The Influence of $PM_{2.5}$ and PM_{10} on Air Pollution Index (API)

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Abstract: Haze problem was faced by Malaysia annually and has largely affected the daily activities of Malaysians. The differential reading of API between Singapore and Malaysia has caused confusion due to the difference in the particulate matter measurement, namely $PM_{2.5}$ and $PM_{10.}$ The effect of $PM_{2.5}$ was believed to have caused more adverse effect on human health than $PM_{10.}$ In this study, the concentration of PM_{10} and $PM_{2.5}$ during haze and non-haze period was measured. This was followed by the correlation evaluation of the concentration of the two particulate matters with the meteorological factors such as temperature and humidity. For this, air sample was collected using miniVol during haze and non-haze period. The results showed that the concentrations of PM_{10} and $PM_{2.5}$ during haze period are much higher compare to non-haze period. $PM_{2.5}$ was proved to be higher than PM_{10} in both periods. The study also revealed that PM_{10} and $PM_{2.5}$ have negative correlation towards humidity. Besides that, it was revealed that PM_{10} and $PM_{2.5}$ have negative correlation towards temperature during haze and non-haze period except $PM_{2.5}$ during haze period.

Introduction

Air pollution refers to the contamination of air regardless of indoor or outdoor. It occurs when any harmful gases, dust or smoke enters the atmosphere, causing the living environment not suitable for plants, animals and humans [1]. Air pollution is not a recent occurrence. In fact, the Great London has caused fatalities of approximately 12000 [2]. Another tragedy named ‘Bhopal disaster’ killed 15000 due to the leakage of 30 tons of highly toxic gas, methyl isocyanides [3]. These two incidents revealed that air pollution can bring adverse impact to human if not properly handled. Apart from accidents caused air pollution, agricultural sector especially palm oil plantation can severely affected air quality.

Palm oil industry brought about the huge contribution to the economy of Indonesia, which enabled Indonesia in becoming the largest producer of palm oil in the world. In order to provide sufficient supply and increase the profit, Indonesia government allowed the conversion of forestland into palm plantation [4]. However, the lands were not suitable for palm plantation, many of the farmers used slash and burn method because it is inexpensive, i.e. 30 to 98 % less than the mechanical technique. Although there is law enacted towards open burning, the decentralization governance has caused the uncontrolled widespread of fire which then resulted as haze [5].

In South-East Asia, especially Malaysia and Indonesia, air pollution is always related to haze. The first haze brought considerable disruption to daily life in Malaysia was in April 1983 [6]. Haze has started to affect neighboring countries such as Malaysia, Singapore, Brunei, Thailand, Vietnam and Philippines in 1997, owing to the forest fire burning in Indonesia [4]. The burning of 8 million hectares of land has caused the spreading of thick clouds of smoke and haze producing approximately 30% of annual global average greenhouse gas [7]. Within 15-day period, the Air Pollution Index (API) in Kuching has exceeded 850, marking the worst haze pollution in Malaysia history [8]. In a span of nearly a decade, i.e. 2006, the forest fire in Sumatra and Kalimantan has recurred haze pollution in Malaysia which the air quality was recorded to be at ‘unhealthy’ level [9]. Since then, the air quality level has not been approving [10]. Annual hotspots counted in Southeast Asia are shown in Figure 1. Hotspot indicates the area where spectral signals are emitted from land fires. The hotspots counted were high every year especially for Sumatra and Kalimantan region and can be concluded these are the reason why haze happened every year.

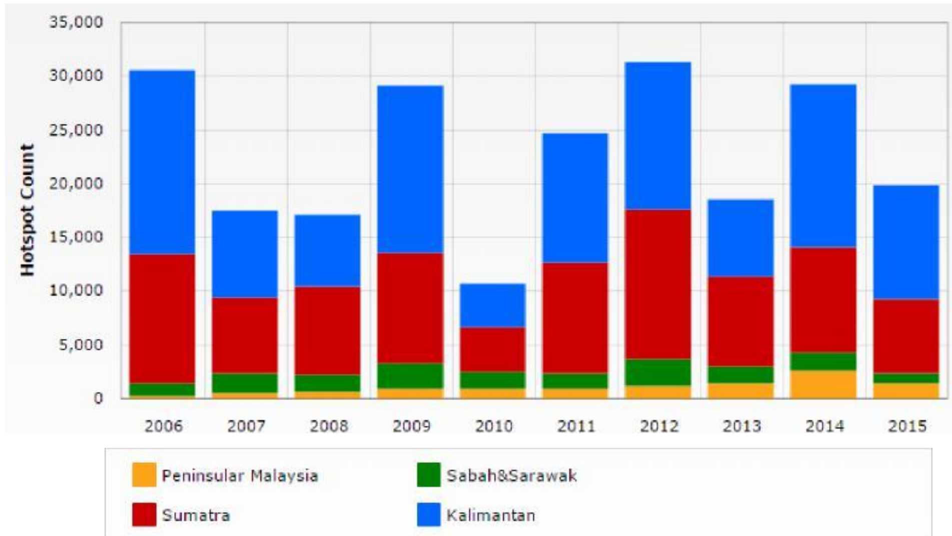


Figure 1: Annual Hotspot Count (2006-2015) [10]

The occurrence of haze has severely impacted the daily live hood of the people in and surrounding the countries. In Indonesia, 300,000 people suffered from respiratory diseases and other ailments, while endangered animals such as orang utans were threatened [11]. Schools in Malaysia were ordered to close and the general public was advised to wear masks if they were to venture out [12]. In 2010, according to data gathered, the number of daily patient visits rose by 31% in hazy period in Kuala Lumpur [5]. Meanwhile, a 14.4% drop in Singapore tourism during the fourth quarter of the year was witnessed [8].

The Air Pollution Index (API) is reading provided by the Department of Environment (DOE) Malaysia as an indication of air quality. During haze, API value becomes critical as it evaluates the harmfulness of air towards human health. However, due to the different air pollutant measurements between Singapore and Malaysia, where $_{PM2.5}$ reading was added to Singapore's air quality index (AQI) measurement in 2014. Therefore, there was a huge difference of value in their AQI between Singapore and Malaysia. This then causes confusion among Malaysians as if there is a problem in our API measurement. Because during haze period, PM will be the critical parameter, hence we only focus on the measurement for PM_{10} and $PM_{2.5}$ only.

Therefore this study aimed to determine the concentration of $PM_{2.5}$ and PM_{10} during haze and non-haze period. In addition, the relationship between meteorological factors (e.g.: temperature and humidity) and concentration of pollutants were evaluated.

Previous Studies

Rapid development and urbanization in the world have affected the air quality and it attracts the attention of researchers to study the causes and effects of air quality. Researchers believed that the poor air quality will affect the health of publics [13]. In Malaysia, studies were done to identify the trends of activities on the air quality. They believed the carbon monoxide (CO) and nitrogen dioxide (NO_2) concentration was related to the motor vehicle emissions and they also relate the high concentration of PM_{10} with the high industries activities and businesses around that area. High concentration of PM_{10} was also linked to the incident of haze from Southeast Asia, the consequences of uncontrolled burning of forest in Indonesia [14]. A sharp increase in the concentration of TSP also found by the other researcher during serious haze period, indicating during haze period, large amount of particulate matters was emitted and transported widely to Malaysia [15].

Based on the above findings, the main pollutant affecting the air pollution in the Southeast Asia region is particulate matter (PM). Singapore started to include $PM_{2.5}$ in their air quality measurements instead of PM_{10} only in 2014. The reasons were the health effect of $PM_{2.5}$ is more adverse than PM_{10} and temporal exposure to high concentrations of $PM_{2.5}$ increases the risk of myocardial infarction (MI) after a few hours in high risk population as finer particles ($PM_{2.5}$) appeared to enter cells passively whereas larger particles are taken up by macrophages [17, 18]. Evidence on the effect of $PM_{2.5}$ on all-cause, cardiopulmonary, and lung cancer mortality was found. With an increase of 10μg/m^3 in $PM_{2.5}$, the risk was increased to 4, 6 and 8% for all cause, cardiopulmonary and lung cancer mortality respectively. Besides that, long-term exposure to $PM_{2.5}$ and sulphur oxide related air pollution were the critical factor for cardiopulmonary and lung cancer mortality [19]. It is proven that $PM_{2.5}$ has direct correlation with the upper respiratory tract infections as during haze period the patient sought treatment under the symptoms increased [16].

It was deduced that air pollution was largely influenced by meteorological factors such as temperature, humidity and wind. Air pollutants such as PM, CO, NO_2, sulphur dioxide (SO_2) and ozone (O_3) are small particles and are very sensitive towards the surrounding condition. It was reported the pollutants (CO, NO_2, SO_2 and O_3) showed a positive correlation with wind velocity, temperature and humidity whereas PM showed positive correlation with wind velocity and temperature but negative correlation with humidity [14, 20]. An argument was made as the atmospheric moisture helps the suspended particle, particulate matter to be precise to stick together, forming heavier particulate which then fall down to ground [20]. Depending on the location of research conducted the trends varies. A study was done in the coastal urban area and SO_2 and NO_2 showed negative correlation with temperature during summer and monsoon season except post monsoon seasons whereas PM showed positive correlation with temperature during all season except post monsoon season. For humidity, SO_2 showed positive correlation with humidity however PM showed negative correlation with humidity [21].

As stated above, $PM_{2.5}$ are the most critical pollutant followed by PM_{10}, thus it is unavoidable to include $PM_{2.5}$ into consideration during the measurement of air quality especially during haze period. Besides that, it was showed that $PM_{2.5}$ has more adverse effect on public health among all the other pollutants under short and long exposure. Hence, it would be the first in Malaysia conduction studies on $PM_{2.5}$.

Methodology

According to United States Environmental Protection Agency (USEPA), the main criteria of the sampling site should free from any obstacle [22]. This was to ensure the content of air passing through the miniVol is same as in the atmosphere. Therefore, UTM Skudai, Padang Kawad was selected.

The apparatus used to measure the air sampling was MiniVol Portable Air Sampler. The MiniVol Portable Air Sampler is used to measuring particulate matter sample ($PM_{2.5}$, PM_{10} or TSP) in the air, but only capable of taking either one type at a time. MiniVol uses 12-volt battery that normally functions up to 18 hours. MiniVol was clamped to tripod stand and the volumetric flow was adjusted to 5 litres per minute at ambient conditions. The 10 micron or 2.5-micron separation was achieved by the impactor and TSP sample can be collected by removing the impactor. Once being pumped into the impactor, the gas will be trapped on 47mm filter.

There were only 2 air parameters being considered in our study which is $PM_{2.5}$ and PM_{10}. In collecting the air sampling, the procedures have to be conducted as in USEPA. The sample was collected for 1 week during haze and non-haze period. According to USEPA, the MiniVol should be positioned with the intake upward and should be located in an unobstructed area at least 30cm from any obstacle to air flow [22]. The air sampling should not be conducted during or after periods of heavy rains. 47mm filter paper was used to trap the particulate sample. The filter paper has to be dried in an oven for at least 1 hour with 100°C before the experiment conducted. The field test will be conducted for 3 hours and filter holder was detached and brought to lab. The 47mm filter was handled with care and has to be dried at 100°C for 1 hour and weighed. The filter was weighed using a microbalance accurate to one microgram.

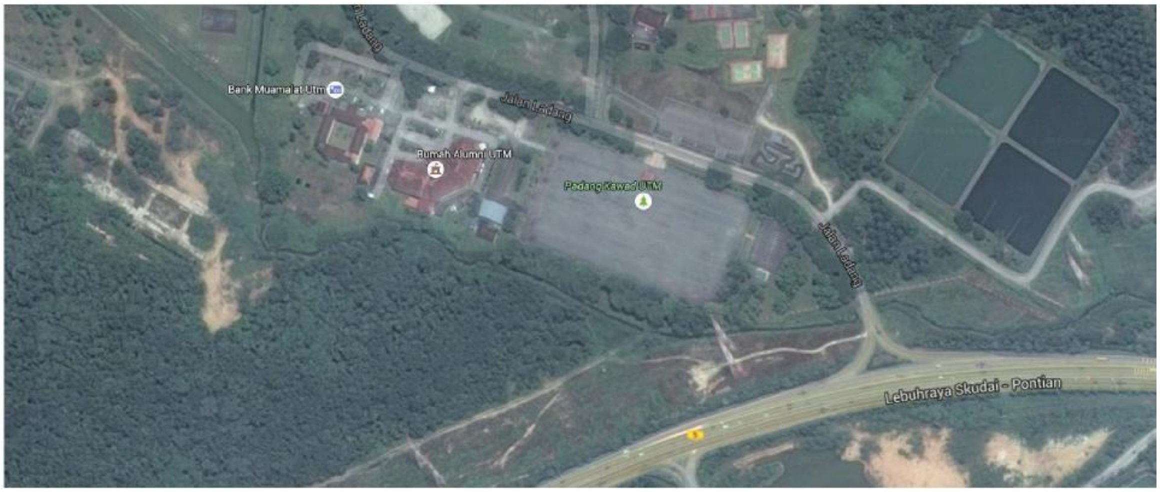


Figure 2: The sampling location

The data was recorded and the air pollution indexes were calculated for each sub-indexes by using Microsoft Excel 2010 and compare with Recommended Malaysian Air Quality Guidelines (RMG) before we classify the air quality. Equation adopted from Department of Environmental Malaysia will be used to calculate PM_{10} whereas the equation adopted from USEPA from United States and PSI from Singapore will be used to calculate $PM_{2.5.}$ Besides that, meteorological data such as temperature and humidity were gathered in analyzing the correlation between the concentrations of PM with meteorological factors.

Table 1: Air Pollution Index (API)

API	**Descriptor**
0 - 50	Good
51 - 100	Moderate
101 - 200	Unhealthy
201 - 300	Very Unhealthy
301 - 500	Hazardous
Above 500	Emergency

$$V = \frac{60_{min/hr} \text{ x } Q \text{ x } t_{hr}}{1000_{l/m^3}} \quad (1)$$

where:
Q = Flow rate
t = Time

$$PM = \frac{M_{PM}}{V} \quad (2)$$

where:
PM = PM concentration in $\mu g/m^3$
M_{PM} = Mass of particulate matter collected on the filter (μg)

Table 2: Equation of Calculation of API for Particulate Matter 10 (PM10) based on 24-hour Average Concentration

Concentration (µg/m^3)	API Equation
Conc. < 50	Conc.
50 < Conc. < 150	50 + {[Conc. – 50] × 0.5}
150 < Conc. < 350	100 + {[Conc. – 150] × 0.5}
350 < Conc. < 420	200 + {[Conc. – 350] × 1.4286}
420 < Conc. < 500	300 + {[Conc. – 420] × 1.25}
Conc. > 500	400 + [Conc. – 500]

For $X_{i,j} \leq X_i \leq X_{i,j+1}$

$$I_i = \frac{I_{i,j+1} - I_{i,j}\left(X_i - X_{i,j}\right) + I_{i,j}}{X_{i,j+1} - X_{i,j}} \quad (3)$$

where

X_i = Observed concentration for the ith pollutant

$I_{i,j}$ = PSI value for the ith pollutant and the jth breakpoint as given in the table

$I_{i,j+1}$ = PSI value for the ith pollutant and the (j+1)th breakpoint as given in the table

$X_{i,j}$ = Concentration for the ith pollutant and jth breakpoint as given in the table

$X_{i,j+1}$ = Concentration for the ith pollutant and (j+1)th breakpoint as given in the table

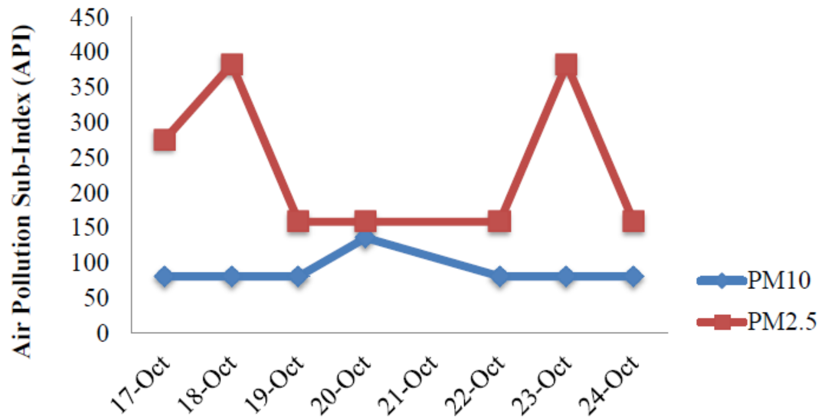
Results and Discussion

Comparison between Concentrations for PM_{10} and $PM_{2.5}$ during Haze and Non-Haze Period

Figure 3 shows the plot with regards to the API sub-index for PM_{10} and $PM_{2.5}$ during haze period. The API sub-index for $PM_{2.5}$ is higher than $PM_{10.}$ The highest and lowest values recorded for PM2.5 are 383 and 159 whereas the highest and lowest values for PM_{10} are 136 and 81. The value of PM_{10} remains constant from 17 October 2015 to 19 October 2015 with a value of 81, the value increases to 136 on 20 October 2015 before decreases back to 81 and stays constant from 22 October 2015 to 24 October 2015. According to API standard, the air quality is considered moderate for the sampling period except for 20 October 2015 with unhealthy air quality. Thus, daily activities can be carried out for all groups of people for sampling period except for 20 October 2015, high risk people are not allowed to carry out daily activities especially outdoor activities.

The values for $_{PM2.5}$ are fluctuating. The high value of 383 is shown twice (18 October 2015 and 23 October 2015) during our sampling period for $_{PM2.5.}$ A value of 276 for $_{PM2.5}$ is acquired on the first day of the sampling period. A value of 159 is remained constant for 20 October 2015 to 22 October 2015 and 24 October 2015. There is no value for 21 October 2015 because it rained and the experiment was not being able to conduct. Although the values for $_{PM2.5}$ are fluctuating, the high-risk people are not allowed to carry out daily activities especially outdoor activities because the air qualities are at unhealthy level. For 16 October 2015, the air quality is at a very unhealthy level and worst for 18 October 2015 and 23 October 2015 with hazardous level. During unhealthy level, children, elderly and people with heart and lung diseases should avoid prolonged and heavy exertion. During hazardous level, everyone should avoid all the physical outdoors activities.

As can be observed on the above, as if $_{PM10}$ was used to determine the API, although the visibility is unclear, a moderate air quality can still be obtained. Hence, it has been proven that using $_{PM10}$ will not be sufficient to determine the API during critical time especially haze period.



	17-Oct	18-Oct	19-Oct	20-Oct	22-Oct	23-Oct	24-Oct
PM10	81	81	81	136	81	81	81
PM2.5	276	383	159	159	159	383	159

Date

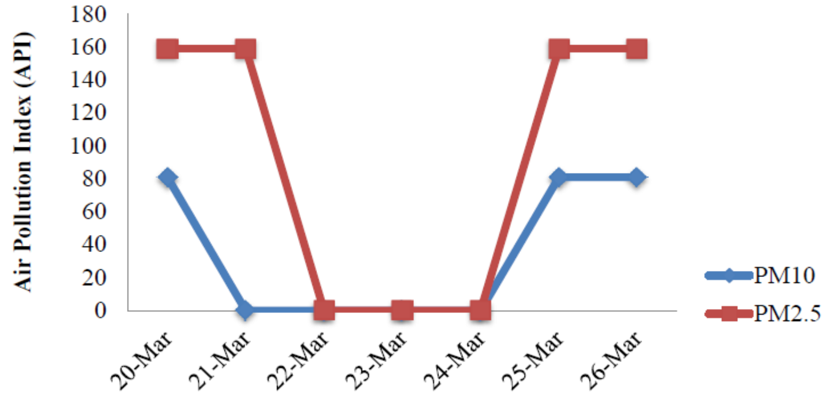
Figure 3: API sub-index for PM_{10} and $PM_{2.5}$ during haze period

Figure 4 shows the plot with regards to the API sub-index for PM_{10} and $PM_{2.5}$ during non-haze period. It is noticeable that the API sub-index for $PM_{2.5}$ is higher than $PM_{10.}$ The value of API for sub-index PM_{10} on the first day hit the moderate level of air quality with a value of 81. The value is in the good level of air quality with a value of 0 for 4 days consecutively before rises back to moderate level of air quality with a value of 81 in the last 2 days of the sampling period. According to API standard, the air quality which is good or moderate is suitable to carry out normal daily activities for all groups of people.

The values for $PM_{2.5}$ possess the similar pattern as $PM_{10.}$ At the first and second day of the sampling time, the API sub-index for $PM_{2.5}$ is 159 before dropped to 0 for the third day. The value remains at 0 from 22 March 2016 until 24 March 2016 before rises back to 159 on the 25 March 2016 and 26 March 2016. From the API sub-index for $PM_{2.5,}$ we found that the air quality during 20, 21, 25 and 26 March 2016 are in the level of unhealthy air quality. During unhealthy level, children, elderly and people with heart and lung diseases should avoid prolonged and heavy exertion.

During haze period, we can notice the API value is higher than non-haze period, indicates that during forest fires, large amount of gases and particles such as greenhouse gases, photo-chemically reactive compounds and fine and coarse particulate matter are being emitted which bring adverse effect to environment and health. Hence during haze period, the concentrations of PM_{10} and $PM_{2.5}$ increase abruptly. During non-haze period, particulate matters are only formed through either moving sources (vehicles) or stationery sources (factories). However there are only moving sources contributing as particulate matter since no factories operating nearby sampling site.

By comparing the results for haze and non-haze period, the results recorded possesses the similar trends as the study done by Siti Rahmah et al, the concentration for PM_{10} during haze period was higher (>150µg/m^3), which has exceeded the Malaysia Ambient Air Quality Guidelines (MAAQG) standard whereas during normal day, the concentration of $_{PM10}$ was under the MAAQG standard [14]. Similar result was found from the study made by Mohamed and Jamaluddin that the value for total suspended solid (TSP) was exceptionally high during haze period (September 1997) [15]. The result also found coherent to the finding from Nur Aleesha et al. [23] the PM_{10} concentrations were found higher, and they pointed out trans-boundary transport of air pollutants from biomass burning from neighboring countries as one of the factors contribute to the concentration of PM_{10} [23].



	20-Mar	21-Mar	22-Mar	23-Mar	24-Mar	25-Mar	26-Mar
PM10	81	0	0	0	0	81	81
PM2.5	159	159	0	0	0	159	159

Date

Figure 4: API sub-index for PM_{10} and $PM_{2.5}$ during non-haze period

Comparison between Temperature and Concentrations for PM_{10} and $PM_{2.5}$ during Haze and Non-Haze Period

Figure 5 shows the relation between temperature and concentration of PM_{10} and $PM_{2.5}$ during haze period. The temperature recorded at the sampling site range from 35°C to 41°C. When the temperature is lower (35°C), the concentration for $_{PM10}$ is higher (222.22µg/m^3) as compare to the higher temperature (40°C) with a concentration of only 111.11µg/m^3. However for $PM_{2.5,}$ the relationship is different from $PM_{10.}$ The concentration of $PM_{2.5}$ is higher (333.33µg/m^3) during higher temperature (41°C), and the concentration is lower (111.11µg/m3) when the temperature is lower (39°C).

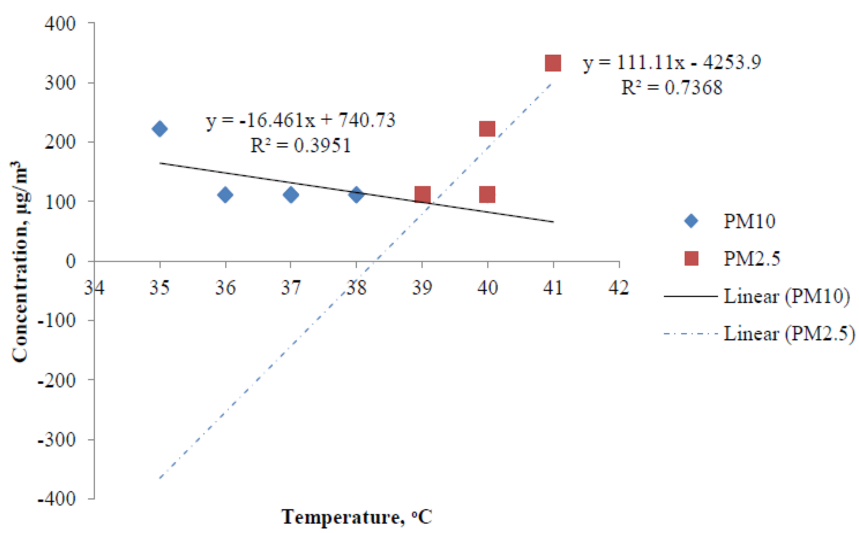


Figure 5: Relation between temperature and concentration of PM_{10} and $PM_{2.5}$ during haze period

PM_{10} possess a negative weak correlation (r^2=0.3951) whereas $PM_{2.5}$ possess a positive high correlation (r^2=0.7368) with temperature during haze period. Negative correlation is showed by PM_{10} indicates that the high temperature enhanced the vertical mixing of air particles which pulls the air pollutants upwards, thus reducing the concentration of air pollutants on the surface of the earth. However, a positive correlation is showed by $_{PM2.5.}$ There is vertical mixing occurred as well, however the concentration is higher as the temperature increases. This may due to the air pollutants on the above has higher concentration, therefore when vertical movement occurred, more air pollutants are drawn down as compared moved upward, hence the concentration of air pollutants are greater.

Figure 6 shows the relation between temperature and concentration of PM_{10} and $PM_{2.5}$ during non-haze period. The maximum temperature and minimum temperature recorded during the experiment are 45°C and 35°C. For $PM_{10,}$ with lower temperature, the concentration is higher as compare to higher temperature. For temperature of 33°C, PM_{10} obtains a concentration of 111.11µg/m^3, however as the temperature increases, concentration of PM_{10} is dropped to 0µg/m^3. The same case goes to $PM_{2.5}$ although the data is not as obvious as PM_{10} does. At the higher temperature, $PM_{2.5}$ obtains a concentration of 0µg/m^3, as the temperature decreases, the concentration increases to 111.11µg/m^3 at 39°C.

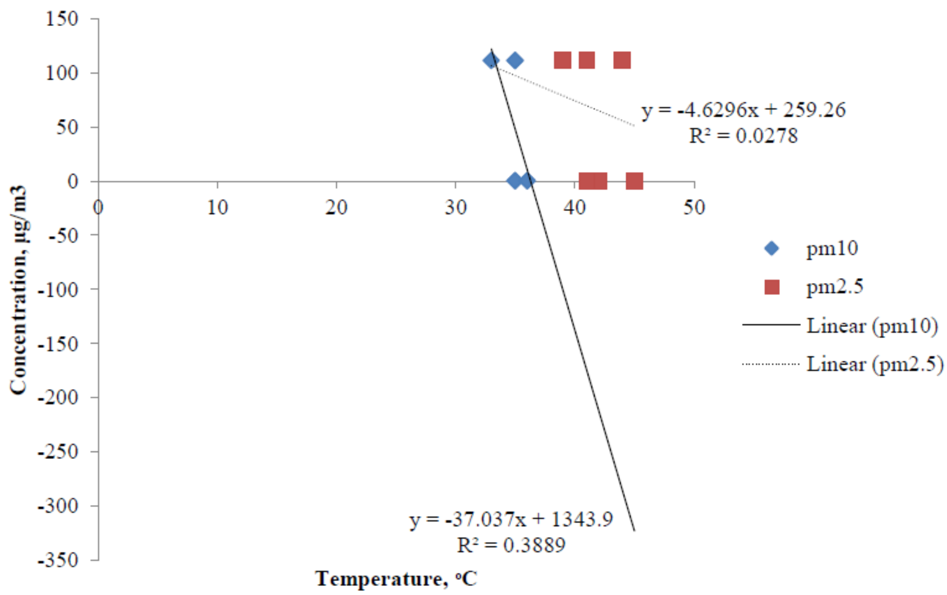


Figure 6: Relation between temperature and concentration of PM_{10} and $PM_{2.5}$ during non-haze period

Both PM_{10} and $PM_{2.5}$ possess negative weak correlation with temperature with r^2=0.3889 and r^2=0.0278 respectively. The trends are similar to the PM_{10} during haze period. With high temperature, the air pollutants are drawn upwards in order to stabilize the pressure in the atmosphere, forcing cleaner air to sink to the surface, hence the concentration of air pollutants become lower.

The results recorded have similar trends with the study conducted by Nam et al. where the concentration of pollutants increases as the temperature decreases [24]. However, the result gathered possessed opposite correlation with Cuhadaroglu and Demirci [25] study. From their study, they found the concentration of particles increases as the temperature increases due to the existing of inversion layer where the temperature at the surface is lower as compared to the ambient temperature in the days which prevent the air from vertical dispersion [25].

Comparison between Humidity and Concentrations for PM_{10} and $PM_{2.5}$ during Haze and Non-Haze Period

Figure 7 shows the relation between humidity and concentration of PM_{10} and $PM_{2.5}$ during haze period. The humidity of environment is high during PM_{10} sampling, ranging from 71% to 78%. For PM_{10}, the concentration decreases as the humidity increases. When the humidity is 71%, the concentration is 111µg/m^3, the value increases to 222.22µg/m^3 at 75% humidity and the value decreases to 111µg/m^3 when humidity achieves 76% and above. For $PM_{2.5,}$ the humidity ranged from 45% to 53%. However, for $PM_{2.5,}$ the concentration is higher (222.22µg/m^3) for lower humidity (45%), and the concentration is lower (111.11µg/m^3) when the humidity is higher (53%). The concentration is highest (333.33µg/m^3) when the humidity is 48% and 50%.

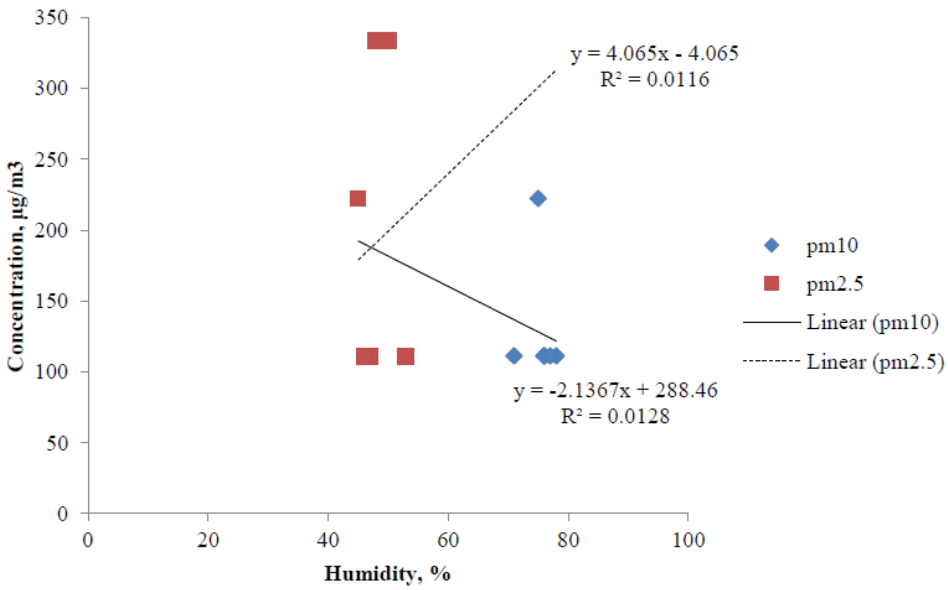


Figure 7: Relation between humidity and concentration of PM_{10} and $PM_{2.5}$ during haze period

PM_{10} possesses a negative weak correlation with the humidity whereby $PM_{2.5}$ possesses a positive weak correlation with the humidity. For PM_{10}, the moisture in the atmosphere helps to stick the fine particulate to formed larger and heavier particulate which caused them to fall down. Hence the concentration of PM_{10} reduces as the particulate has coagulated. However, for $PM_{2.5}$, during haze period, lots of finer particles are formed. The moisture in the air helps to coagulate finer particles into larger particulates, causing a more polluted environment formed, hence causing the concentration of $PM_{2.5}$ to be increased.

Figure 8 shows the relation between humidity and concentration of PM_{10} and $PM_{2.5}$ during non-haze period. The humidity of PM_{10} ranges from 85% to 93%. The concentration of PM_{10} decreases as humidity increases. At lower humidity (85%), the concentration of PM_{10} is 111.11µg/m^3, however the concentration decreases to 0 when the humidity getting higher (93%).The similar trend goes to $PM_{2.5}$. At lower humidity (58%), the concentration of $PM_{2.5}$ is 111.11µg/m^3, however as the humidity increases (78%), the concentration of $PM_{2.5}$ becomes 0.

Both PM_{10} and $PM_{2.5}$ during non-haze period possess negative weak correlation with humidity. The argument would be similar as for PM_{10} during haze period where the moisture in the atmosphere helps to coagulate smaller particles into larger particles, cleansing effect occurred, hence reducing the concentration of pollutants.

The results were similar to the study conducted by Cuhadaroglu and Demirci where a negative correlation was acquired. The concentration of particle decreases as the humidity increases [25]. Besides that, a similar trend was also found from the study conducted by Fadl et al. where high humidity was inversely correlated with PM_{10} as the fine particle may settle due to the effects of humidity on coalescence [20]. A study conducted by Siti Rahmah et al. also showed the similar trends as our findings where PM_{10} showed a negative low correlation with relative humidity (r = -0.130) [14].

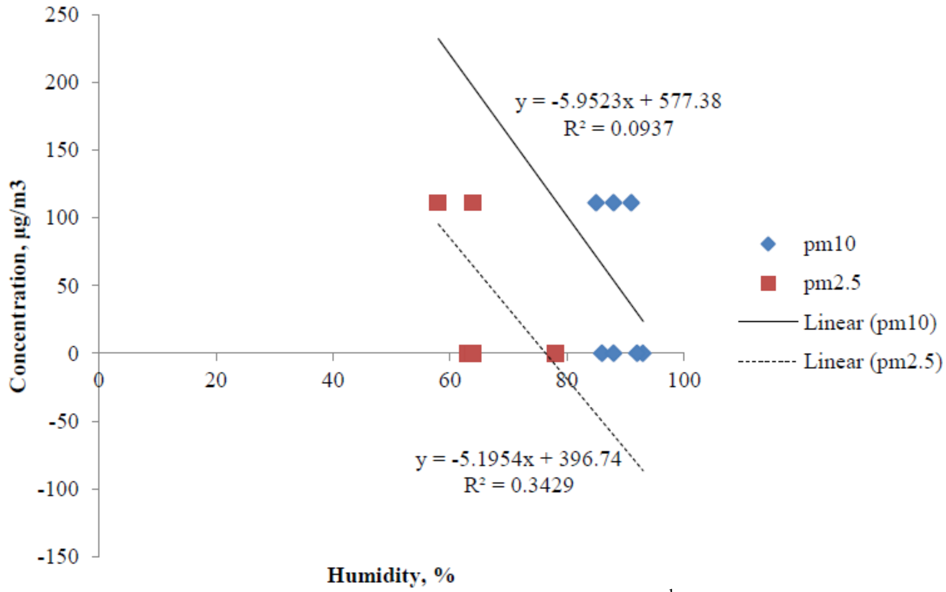


Figure 8: Relation between humidity and concentration of $_{PM10}$ ^{and} $_{PM2.5}$ during non-haze period

Conclusion

Throughout this study, it has been found that the APIs for UTM during non-haze period are considered to be moderate averagely where students are encouraged to go for outdoor activities more frequent instead of staying indoors. Only that, UTM can produce students who are healthy physically and mentally.

The API sub-index for PM_{10} and $PM_{2.5}$ are higher during haze period than non-haze period and API sub-index for $PM_{2.5}$ is higher than $PM_{10.}$ Therefore $PM_{2.5}$ should be considered during Air Pollution Index (API) measurements. PM_{10} and $PM_{2.5}$ have negative correlations with humidity during haze and non-haze period whereas PM_{10} and $PM_{2.5}$ has negative correlations with temperature during haze and non-haze period except for $PM_{2.5}$ during haze period. Actions such as wearing mask N95, drinking more water and eat fruits and vegetables as well as shutting all windows and doors and open air conditioners should be implemented in order to reduce the effect of haze to our human body.

Recommendations

There are few recommendations can be made for future studies. As current study only focuses on the effect of PM_{10} and $PM_{2.5}$ during haze and non-haze period on API, however for future studies, the scope can be extent to the effect of haze on health and socioeconomic. The duration of sampling period can be extended to month or year in order to see the overall trend of API in UTM. Sampling for air pollutants such as SO_2, NO_2, CO and O_3 should be taken although during haze period the critical pollutant was proved to be $_{PM2.5.}$ Simulation and Modeling can be done to see the transportation of air pollutants and the travelled time and landing location of pollutants can be gathered.

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