samples thrice per month for each particulate matter sizes were collected starting from June 2015 to September 2015. Meteorological data were obtained from the Meteorological Department of Penang on daily basis and 24-hours averages. Descriptive statistical analysis was conducted in characterizing the relationship between particulate matter concentrations and the target meteorological parameters. Result showed that $PM_{2.5}$ and PM_{10} concentrations ranged between 18.06 – 79.51 µg/m³ and 22.38 – 130.90 µg/m³ with the overall mean concentration of 39.35 µg/m³ for $PM_{2.5}$ and 45.24 µg/m³ for PM_{10}. For the $PM_{2.5}$, weak negative correlation was obtained between PM and precipitation (r = -0.462), strong negative correlation with relative humidity (r = -0.799) and weak positive correlation between temperature (r = 0.456). PM_{10} showed weak negative correlation between PM with temperature (r = -0.061) and precipitation (r = -0.022), and strong positive correlation between PM and relative humidity (r = 0.130).

1. Introduction

Air pollution have become a global issue and becoming a great concern of many countries for their health effects to human and the environment. Quality of urban environment has deteriorated as a result of rapid urbanization and constant demand of land for infrastructural development in urban area. In highly populated areas, anthropogenic activities can trigger more concentrations of air pollutants into the environment. United States Environmental Protection Agency (USEPA) has declared six major air pollutants responsible for severe air pollution effects, and one of them is the particulate matter. Particulate pollution may derive either from natural processes such as wind-blown dust, volcanic ash and sea salt or anthropogenic sources such as vehicles and power plant emissions (Frank & Julia, 2012). Particulate matters with diameters less than 10 microns are divided into two groups, course and fine particulate matter. Course particulate matters also known as PM_{10} have diameters between 2.5 microns and 10 microns while fine particulate matters ($PM_{2.5}$) have diameters less than 2.5 microns (Negah, 2016).

Particulate matter with a diameter of less than 2.5 µm ($PM_{2.5}$) has given much interest due to the particle size is very fine and can be easily penetrated into the human body system through inhalation (Kennedy, 2006) and being able to be transported longer distance through trans-boundary movement. To be more focused, particulate matter with aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$) is proven to be more harmful than PM_{10} (Vilar-Vidal et al., 2014). In addition, the atmospheric particulate matters are responsible reducing visibility of the air, decaying materials (Grossi & Brimblecombe, 2002), acid rain formation, enhanced sea-level, heat stress and play important roles in global climate change (Jacobson, 2002). Malaysian Department of Environment (DOE) through New Malaysia Ambient Air Quality Standard (MAAQS) has set its standard limit for $PM_{2.5}$ daily 24-hours and annual average of PM concentrations at 75 µg/m^3 and 35 µg/m^3 while for PM_{10} standard is 150 µg/m^3 for daily 24-hours and 50 µg/m^3 for its annual average. This target was applied for the interim target 1 (IT-1) in 2015 to 2017.

Malaysia is undergoing rapid urbanization and industrialisation processes in order becoming a developed nation by 2020 which is a part of the millennium goal. During these processes, tremendous amount of atmospheric pollutants have been released into the atmosphere including the particulate matter, $PM_{2.5}$ as well as PM_{10}. Malaysia only aware about the severity of $PM_{2.5}$ that is more interrelated to public health and started to get into act in December 2012 when five air quality monitoring stations were fitted with equipment to measure fine particulate matter. However, PM_{10} is still

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being used as one of the criteria pollutants in API system to measure particulate pollution. High particulate event or normally known as haze episodes is annually experienced by Malaysian. In 2015, massive land and forest fires in Sumatra and Kalimantan Indonesia (DOE, 2015) which started from August to September 2015 were badly affecting Malaysia, and the dominant pollutant during the event was the $PM_{2.5}$ (Hui, 2015). Therefore, more studies on $PM_{2.5}$ particularly in Malaysia are considerable important.

Climate change could have significant effect in the distribution of particulate matter, $PM_{2.5}$ (Tai et al., 2010). Therefore, study on role of meteorological parameters such as temperature, precipitation, humidity, wind speed, and wind direction is very important carried out parallel to air pollutant research. In European countries, $PM_{2.5}$ appears to be very sensitive to temperature changes in all seasons (Amil et al., 2015). Despite many studies have been conducted around the world, very less observational studies have been done in Malaysia on the correlation of particulate matter with the meteorological variables. In addition, the different seasons in other countries compared to Malaysia could give different interpretation on the particulate matter distribution. To address the need and interpret the meteorological mechanisms on both $PM_{2.5}$ and PM_{10} this paper presented a systematic statistical analysis to quantify the correlations of total $PM_{2.5}$ and PM_{10} with meteorological variables will be presented here. Present study aimed to evaluate the relationship between fine particulate matter ($PM_{2.5}$) and course particulate matter (PM_{10}) and its associated meteorological parameters in Penang, focussing on roadside emissions.

2. Materials and Methods

The study was performed at the roadside of First Penang Bridge (N05°21.375'; E100°23.584'), Penang (Figure 1). The sampling location located at roadside area of highway near to the First Penang Bridge. The highway connects Gelugor on the island of Penang and Seberang Perai on the mainland. It was a very busy route where massive traffic congestion always occurred especially during peak hours. Samples were collected on 24-hours daily basis using Low Volume Air Sampler (LVAS) (LV-20P, Sibata Co. Japan) using quartz fibre filter (Sibata Co. Japan, 25 mm). A total of 12 samples were collected thrice a month for each particulate matter sizes ($PM_{2.5}$ and PM_{10}) during June 2015 to September 2015.

The LVAS fitted with quartz microfiber filter paper was placed 2 m above ground level with air flow rate of 20 $Lmin^{-1}$. Direct impactor used to separate fine and course mode aerosols. Before the sampling was carried out, the filter papers were pre-baked at 500°C for five hours in an electric oven to remove any deposited organic compounds. The filters then were kept under control conditions in a desiccator for about 48 hours to minimize the influence of water adsorption. Filter papers were then weighed by using digital micro balance with 0.00001 mg sensitivity before and after sampling. The pollutants concentrations were determine using gravimetric mass method using Equation (1) as follow:

$$\text{Sample concentrations } (\mu g/m^3) = \text{Final weight (g)} - \text{Initial weight (g)} / Q3 \quad (1)$$

Where Q is the quantification limit comprising the multiplication of flow rate by time.

Figure 1: Sampling location at Penang First Bridge (Source: Google Map, 2016)

Daily average meteorological parameters data for the sampling period was obtained from the Meteorological Department of Penang. It included surface temperature, relative humidity and precipitation, wind speed, wind direction and air pressure. Daily mass concentrations of $PM_{2.5}$ and PM_{10} obtained were compared with the standard guidelines set by MAAQS. Correlation between PM concentrations and meteorological data were calculated using Spatial Package for Social Sciences, SPSS version 19 to determine the strength of association.

For the quality assurance and quality control (QA/QC), blank control procedure for particulate sampling was performed where the initial and final weight of blank sample was measured. The initial and final weight were almost the same and within permissible measurement error. All the instrumentation set up and monitoring activities were carried out in accordance to similar method performed by Salam et al. (2011) with minor modification.

3. Results and Discussion

3.1. Descriptive Statistics of $PM_{2.5}$ and PM_{10} Concentrations at roadside of Penang Bridge

Table 1 shows the daily average mass concentrations value for $PM_{2.5}$ and PM_{10} which measured at roadside area were 39.35 and 45.24 µg/m^3, respectively. Result show that concentrations of $PM_{2.5}$ was in range of 18.06 and 79.51 µg/m^3 with median and standard deviation value of 31.43 and 22.12 µg/m^3, respectively. Meanwhile, concentration for PM_{10} ranged from 22.38 and 130.90 µg/m^3 with the median and standard deviation of 32.81 and 30.25 µg/m^3. The obtained result indicated that mean concentrations of PM_{10} was slightly higher than $PM_{2.5}$ during the sampling period.

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Table 1: Descriptive statistics of $PM_{2.5}$ and PM_{10} concentrations at roadside area of First Penang Bridge

Parameters	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
Mean	39.35	45.24
Standard Deviation	22.12	30.25
Median	31.43	32.81
Maximum	79.51	130.90
Minimum	18.06	22.38
No. of samples	12.00	12.00

Based on Table 2, the highest mean concentrations of $PM_{2.5}$ was observed during August 2015 with of 50.23 ± 27.63 µg/m^3 while the lowest value was 22.11 ± 4.37 µg/m^3 recorded in July 2015. For the PM_{10} monthly mean concentrations, the highest value was recorded in September 2015 with 76.27 ± 49.31 µg/m^3 and the lowest was observed in August 2015 with 22.22 ± 15.96 µg/m^3. The monthly mean of mass concentrations for both $PM_{2.5}$ and PM_{10} calculated by using t-Test showed no significance difference (p-value < 0.05) at the roadside area of First Penang Bridge.

Table 2: Monthly mean concentrations of $PM_{2.5}$ and PM_{10}

Month	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
June	43.98 ± 11.88	35.65 ± 8.99
July	22.11 ± 4.37	40.62± 21.27
August	50.23 ± 27.63	28.41 ± 5.29
September	41.09 ± 33.28	76.27 ± 49.31

3.2. Daily Variation of $PM_{2.5}$ and PM_{10} Concentrations at Roadside of Penang Bridge

Figure 2 and 3 show the variations in the daily concentrations of $PM_{2.5}$ at the roadside of Penang Bridge. Result revealed that the mass concentrations of all samples for both sizes of particulate matter were fluctuated and varied throughout the sampling duration. The increasing and decreasing trend of mass concentrations of particulate matter was believed to be influenced by meteorological factors such as temperature, relative humidity, precipitation, wind speed and wind direction (Wang & Ogawa, 2015). As the sampling location is a roadside of First Penang Bridge, the major source of particulate matter were believed from the combustion sources such as vehicle emissions, and other forms of combustion processes. According to Owoade et al. (2012), the major sources of $PM_{2.5}$ in Ile-Ife, Nigeria were originating from fossil fuel burning, vehicular emissions and other forms of combustion processes. In parallel, Abdullah (2012) also reported that vehicles emissions are the major sources of air pollution in Malaysia due to the increasing numbers of registered vehicles in the country.

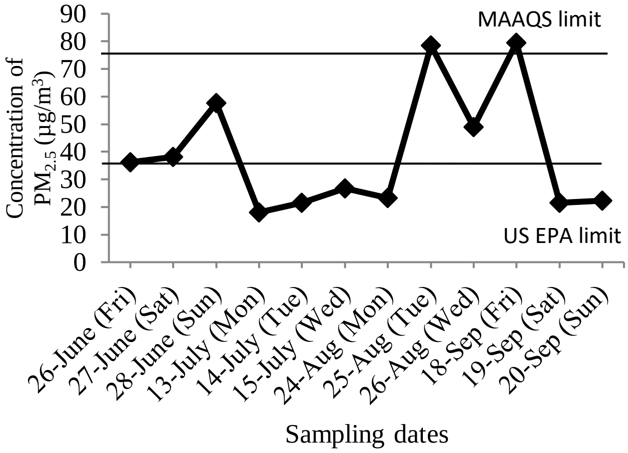

Figure 2: Daily variations of $PM_{2.5}$ concentrations

The daily variation of $PM_{2.5}$ and PM_{10} concentrations was compared with the air quality guidelines limit propose by MAAQS and US EPA. Result indicated that 50% of the $PM_{2.5}$ samples which measured on 13th July, 14th July, 15th July, 24th August, 19th September and 20th September were below the US EPA standard of 35 µg/m^3. Daily of $PM_{2.5}$ concentrations during the same period were 18.06, 21.53, 26.74, 23.26, 21.53 and 22.22 µg/m^3, respectively. Meanwhile, the other half of $PM_{2.5}$ samples were exceeding the US EPA standard of 35 µg/m^3 with two of the samples taken on 25th August and 18th September were also exceeding the MAAQS of 75 µg/m^3 based on 24-hour average, which were 78.47 and 79.51 µg/m^3 which were also reported as the highest $PM_{2.5}$ mass concentration recorded during the study period. It was believed that the highest concentration of $PM_{2.5}$ during that period was due to the 2015 Southeast Asian Haze caused by forest fire in Indonesia which affected Malaysia as well as nearby countries.

Figure 3 shows the variations in daily concentrations of PM_{10} measured at the roadside of Penang Bridge. Different trend of concentrations were observed among all of the samples throughout sampling period. Decreasing in PM concentrations pattern were observed from the first month of sampling, 23rd June until the second month of sampling, 10th July from the value of 45.83 µg/m^3 to the value of 23.96 µg/m^3. The concentrations of PM_{10} rose on 11th July until 12th July with value of 33.33 to 64.58 µg/m^3 before dropped to its lowest concentrations on 21st August with value of 22.38 µg/m^3. The PM_{10} concentrations continue to increase from 22nd August with value of 30.56 µg/m^3 until it reached its maximum concentration of 130.90 µg/m^3 on 15th September coincided with the Southeast Asian Haze episode. The concentrations of PM_{10} then dropped again during the last month of sampling from 62.85 to 35.07 µg/m^3 on 16th September and 17th September of 2015. Overall, none of the samples exceeded the US EPA and MAAQS standard for daily PM_{10} concentration limit of 150 µg/m^3.

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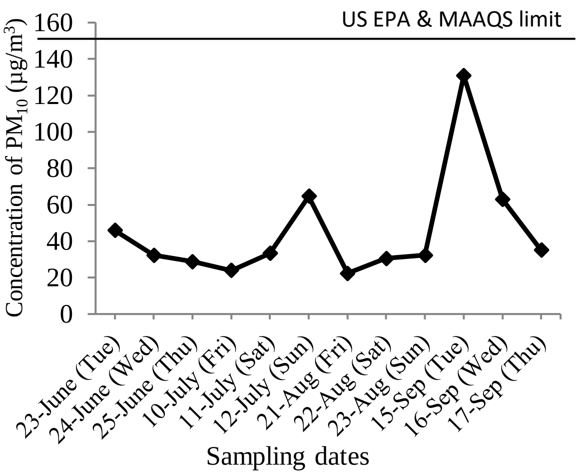

Figure 3: Daily variations of PM_{10} concentrations

Figure 4 shows the monthly average concentrations of $PM_{2.5}$ and PM_{10}. On June 2015, it was observed that monthly mean mass concentrations of $PM_{2.5}$ were higher than the monthly mean mass concentrations of PM_{10} with mean value of 43.98 µg/m^3 compared to 35.65 µg/m^3. Daily average concentrations of two samples from $PM_{2.5}$ exceeded the daily average concentrations of PM_{10} on this month. On July 2015, monthly mean mass concentrations of PM_{10} were higher than the monthly mean mass concentrations of $PM_{2.5}$ with mean value of 40.62 µg/m^3 compared to 22.11 µg/m^3. Daily average concentrations of all samples from PM_{10} were found higher than all samples from $PM_{2.5}$ in the same month. On August 2015, monthly mean mass concentrations of $PM_{2.5}$ were found higher than the monthly mean mass concentrations of PM_{10} with value of 50.23 µg/m^3 compared to 28.41 µg/m^3. The daily average concentrations of all $PM_{2.5}$ samples exceeded the daily average concentration of all samples from PM_{10}. Monthly mean mass concentrations of PM_{10} samples taken on September 2015 were higher than the monthly mean mass concentrations of $PM_{2.5}$ with mean value of 76.27 µg/m^3 compared to 41.09 µg/m3, where all samples from PM_{10} exceeded all $PM_{2.5}$ samples in their daily average concentrations. Overall, PM_{10} mean mass concentrations were higher than the $PM_{2.5}$ mean mass concentrations with mean value of 45.24 µg/m^3 compared to 39.35 µg/m^3. By percentage, 58.33 % of PM_{10} samples at the roadside area exceeded the $PM_{2.5}$ (41.67 %) in their daily average mass concentrations for the whole study period. Charron & Harrison (2005) also reported the mean mass concentrations of PM_{10} at the Marylebone Road of London Highway were higher than the mean mass concentrations of $PM_{2.5}$ on hourly basis.

Correlation between both particulate matter concentrations for both sample sizes however show weak positive correlation (r = 0.4377). Neither $PM_{2.5}$ nor PM_{10} emissions have effect on one another. $PM_{2.5}/PM_{10}$ ratio for monthly concentrations showed lowest value on July and September (0.54), while highest value was obtained for the month of August (1.77). The differences between these values might be related to different meteorological conditions, traffic conditions or carriageway conditions in each month (Charron & Harrison, 2005).

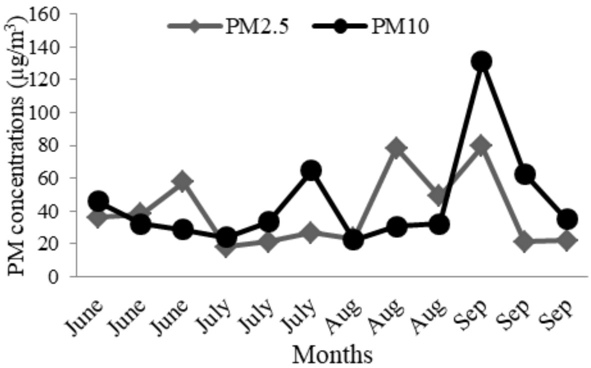

Figure 4: Monthly variations of $PM_{2.5}$ and PM_{10} concentrations

3.3. Variation of $PM_{2.5}$ and PM_{10} Concentrations with Meteorological Parameters

Precipitation is an important factor in maintaining the atmospheric composition. Figure 5 shows the daily variation of $PM_{2.5}$ concentrations and its relationship with temperature and other meteorological factors. The highest concentration (79.51 µg/m^3) was observed when the temperature was at 29.6°C with no precipitations being recorded. In ambient air, rainwater aids the removal of course particles but have less effect on fine particles (Li et al., 2015) through wet deposition and washout process. Therefore, low rainfall has minimal influence on fine particles deposition process. Meanwhile, high temperature condition accelerates high accumulation process of fine particles. In addition, haze episodes during the sampling month contributed to the higher accumulation of particulate matter concentrations due to increase in sources of pollutant. Meanwhile, the lowest concentration of $PM_{2.5}$ (18.06 µg/m^3) was recorded at the temperature of 28.8°C. For the relative humidity and $PM_{2.5}$ concentrations trend, it showed that particle concentrations were reduced when relative humidity is higher, and increased when relative humidity is lower.

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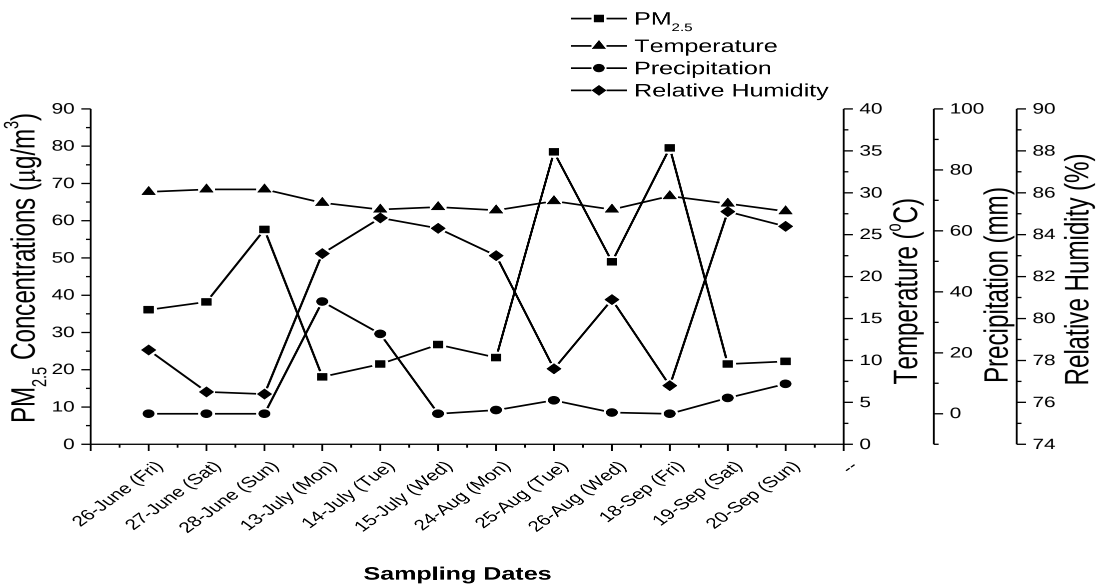

Figure 5: Daily variations of $PM_{2.5}$ concentrations with temperature, precipitation and relative humidity at roadside area of Penang First Bridge

Figure 6 illustrates the daily variation of PM_{10} concentrations with its relation to meteorological parameters. The highest mass concentration (130.90 µg/m³) was recorded on 15th September at the temperature of 28.1°C and no precipitation. High temperature was clearly conducive to intense convection and lower precipitation caused the particulate to sustain longer in the environment which consequently increasing their concentrations by time. Lowest PM_{10} concentration (22.38 µg/m³) was observed at the temperature of 26.9°C with precipitation amount of 11.0 mm. Result also suggested that the temperature showed a relatively uniform trend. Higher precipitation aids in washout processes of particulate matter in environment thus, reducing its concentrations. Therefore, temperature and precipitation played important role in maintaining the atmospheric composition.

On the other hand, the trend of high relative humidity lead to the lower concentrations of particulate matter had been observed. Highest relative humidity (88.8%) resulted to lower PM_{10} concentration (23.96 µg/m^3). When the particulate matter concentrations were the highest during 15th September, which is 130.9 µg/m^3, the humidity was 83.0%. It was a reversed relationship compared to the other days of sampling, where it was believed that haze episode had influenced to the increasing of particulate matter emission at sampling location. Higher relative humidity during hazy days may favour the accumulation of atmospheric pollutants in the environment (Li et al., 2015).

3.4. Correlation between $PM_{2.5}$ and PM_{10} with Meteorological Parameters

Table 3 shows the correlation between $PM_{2.5}$ and meteorological data. The result indicated that negative correlation (r = -0.462) was found between $PM_{2.5}$ and precipitation. The similar result was reported by Owoade et al. (2012) in Ile-Ife, Nigeria. The same result was also obtained in Beijing, China based on research by Huang et al. (2015) where precipitation was negatively correlated with $PM_{2.5}$. Mass concentration of atmospheric particulate was reduced by washout process induce by rain that promote wet deposition effect on particulate matter. According to Wang & Ogawa (2015), precipitation can effectively remove the atmospheric particulate matter, especially the fine particle. Positive correlation (r = 0.456) was obtained between $PM_{2.5}$ and temperature. During highest temperature days with the presence of solar radiation had reached its peak value, fine particles are favourable of the transformations processes within the atmosphere (Pateraki et al., 2012). Study conducted by El-Sharkawy & Zaki (2015), in the Eastern Province of Saudi Arabia also reported positive correlation between $PM_{2.5}$ and air temperature. High temperature was clearly conducive to intense convection of PM in atmosphere.

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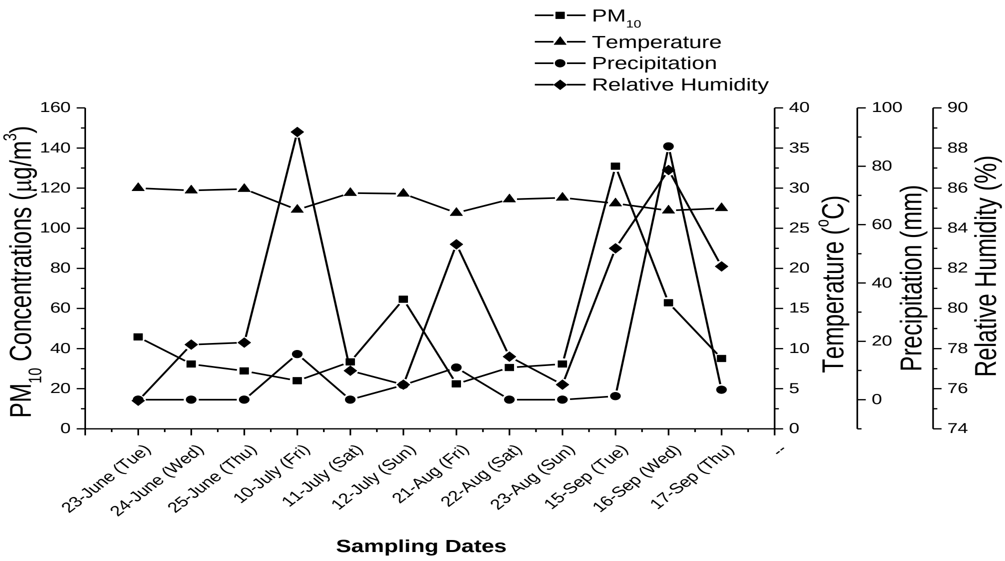

Figure 6: Daily variations of PM_{10} concentrations with temperature, precipitation and relative humidity at roadside area of Penang First Bridge

$PM_{2.5}$ yielded strong negative correlation with relative humidity (r = -0.799). In low humidity, the concentration of particulate matter was decreased due to hygroscopic growth. However, when the humidity was high enough, the particles will grew too heavy to stay airborne resulted in dry deposition which caused the particles deposited to the ground. Therefore, particle numbers reduced and the concentrations decreased (Wang & Ogawa, 2015).

Table 3: Correlation between $PM_{2.5}$ and meteorological data

	$PM_{2.5}$	Temperature	Precipitation	Humidity
$PM_{2.5}$	1.000			
Temperature	0.456	1.000		
Precipitation	-0.462	-0.319	1.000	
RH	-0.799**	-0.831**	0.474	1.000

Note: ** indicate correlation is significant at the 0.01 level (2-tailed); RH is relative humidity

Table 4 shows the correlation between PM_{10} and meteorological data. Positive correlation (r = 0.130) was attained between PM_{10} concentrations and humidity while negative correlation was found between PM_{10} concentrations with temperature (r = -0.060). The outcomes were supported by research conducted in Baghdad city where positive correlation was obtained between relative humidity and PM_{10} concentrations (Al-Taai & Al-Ghabban, 2016). Higher humidity leads to increasing amount of water droplets in the atmosphere where the droplets trapped particulate matter by attracting and increasing particles on the surface of water droplets. Therefore, it limited spreading of contaminant and particles toward the top and enhances the density of pollutants and suspended particles (Al-Taai & Al-Ghabban, 2016). On the other hand, when temperature increased, relative humidity will decrease, reducing the water droplets in the atmosphere reducing collection and retention on pollutants and suspended particles.Negative correlation (r = -0.022) was acquired from the relation of PM_{10} concentrations with precipitation. When precipitation was higher, the mass concentrations of particle will be lowered. Same trend was found in Morogoro, Tanzania where the research found out PM_{10} mass concentrations was systematically low during precipitation event (Mkoma & Mjemah, 2011). When precipitation is higher, intense washout process will reduced the mass concentrations of particulate matter in atmosphere with the aid of rain.

Table 4: Correlation between PM_{10} and meteorological data

	PM_{10}	Temperature	Precipitation	Humidity
PM_{10}	1.000			
Temperature	-0.062	1.000		
Precipitation	-0.022	-0.511	1.000	
RH	0.130	-0.843**	0.607*	1.000

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

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

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4. Conclusion

The study concluded that meteorological parameters play a significant role in day-to-day variations of mass concentrations for both $PM_{2.5}$ and PM_{10} at the roadside area of Penang Bridge. $PM_{2.5}$ daily mean concentrations ranged in between 18.06 to 79.51 µg/m³ whereas PM_{10} daily mean concentrations ranged in between 22.38 to 130.90 µg/m³ for the whole study period. Half of the $PM_{2.5}$ daily mean concentrations exceeded daily standard limit established by US EPA and MAAQS during the sampling period however, none of PM_{10} samples exceeded the daily standard limit established by both US EPA and MAAQS. The highest monthly mean mass concentrations of $PM_{2.5}$ was found on August 2015 with value of 50.23 µg/m³ while the lowest mean mass concentrations was recorded on July 2015 with value of 22.11 µg/m³. PM_{10} monthly mean mass concentrations was recorded the highest on September 2015 with value of 76.27 µg/m³ and the lowest monthly mean concentrations recorded was on August 2015 with value of 28.41 µg/m³. Result from correlation test proved that meteorological parameters such as temperature, precipitation and relative humidity have significant role in the daily variations of mass concentrations for both particulate matter sizes.

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