Physicochemical characteristics of PM$_{2.5}$ particles during high particulate event (HPE) in school area

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Abstract. Observations of fine particulate matter (PM$_{2.5}$) and meteorological parameter (temperature, relative humidity and wind speed) fluctuations during a high particulate event (HPE) in Sekolah Kebangsaan Bayan Lepas, Malaysia have been conducted for three days (48 hrs). Selected sample spot of collected PM$_{2.5}$ particles with high concentration was chosen to investigate the physicochemical characteristics using Field Emission Scanning Electron Microscope coupled with Energy Dispersive X-ray (FESEM-EDX). The results show that the 24 h average concentration ± standard deviation of PM$_{2.5}$ (81.87 µg m$^{-3}$ ± 31.83) exceeded the limit suggested by Malaysia Ambient Air Quality Standard (MAAQS-2020) and United State Environmental Protection Agency (USEPA) which is 35 µg m$^{-3}$. The diurnal variations of PM$_{2.5}$ concentration fluctuated significantly during HPE. Results from Pearson correlation shows that relative humidity gives the most significant influence towards PM$_{2.5}$ concentration ($r=0.410; p < 0.01$) followed by wind direction ($r=-0.306, p < 0.01$), temperature ($r=-0.262, p<0.01$) and wind speed ($r=-0.206; p < 0.01$). From a morphological and elemental analysis, it shows that PM$_{2.5}$ particles collected on a filter consist of two possible sources, natural and anthropogenic sources. The element components found in the natural particles were C, O, Na, Al, Si, K and Fe. The major components were C, O, Al, and Si with weight percentages were 18%, 39%, 9%, and 22%. Dominant elements in anthropogenic particles were C (41%) and a significant amount of K (3%) are found which considered as biomass burning soot. Besides that, the particles also consist of O, Na, Al, Si, and Cl. In summary, particles from natural and anthropogenic sources are dominant in the ambient PM$_{2.5}$ during HPE.

1. Introduction

Haze is not a new phenomenon in Malaysia, as it was first recorded in 1982 when biomass burning regional haze disrupted everyday life in Malaysia [1-2]. Previously, the adverse impacts of the June 2013 haze on the air quality level and reduction in visibility of countries along the Strait of Malacca (i.e. Malaysia, Singapore and Indonesia) have been reported in many studies in terms of primary interpretations during the event [3] and direct effects on ecosystems and environment [4]. Due to that event, about 600 schools in southern Peninsular Malaysia were closed (API more than 300 which is a hazardous point) [5-6]. In September 2019, haze occurred again and 2549 schools in a few states (Selangor, Wilayah Persekutuan Putrajaya, Kuala Lumpur, Pulau Pinang, Kedah, Perak, Negeri Sembilan and Sarawak) were closed because of the haze that blanketed the atmosphere [7]. According to Awang et al. [8], a high particulate event (HPE) is defined as the condition wherein the readings of an air pollution index (API) consecutively exceeds 100 for a 72-h period or longer [9].

PM$_{2.5}$ (particles with an aerodynamic diameter of less than 2.5 µm) is defined as fine particles containing carbon and absorbing various chemical compounds such as metals, organic compounds and salts and biological groups such as pollen and toxins which can lead to severe impacts on human health [10-11]. PM$_{2.5}$ is tiny enough to penetrate even the lowest airways into the lungs [12] plus it is...
also classified as the most harmful to human health among all noxious pollution in the air [13].
Children are the most affected group having health problems, who inhale higher airborne particles if
compared to adults due to their lung capacity and higher breathing rates for physical activities [14-15].
School becomes the priority to investigate the particle pollution as the children spend most of their
time hereafter the home [16-17]. Few researchers have been focusing on investigating indoor, and
outdoor relationships in primary schools found that the variability of indoor PM concentration is
determined by the outdoor contaminants.

Morphology and elemental characterization of individual atmospheric particles are very important
due to their effect on chemical properties [18] and also provide useful information about their origins,
history of the atmosphere, reactivity, formation and removal of chemical species in the atmosphere
[19-21]. The presence of trace metals in most airborne PM fractions of each aerosol volume contains
Cadmium (Cd), arsenic (As), chromium (Cr), copper (Cu), cobalt (Co), iron (Fe), nickel (Ni), lead
(Pb), manganese (Mn), strontium (Sr), titanium (Ti), zinc (Zn) and vanadium (V) were reported to be
widespread in PM$_{2.5}$ [22-23].

Single-particle analysis can provide direct evidence of the composition and morphology of aerosol
particles [24-25]. Based on Satsangi and Yadav [21], Pipal et al. [26] and Salma et al. [27], Field
Emission Scanning Electron Microscope coupled with Energy Dispersive X-ray (FESEM-EDX) is a
beneficial approach in distinguishing the particles originating from a variety of sources regarding on
information about the elemental components, size and shape of particulate matter. Thus, the purpose
of this research is to investigate the levels of PM$_{2.5}$ concentration and characterize the morphological
and elemental components in the school environment at Sekolah Kebangsaan Bayan Lepas, Pulau
Pinang during HPE. During the monitoring campaign, the school was closed due to the worsening
haze.

2. Materials and Methods

2.1. Study area and sampling site
Monitoring was conducted continuously for 24 hours on 19th September 2019 until 20th September
2019 (48 h) which started from 12.00 a.m until 12.00 a.m next day at one sampling point located at
Sekolah Kebangsaan Bayan Lepas (5° 17’ 48.029”N, 100° 15’ 38.163”E) located in Pulau Pinang,
Malaysia. This school was selected because it was affected by the recent high particulate event (HPE)
with the API more than 200 (unhealthy status) that happened across Peninsular Malaysia during
September 2019 [7, 28]. The location of the study area is shown in Figure 1. The school located near
to the main road and residential area. In addition, during the monitoring campaign, this school was
closed and no presence of school children and teachers except only five administration staff.
The instrument was set up at one point beside the main gate of the school as shown in Figure 1 with the
distance of 15.81 m from the main road.

2.2. Measurement on variations and collection of PM$_{2.5}$ samples
The PM$_{2.5}$ concentration and 48 samples were collected on fiberglass filter tape with pore size 2 µm by
using a portable environmental beta-attenuation monitor (E-BAM) (Met One Instrument Inc., Oregon)
at a flow rate of 16.7 L min$^{-1}$. Besides that, E-BAM also measures meteorological parameters such as
wind speed (m/s), ambient temperature (°C) and relative humidity (%) continuously at 1 minute time
interval. The particles are accumulated on 11 mm diameter spots. The tapes advanced automatically
every hour forming 24 spots for each hour. PM$_{2.5}$ samples were collected 24 h continuously (1 h - 24
h). The samples then were immediately transferred into a petri dish and stored in a refrigerator (<4 °C)
[29] until further analysis by using Field Emission Scanning Electron Microscopy coupled with
Energy Dispersive X-ray (FESEM-EDX).
2.3. Physicochemical characteristics analysis of ambient PM$_{2.5}$

The PM$_{2.5}$ collected on the fiberglass filters tape were then examined using high-resolution FESEM-EDX (Quanta FEG 650, Oxford Instrument) for morphology, size and elemental compositions of individual particles. Selected different samples were chosen and analyzed. Samples are punched using a 12 mm diameter steel puncher from the glass fibre filter tape, then half of the sample was cut using a disposable scalpel as the other half filtered samples will be used for further analysis. A stub with a carbon tape was used for sample mounting and proceed to be coated with a thin sheet of gold using coater (Quorum 150T) [27]. The coated samples were examined manually using FESEM-EDX at magnifications 35000x in order to obtain the morphological characteristics and elemental composition of particles. Energy dispersive X-ray (EDX) is a technique used to identify the elemental compositions of the samples. The EDX analysis will generate data that consists of spectra showing peaks corresponding to the elements that make up the sample's true composition and the results also reveal the content of elemental composition in form of weight percentage.

3. Results

3.1. Variations of PM$_{2.5}$ concentrations and meteorological parameter

Table 1 shows the variations of PM$_{2.5}$ concentrations and meteorological parameters recorded during HPE. PM$_{2.5}$ concentration range was between 20.0 µg m$^{-3}$ and 125.0 µg m$^{-3}$. The result shows that the 24 h mean concentration ± standard deviation of PM$_{2.5}$ (81.87 µg m$^{-3}$ ± 31.83) is exceeded the limit as suggested by MAAQS-2020 [30] and USEPA [31] of 35 µg m$^{-3}$. The maximum PM$_{2.5}$ concentration was recorded at 7.00 am. Meanwhile, the mean temperature, relative humidity and wind speed were in the range of 28.4 °C, 72.19% and 0.82 m/s, respectively. Based on Table 2, Pearson Correlation was used to investigate the correlations between atmospheric pollutants and meteorological parameters at the sampling station. The most significant correlation is between PM$_{2.5}$ and temperature ($r$=-0.262, $p<0.01$), PM$_{2.5}$ and relative humidity ($r$=0.410, $p<0.01$) followed by PM$_{2.5}$ and wind speed ($r$=-0.206, $p<0.01$) and PM$_{2.5}$ and wind direction ($r$=-0.306, $p<0.01$). Based on Dominick et al. [32], the range of correlation coefficient is between -1.0 and +1.0. The positive sign indicates the correlation is directly proportioning between the independent parameter and the dependent parameter. For indirect proportion, the correlation between dependent and independent parameters is indicated by a negative sign.
Table 1. Variations of PM$_{2.5}$ concentrations and meteorological parameters recorded during HPE (48 hours).

| Parameter                          | Mean   | Standard Deviation | Min  | Median | Max  |
|------------------------------------|--------|--------------------|------|--------|------|
| PM$_{2.5}$ Concentration (µgm$^{-3}$) | 81.87  | 31.83              | 20   | 95.5   | 125.0|
| Temperature (°C)                   | 28.40  | 1.92               | 23.7 | 28.3   | 32.9 |
| Relative Humidity (%)              | 72.19  | 8.01               | 54.0 | 73.0   | 89.0 |
| Wind Speed (ms$^{-1}$)             | 0.82   | 0.70               | 0.30 | 0.60   | 4.8  |
| Number of samples (n = 2880)       |        |                    |      |        |      |

Table 2. Correlation of PM$_{2.5}$ and meteorological parameters at Sekolah Kebangsaan Bayan Lepas, Pulau Pinang.

| PM$_{2.5}$ | Temperature | Relative Humidity | Wind Speed | Wind Direction |
|------------|-------------|------------------|------------|----------------|
| PM$_{2.5}$ | 1           |                  |            |                |
| Temperature| -0.262**    |                  |            |                |
| Relative Humidity | 0.410** | -0.943** | 1 |            |
| Wind Speed   | -0.206**    | 0.517**          | -0.545**   | 1              |
| Wind Direction| -0.306**  | 0.276**          | -0.306**   | 0.208**        | 1 |

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

Diurnal variations of PM$_{2.5}$ concentration along with meteorological parameters are presented in Figure 2. It shows that there was one peak during this HPE i.e. at 07:00 h. Normally, the peaks’ time during normal days (non-HPE) was categorized as a rush hour morning (7.00 am - 8.00 am), afternoon (1.00 pm - 2.00 pm) and evening (5.00 pm – 6.00 pm) [33], induced by vehicles emissions as found by [34-35]. However, in this study, the peaks occurred at different time because concentration increased due to HPE rather than the traffic density when there was absence of student. In addition, at 12:00 h to 14:00 h, wind speed and temperature reached their highest levels with 4.8 m s$^{-1}$ and 32.9°C, respectively. However, the concentration of PM$_{2.5}$ started to rise again at 6.00 pm as the wind speed lessen. This also supported by correlation between PM$_{2.5}$ and wind speed, an indirect proportion which mean when the wind speed increase, PM$_{2.5}$ decreased. This is due to the condition which wind speed dilute the concentration as it carries away the particles. The correlation between PM$_{2.5}$ and relative humidity indicates a strong positive correlation when the value of PM$_{2.5}$ increases as the relative humidity rises which has been recorded in the diurnal plot.

![Figure 2. Diurnal variations of PM$_{2.5}$ concentration and meteorological parameter.](image-url)
3.2. Morphological of selected PM$_{2.5}$ particles

Based on the characteristic of different elemental and morphology, two main particle categories were observed, which are particle from natural sources (soil dust or minerals) and anthropogenic sources (metals, fly-ash, soot and organic particles). From Figure 3, it shows the irregular shapes of particles in the electron images. Studies by Prospero et al. [36] and Philip et al. [37] have classified the sources of natural particles into three general categories: normally windblown mineral dust from the dry desert regions, anthropogenic windblown dust from human-disturbed soils due to changes in land use rehearses, and agriculture and deforestation, mostly emitted from high-temperature combustion processes. The element components found in the particles were C, O, Na, Al, Si, S, K and Fe. The major components were C, O, Al, and Si with weight percentages were 18%, 39%, 9%, and 22%. This finding is in line with Latif et al. [15], biomass burning process that occurred with high scale conditions could cause the occurrences of HPE, regional haze pollution and also transboundary air pollution (TAP).

Occasionally, soot is an agglomeration of many fine spherical primary particles [36]. This kind of particle is shown in Figure 4. It has an irregular morphology of various shapes. The major components in these particles were C (41%) and a significant amount of K (3%) are found which considered as biomass burning soot comes from agriculture activities [38]. Besides that, the particles also consist of O, Na, Al, Si, and Cl. Reid et al. [39] reported that a high amount of K in biomass burning particles was emitted by the burning of K-rich plant materials. Kim et al. [40] found a similar image during the Asian dust storm event in Kwangju, Korea that shows soot particles stuck to a mineral dust particle collected on a polycarbonate Nuclepore filter.

Based on the characteristic of different elemental and morphology, two main particle categories were observed, which are particles from natural sources (soil dust or minerals) and anthropogenic sources (metals, fly-ash, soot and organic particles). Soil dust and minerals mainly come from construction activities, re-suspended from the road (vehicles movement), and natural dust. The result may be affected by the mobile sources since the school is located near to the roadside and do not influence by the existence of school children and teachers since during the sampling and monitoring performed, there was no teaching and learning session because the school was closed.
4. Conclusions

In a school environment, whether it is indoor and outdoor, air quality is a major concern. PM is a dominant pollutant that is usually measured with higher concentrations during HPE compared to non-HPE. The result shows that the 24 h mean average concentration ± standard deviation of PM$_{2.5}$ (81.87 µg m$^{-3}$ ± 31.83) exceeded the limit suggested by MAAQS-2020 and USEPA that is 35 µg m$^{-3}$. Two main particle categories were observed, which are particles from natural sources (soil dust or minerals) and anthropogenic sources (metals, fly-ash, soot and organic particles). The element components found in the natural particles were C, O, Na, Al, Si, S, K and Fe. The major components were C, O, Al, and Si with weight percentages were 18%, 39%, 9%, and 22%. Meanwhile, the elements in anthropogenic particles were C, K, O, Na, Al, Si, and Cl. The compositions of PM$_{2.5}$ are very important in determining the possible sources during HPE as it gives a health impact on human beings and also environments. Therefore, this research has proved that PM$_{2.5}$ concentration during HPE was influenced not only by the biomass combustion but aggravated by existing anthropogenic sources.

5. References

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