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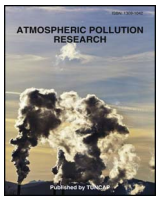

Road traffic as an air pollutant contributor within an industrial park environment

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ABSTRACT

This study aims to understand the relationship of the composition of pollutants and road traffic volume in an industrial environment. Two sampling stations were selected and samples were taken at two points, 1 m and 100 m from the roadside for each station, comparing a working day to a non-working day. The concentration of particulate matter with diameters of less than 10 μm (PM_{10}), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) and the number of vehicle travelling the road on a site in an industrial area were monitored. The results show that the concentrations of pollutants at the sampling point 1 m from the roadside were significantly higher than at the sampling point 100 m from the roadside for PM_{10} and CO, while the opposite was observed for the concentration of O_3 ($p \leq .05$). The levels PM_{10}, CO and SO_2 were significantly higher on a working day compared to a non-working day ($p \leq .05$). The number of vehicles on a working day and the concentration of PM_{10} and CO were significantly correlated with $r = 0.62$ and 0.81, while O_3 showed a negative significant correlation $r = -0.86$ at the 0.05 level (2-tailed). The results demonstrate that the concentration of pollutants relates to the number of vehicles on the road and the distance from the road. Even though the selected sampling site is an industrial area, the majority of the pollutants detected were related to the road traffic activity.

1. Introduction

The development process is unavoidable as countries keep up with global development and the growth of the human population. With fast urbanization and industrialization, transportation and accommodation have become important issues. Increasing activities and energy production to meet daily human needs are causing more pollutants to enter our environment, which can lead to issues such as severe air pollution and subsequent effects on human and environmental health (Grahame and Schlesinger, 2010; Ramos et al., 2016; Zhang and Batterman, 2013). It is well established that industrial activities are usually the main contributors of air pollution (Alyuz and Alp, 2014; Jerrett et al., 2005; Zhang et al., 2010). However, there are decreasing trends in the emissions of air pollutants from factories and now vehicular traffic is considered the main source of contaminants (González et al., 1996). Most factories prioritize cleaner production processes and focus on manufacturing and assembling products using less materials and energy, while at the same time generating less waste, effluents and air pollutants (Luken et al., 2016). However, as the industrialization process continues, this leads to increasing activities and numbers of vehicles within industrial areas (Luken et al., 2016). Thus road traffic has replaced factories as the main contributor to air pollutants.

Traffic systems were developed to allow mobility, and road transport is undoubtedly the most preferred system for the transport of people and goods, which results in the use of diesel- and petrol-fuelled vehicles (Gruden, 2003). Research has been carried out relating to air pollution problems originating from the development process and also from road traffic in urban areas (Cárdenas Rodríguez et al., 2016; Lee et al., 2011; Smith et al., 2015; Wahid et al., 2013). The products of combustion are mainly gases, particulate matter and ozone (O_3) precursors, including oxides of nitrogen (NO_x) and volatile organic carbons (VOCs), which are then emitted into the environment as exhaust gases (Sánchez-Ccoyllo et al., 2009). It has been determined that fossil fuelled vehicles are the main sources of carbon monoxide (CO), hydrocarbons (HCs), lead (Pb), oxides of nitrogen (NO_x), particulate matter (PM), sulphur dioxide (SO_2), ozone (O_3) and methane (CH_4), among others (Colvile et al., 2001; D'Angiola et al., 2010; Soylu, 2007). Yan et al. (2011) carried out a global emissions projection of particulate matter focusing on exhaust emissions from road vehicles and discovered that the total emissions of particulate matter could decrease 1.3–2% each

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year with control measures and the introduction of better vehicles, proving that vehicular emissions play an important role in global emissions of particulate matter (Yan et al., 2011). It was reported by Giovanis (2017) that attempts to reduce road traffic activities reduced the concentrations of nitrogen dioxide (NO_2), SO_2, CO and particulate matter with a diameter size of below than ten micrometres (PM_{10}) in the atmosphere. It was also discovered that traffic emissions make a greater contribution to ground level concentrations of NO_2 than industrial sources per unit emission (Leksmono et al., 2006).

The abundance of anthropogenically-sourced substances in the atmosphere contributes to a very uncomfortable environment to live in. The complex mixture of different air pollutants means that the exact composition varies both over time and between individual towns and cities due to changes in patterns and sources of emissions. This results in complications in the management of pollution as a whole (Colvile et al., 2001). The Klang Valley area in Malaysia has been the central focus of development since Malaysia gained independence in 1957; it is also the central pollutant emission source area (Latif et al., 2014). It was observed that there are higher concentrations of NO_2 and PM_{10} in highly constructed and fragmented cities compared to densely populated cities, which suffer from higher SO_2 concentrations (Cárdenas Rodríguez et al., 2016). Focusing on road traffic as one of the major contributors to urban air pollution problems, this paper discusses the five major vehicular pollutants: PM_{10}, CO, SO_2, NO_2 and O_3. This study aims to understand the relationship of the composition of pollutants and road traffic volume in a cleaner-production industrial environment with low emissions from the industrial activity by looking at the relationship of selected pollutants to road traffic activity.

2. Materials and methods

2.1. Study area

Shah Alam is the state capital of Selangor, Malaysia. It is located about 25 km from Kuala Lumpur, the capital city of Malaysia. Shah Alam is a popular industrial city among multinational companies as it is well equipped with modern infrastructure and has a strategic location close to the port and airport. Persiaran Kuala Selangor was chosen to be studied as it is the major road running through the Shah Alam Industrial Estate, one of the biggest industrial estates in Shah Alam and Malaysia as shown in Fig. 1. However, within the study area, most of the industrial activity is focused on the storage, marketing and trading, assembly, and packaging of electronic products (MIDA, 2014) as shown in Fig. 2. These activities are expected to involve less combustion and so produce less air pollution emissions. Very little activity that involves combustion and the emission of air pollutants can be found in the area. As the area is expanding, the industrial area is now located in close proximity to several housing estates with facilities including banks, health clinics, restaurants, and shopping centres, among others.

2.2. Field sampling

This study monitored the concentrations of PM_{10}, SO_2, CO, NO_2 and O_3 using the methods as outlined by Latif et al. (2011). Two sampling stations (St1 and St2) were selected along the Persiaran Kuala Selangor to monitor the concentrations as shown in Fig. 1. At each sampling station, two sampling points were used: i) 1 m by the roadside; and ii) 100 m from the roadside. The data were collected from 9th September 2014 to 24th October 2014.

2.2.1. Concentration of gases

The SO_2, CO, NO_2 and O_3 concentrations were determined using a colorimetric method using the LaMotte Company air pollution sampling and measurement kit (LaMotte Company, USA). Air was absorbed into the respective absorbing solutions in test tubes using an air sampling pump with a flow rate of 1.0 L/min for an hour. The absorbing solutions were as presented by the LaMotte Company. The intensity of the colour developed for each gas was determined using a colorimeter for the respective pollutants and the absorption was compared with the chart produced by LaMotte Company to get the value of the concentrations of respective pollutants. The concentration readings were collected four times daily, at 7 a.m., 9 a.m., 3 p.m. and 5 p.m.

2.2.2. Concentrations of PM_{10}

PM_{10} was collected using a PM_{10} low-volume sampler MiniVol™ PM_{10} portable air sampler (Air Metrics, USA) equipped with pre-weighed filter paper (diameter size 47 mm, pore size 0.45 μm) that had been dried in a desiccator for 24 h beforehand. Air was collected at a flow rate of 5.0 L/min hourly from 7 a.m.–11 a.m. and 3 p.m.–7 p.m. The filter papers with particulate samples were transferred to the laboratory and placed in desiccators for 24 h and weighed again. The concentration of PM_{10} was calculated from the difference in the weight of the filter paper before and after sampling for the volume of air absorbed by the low-volume sampler.

2.2.3. Traffic count

The number of vehicles utilising the road in both directions was obtained by manually counting vehicles at a cross section of the road from 7 a.m. to 7 p.m. both on a working day and a non-working day.

2.3. Continuous air quality monitoring analysis

Air quality data used as a reference in this research was collected from the Department of Environment (DOE) Continuous Air Quality Monitoring Station (CAQMS) at TTDI Jaya Primary School, Shah Alam with coordinates N03° 06.287, E101° 33.368, located about 7 km away from the sampling site at Persiaran Kuala Selangor. The air quality data has been collected through continuous monitoring programme by Alam Sekitar Malaysia Sdn. Bhd. (ASMA) assigned by the Air Quality Division of the Malaysian Department of Environment. The air quality data used in this study was obtained from 2014. The parameters used in this study were PM_{10}, SO_2, NO_2, CO and O_3. The instrument used to monitor PM_{10} was a BAM-1020 Beta Attenuation Mass Monitor (MetOne Instrument, Inc., USA) which was equipped with a cyclone and PM_{10} head particle traps, fibre glass tape, flow control and a data logger. This instrument has a fairly high resolution of 0.1 $\mu g/m^3$ at a 16.7 L/min flow rate, with lower detection limits of $< 4.8\ \mu g/m^3$ and $< 1.0\ \mu g/m^3$ for 1 h and 24 h, respectively. The instrument used to monitor SO_2 was a Teledyne API Model 100A/100E based on the UV fluorescence method where the lowest level of detection was 0.4 ppb. The instrument used to monitor NO_2 was a Teledyne API Model 200A/200E based on the chemiluminescence detection method with a detection limit of 0.4 ppb. The instrument used to monitor CO was a Teledyne API Model 300/300E using the non-dispersive, infrared absorption (Beer Lambert) method with 0.5% precision and a limit of detection of 0.04 ppm. O_3 was determined using a Teledyne API Model 400/400E through the ultraviolet absorption (Beer Lambert) method with a detection limit of 0.4 ppb (all instruments were from Teledyne Technologies Inc., USA). The measurements of SO_2, CO, NO_2 and O_3 were at a precision level of 0.5% (Latif et al., 2014). Wind speed (WS) was recorded using a Met One 010C sensor and wind direction (WD) was measured using a Met One 020C sensor at 10 m measuring height. Ambient temperature (AT) and relative humidity (RH) were measured using a Met One 062 and Met One 083D sensor respectively (Met One Instrument, Inc., USA) (Latif et al., 2014).

3. Results and discussion

3.1. Air quality near to the roadside

Based on the observations, PM_{10}, SO_2, CO, NO_2 and O_3 were present in the atmosphere of Persiaran Kuala Selangor. A summary of pollutants

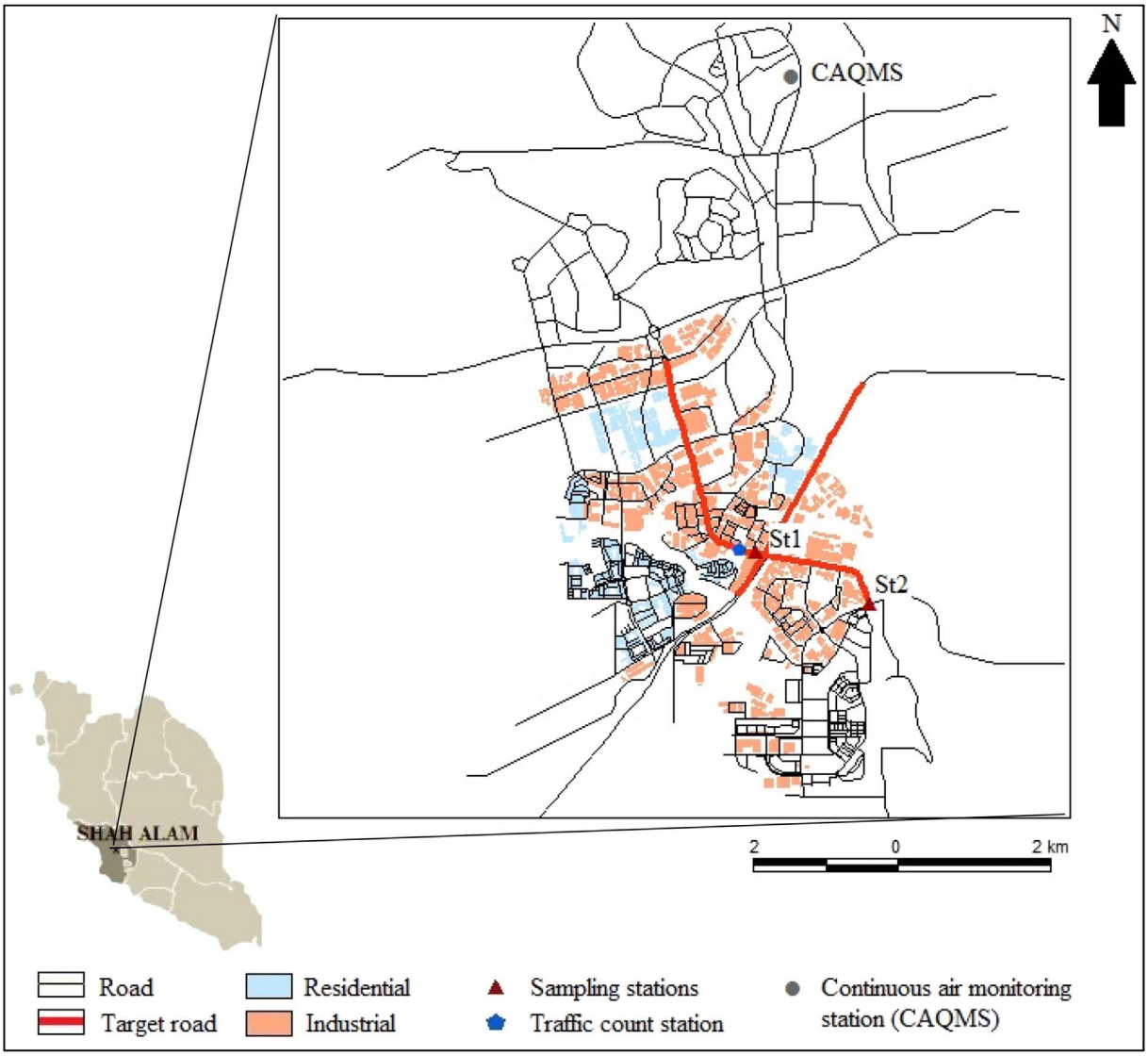

Fig. 1. Location of Shah Alam in Peninsular Malaysia; and location of sampling stations (St1 and St2) and Continuous Air Quality Monitoring Station (CAQMS) in Shah Alam.

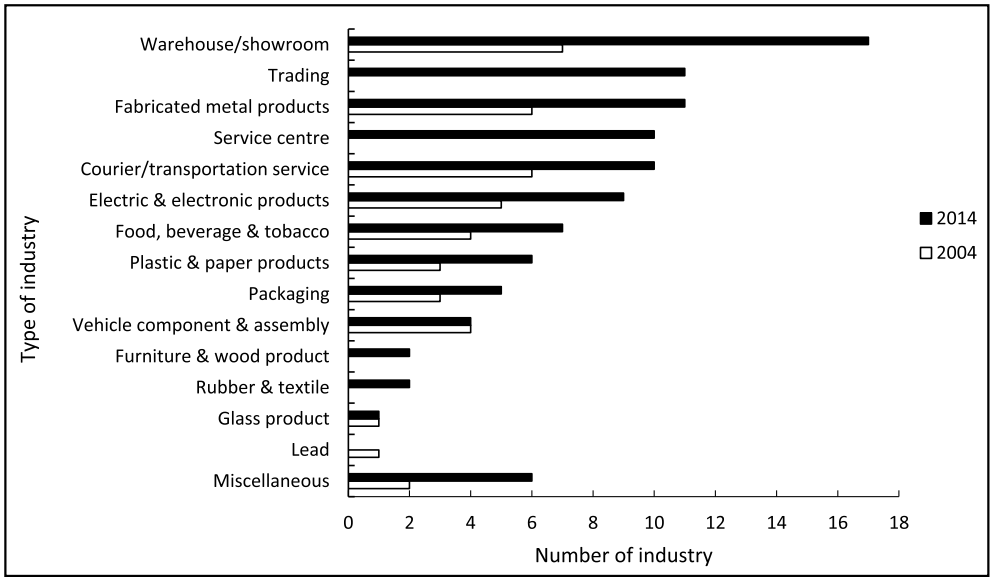

Fig. 2. Types of industry in the Shah Alam Industrial Estate Shah Alam for 2004 and 2014 (Source: MIDA, 2014).

Table 1
Concentration of major air pollutants (in μg/m^3) recorded from field sampling (1 m and 100 m) and Continuous Air Quality Monitoring Station (CAQMS) at Shah Alam.

	PM_{10}	CO	SO_2	NO_2	O_3
Averaging Time (h)	24	1	1	1	1
Site 1 m (working day)	47.2 ± 11.7	1556 ± 161.6	99.8 ± 14.8	25 ± 8.7	38.3 ± 8.7
Site 1 m (non-working day)	17.5 ± 8.2	875.9 ± 230.1	32.4 ± 25.5	ND	33.4 ± 15.5
Site 100 m (working day)	17.8 ± 3.8	912.4 ± 214.6	54.1 ± 9.8	31.3 ± 10.9	55 ± 10.3
Site 100 m (non-working day)	5.31 ± 2.04	250.4 ± 244.4	13.2 ± 16.1	ND	51.3 ± 9.5
CAQMS	55.3 ± 32.1	954 ± 563	7.18 ± 6.75	45.9 ± 22.8	39.0 ± 43.5

- ± i: standard deviation; ND: not detected.

from the site sampling and the CAQMS is shown in Table 1. The average concentrations of PM_{10}, CO, SO_2, and NO_2 were 47.2 ± 11.7, 1556 ± 161.6, 99.8 ± 14.8, and 25 ± 8.7 μg/m^3 respectively at the sampling point 1 m from the roadside, compared to 17.8 ± 3.8, 912.4 ± 214.6, 54.1 ± 9.8, and 31.3 ± 10.9 μg/m^3 respectively at the sampling point 100 m from the roadside. The concentrations of PM_{10} and CO were found to be significantly higher at the 1 m sampling point as indicated by the t value from an independent *t*-test for at station 1 and station 2 ($p \leq .05$). These results show that the concentrations of PM_{10} and CO from vehicle emissions were highest closer to the road source (station 1) and gradually dispersed due to the wind and turbulent mixing when moving further away from the centre of the road (Kim and Guldmann, 2011).

The concentration of O_3 was higher, with an average concentration of 55 ± 10.3 μg/m^3, at the sampling point 100 m from the roadside compared to 38.3 ± 8.7 μg/m^3 at the sampling point 1 m by the roadside ($p \leq .05$). As surface O_3 is not directly emitted by vehicle traffic, but produced by chemical reactions in the atmosphere, the concentration of O_3 is higher further from the roadside, opposite to the scenario that was seen in the other types of pollutants. Several studies report that heavily travelled roadside areas are less polluted by O_3 than urban background regions (Jo and Park, 2005; Kim and Guldmann, 2011). This was observed due to the titration process of NO to O_3 within the busy areas (Eq. (1)). NO_2 contributions from the reaction of NO and O_3 will contribute to amount of O_3 in downwind areas (Eqs. (2) and (3)) (Gao and Niemeier, 2008; Latif et al., 2012).

$$NO + O_3 \rightarrow NO_2 + O_2 \quad (1)$$

$$NO_2 + hv \rightarrow NO + O \quad (2)$$

$$O + O_2 \rightarrow O_3 \quad (3)$$

The comparison of concentration of major air pollutants at the sampling site with previous studies are as depicted in Table 2. The

Table 2
Summary of major air pollutants average concentration (in μg/m^3) from the site sampling in comparison with previous studies.

		PM_{10}	CO	SO_2	NO_2	O_3
	Averaging Time (h)	24	1	1	1	1
Site sampling	Site 1 m (working day)	47.20	1556	99.80	25.00	38.30
	Site 1 m (non-working day)	17.50	875.9	32.40	ND	33.40
Reference	Kuala Lumpur, Malaysia (Wan Mahiyuddin et al., 2013)	58.60	1568	11.90	37.40	34.00
	Delhi India (Tiwari et al., 2016)	NA	2255	NA	23.50	47.20
	Switzerland (Giovanis, 2017)	18.60	262.7	1.590	26.10	62.10
	Background station (Latif et al., 2014)	38.20	NA	2.880	3.570	23.60

-NA: not available; ND: not detected.

average concentrations of PM_{10}, CO, SO_2, NO_2 and O_3 detected at the sampling site is almost similar with the concentrations of elements monitored in Klang Valley by Wan Mahiyuddin et al. (2013). The similarity depicted that the sampling area from Wan Mahiyuddin et al. (2013) and Klang Valley, which are located in the same vicinity, share the same characteristics and issues. The results of this study were found to be lower than the concentrations of major air pollutants in a study at an urban site in Delhi, India by Tiwari et al. (2016). However, the concentrations of PM_{10}, CO, SO_2, and NO_2 were found to be higher while O_3 was found to be lower compared to the concentrations of major air pollutants from road traffic in Switzerland (Giovanis, 2017). The concentrations of pollutants monitored at the sampling site were consistently higher than the concentrations recorded at a background station, showing that most of the elements monitored were coming from anthropogenic sources (Latif et al., 2014).

3.2. Ambient air quality data based on continuous air quality monitoring

The hourly average concentrations for air pollutants from the CAQMS records are 55.3 ± 32.1 μg/m^3, 954 ± 563 μg/m^3, 7.18 ± 6.75 μg/m^3, 45.9 ± 22.8 μg/m^3 and 39.0 ± 43.5 μg/m^3 respectively for PM_{10}, CO, SO_2, NO_2 and O_3 as shown in Table 1. However, as the averages were taken from a large data sample, most of the maximum concentrations were outliers, probably caused by an external pollutant factor. The average concentrations of CO and SO_2 at the CAQMS were lower compared to the concentrations at the 1 m sampling point, while the concentration of PM_{10} at the 1 m sampling points was within the range of the average concentration from the continuous monitoring. The concentration of O_3 on the other hand was higher at background data compared to the roadside observations. It is reported by various researchers that roadside air pollutant concentrations are usually higher than the concentrations further from the road and higher than background levels. An exception is O_3, which usually shows the opposite trend (Gao and Niemeier, 2008; Kim and Guldmann, 2011; Kiss et al., 2005). This situation is related to the fact that nitrogen oxides and sulfur oxides are mainly caused by the incomplete combustion of fossil fuels used by vehicles (Colvile et al., 2001; Kim and Guldmann, 2011; Lee et al., 2011). The concentration of pollutants monitored at the sampling site on a working day and at the CAQMS is almost consistently higher than the concentration recorded at a background station as reported by Latif et al. (2014). This shows that most of the elements monitored are coming from anthropogenic sources (Latif et al., 2014). The average concentrations of elements detected at the sampling site in Shah Alam are consistent with the concentrations of elements monitored in the Klang Valley which implies both areas share the same characteristics and issues.

Fig. 3 shows the diurnal pattern of average concentrations of all the pollutants based on continuous air quality data from the study area. The PM_{10} concentrations showed a peak at 7.00 h–9.00 h and at around 17.00 h–20.00 h, which is normally when rush hour traffic occurs in the morning and evening, indicating that PM_{10} concentration is influenced by vehicular emissions. Peak CO concentrations normally occurred at 7.00 h–10.00 h so can also be attributed to rush hour traffic emissions.

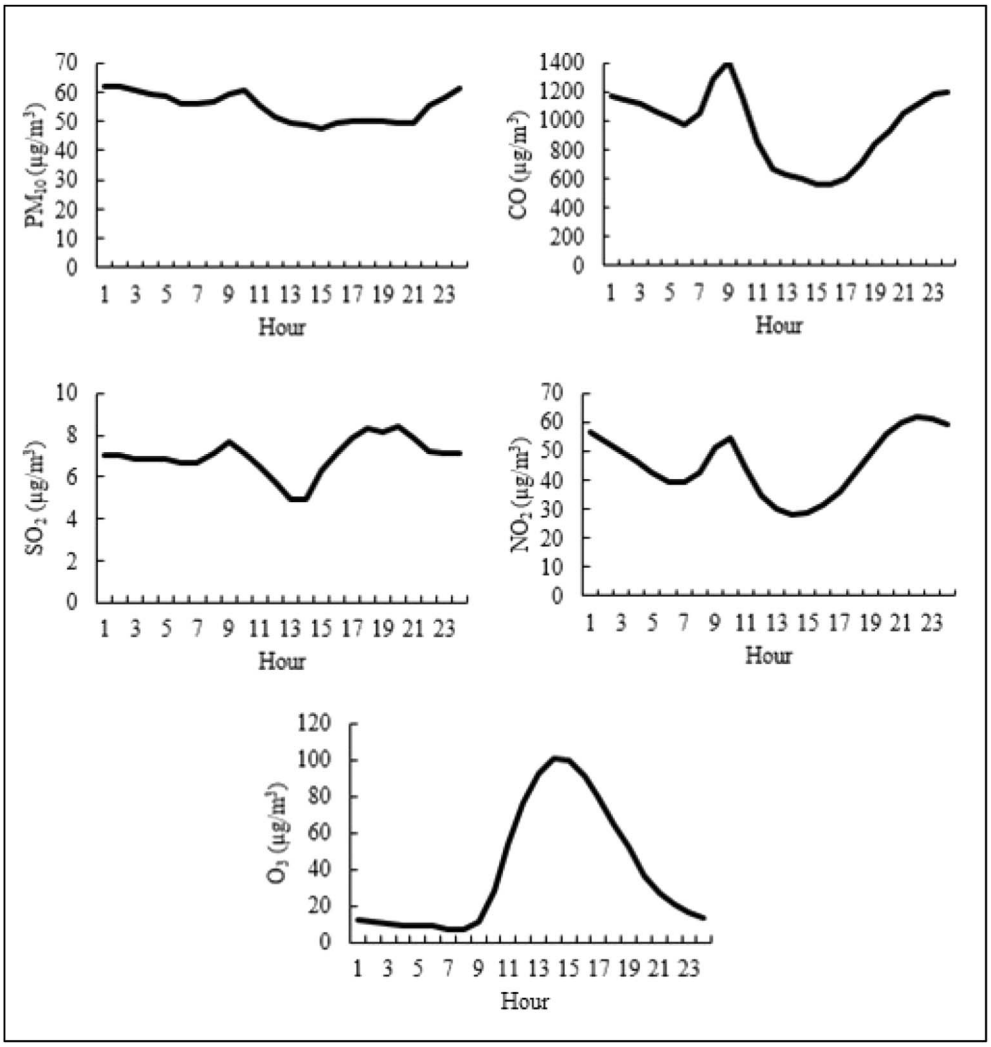

Fig. 3. Diurnal patterns of major air pollutants based on the continuous air quality monitoring station (CAQMS) data collected at Shah Alam in 2014.

NO_2 concentrations were found to peak about 1–2 h later than rush hour because, as mentioned by Latif et al. (2014), NO_2 is formed from the reaction of NO which is usually present in traffic emissions (Colvile et al., 2001; Latif et al., 2014). O_3 was seen to peak in the afternoon at 13.00 h–16.00 h which is consistent with the fact that ozone pollution is a result of the photochemical reaction of precursor volatile organic compounds and nitrogen oxides, which are major pollutants from transportation emissions (Gao and Niemeier, 2008; Latif et al., 2014). O_3 concentration started to increase at 10.00 h after the peak of NO_2 concentration in the morning when the solar activity increases and the concentration started to decrease after 16.00 h when solar activity decreases (Latif et al., 2012).

3.3. Relationship between air pollutant concentrations and number of road traffic users

Fig. 4 shows the number of vehicles that travelled on the road, which totalled up to close to 75 000 on a working day compared to 48 000 on a non-working day, showing the dependency of industrial processes on-road transportation. Various studies in the past has indicated significant correlation between road traffic density and the major air pollutants including PM_{10}, CO, SO_2, NO_2, and O_3 (Giovanis, 2017; Iorga et al., 2015). Based on the results from this study, the concentration of pollutants increases when the number of vehicles increases and drops when the number of vehicles decreases demonstrating that the main contributor of the atmospheric emissions sampled is the vehicles of workers coming to and going back from work in the industrial area and transporting goods and services in and out of the factories. The traffic flow displays a typical urban pattern characterized by two peaks, in the morning and the evening (Kim and Guldmann, 2011). Based on the data acquired from the Department of Statistics Malaysia, the total number of private vehicles increased greatly from 1999 to 2007, and of the total number of on-road vehicles, almost 80% are privately-owned vehicles. These vehicles mostly run on petrol and diesel, a complex mixture of hydrocarbons. Soylu (2007) observed that private cars are the main source of CO and PM_{10} emissions while heavy duty vehicles are mainly responsible for NO_2, PM_{10}, and SO_2 emissions. It was observed that both types of vehicles are abundant on the sampled route, but cars and motorcycles dominated compared to heavy duty vehicles.

3.4. Comparison of pollutant concentrations between working and non-working days

The levels of pollutants detected at the sampling area were found to be significantly higher on a working day compared to a non-working day as indicated by the t value from an independent *t*-test as shown in Table 3. Concentrations of PM_{10} and CO were significantly higher at both station 1 and station 2, at 1 m and 100 m from the roadside ($p \leq .05$), for the working days. For SO_2, concentrations were significantly higher for station 1 at 1 m from the roadside and for station 2 at 1 m and 100 m from the roadside ($p \leq .05$). For NO_2, t values are

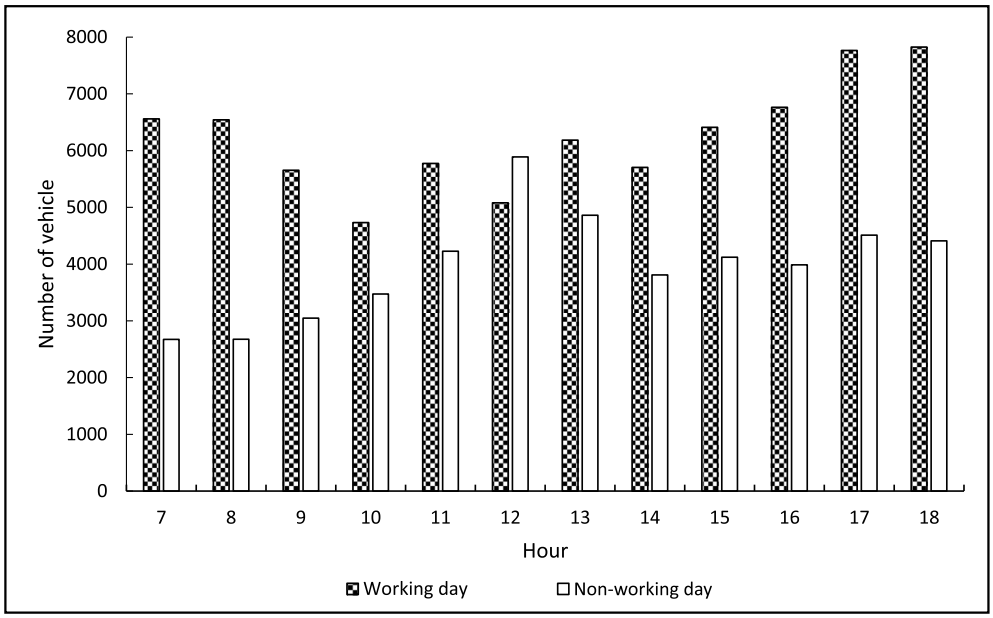

Fig. 4. Number of vehicles that travelled on the selected road on working and non-working day.

Table 3
t-test analysis for comparison of air pollutant concentrations between working days and non-working-days for sample sites.

	PM_{10}	CO	SO_2	NO_2	O_3
Station 1, 1 m	0.009	0.0005	0.01	NA	0.5
Station 1, 100 m	0.0002	0.001	0.09	NA	0.74
Station 2, 1 m	0.0001	0.009	0.01	NA	0.42
Station 2, 100 m	0.0007	0.001	0.01	NA	0.42

NA: not available.

incalculable as the concentrations of NO_2 on a non-working day were usually under the limit of detection. Based on these findings, it can be seen that vehicle emissions are the major source of environmental pollution, contributing a mixture of various pollutants including carbon monoxides, nitrogen oxides, and particulate matter (Colvile et al., 2001; D'Angiola et al., 2010; Smith et al., 2015; Soylu, 2007). It was observed that petrol-fuelled vehicles are the main source of PM and CO, while NO_x, SO_2 and PM mainly originate from heavy duty diesel-fuelled vehicles (Colvile et al., 2001; Soylu, 2007). The increasing share of road traffic emissions is expected due to increasing demand of private mobility due to lack of public transport and also the psycho-social value of a private-own vehicle (D'Angiola et al., 2010; Nasrudin et al., 2013; Pardo et al., 2011).

Correlations calculated between the number of vehicles and the concentrations of pollutants on a working day and a non-working day were as shown in Table 4. The correlation between the number of vehicles and PM_{10} concentration on a working day is 0.62 and was significantly correlated at the 0.05 level (2-tailed). The findings were supported by Cárdenas Rodríguez et al. (2016) who mentioned that fragmented and highly-constructed cities experience higher concentrations of PM_{10}. This is relevant with the current situation in the industrial area where sampling took place, as it is highly-constructed and populated with has on-going industrial activities and residential areas. The correlation between the concentration of CO and the number of vehicles was 0.81 on a working day and 0.97 on a non-working day and was significantly correlated at the 0.05 level (2-tailed). The correlation of the concentration of O_3 and the number of vehicles was -0.86 on a working day and 0.77 on a non-working day and both were significant at the 0.05 level (2-tailed). Various studies have mentioned that up to 70% of total CO emissions every year come from road transport emissions and the highest concentration of CO usually occurs in areas with high traffic volume and congestion (D'Angiola et al., 2010; Mohd Sadullah et al., 2003; Han and Naeher, 2006). The correlation of the concentration of O_3 and the number of vehicles was a significant negative correlation where the concentration of O_3 decreased as the number of vehicles increased. In urban areas and at roadsides, the lowest O_3 concentrations are often observed during the rush hours due to the large amounts of NO_x and VOC released from rush hour traffic; these are efficient scavengers of O_3 (Kiss et al., 2005; Gao and Niemeier, 2008). However, there was no significant correlation between the number of vehicles and concentrations of SO_2 and NO_2. These findings show that vehicular emissions are closely related to the concentration of air pollutants in the atmosphere; this has also been reported by many previous scholars (Colvile et al., 2001; Dominick et al., 2012; Gruden, 2003). The results also depicted that vehicle emissions have been one of the major sources of environmental pollution for the past 30 years with a contribution of various pollutants including carbon monoxides, nitrogen oxides, hydrocarbons and particulate matter as major emissions, which is consistent with the findings from (Colvile et al., 2001; D'Angiola et al., 2010): most air pollutants are caused by petrol- and diesel-fuelled vehicles.

Table 4
Correlation coefficient, *r*, between the number of vehicles and the concentration of pollutants for $p \leq .05$.

	PM_{10}	CO	SO_2	NO_2	O_3
Working day	0.62[a]	0.81[a]	0.12	0.14	−0.86[a]
Non-working day	0.49	0.97[a]	0.36	N/A	0.79[a]

[a] Correlation is significant at the 0.05 level (2-tailed); NA: not available.

3.5. The influence of meteorological factors on the concentrations of air pollutants

The influence of meteorological factors on the concentrations of pollutants are depicted by the correlation coefficients in Table 5. It was observed that the concentrations of PM_{10}, CO, NO_x and NO_2 showed significant negative correlations with AT, with values of $r = -0.75$, -0.84, -0.82 and -0.58, while the concentrations of ground level O_3 were significantly positively correlated with AT, with a value of $r = 0.97$ at the 0.05 level (2-tailed). The concentrations of PM_{10}, CO, NO_x and NO_2 also showed significant negative correlations with WS,

Table 5
Correlation coefficient, *r* matrix between the daily concentrations of pollutants and meteorological conditions for p ≤ .05.

	PM_{10}	CO	NO_x	NO_2	O_3	SO_2	WS	AT	RH
PM_{10}	1.00								
CO	0.83[a]	1.00							
NO_x	0.82[a]	0.99[a]	1.00						
NO_2	0.56[a]	0.76[a]	0.78[a]	1.00					
O_3	−0.82[a]	−0.92[a]	−0.91[a]	−0.71[a]	1.00				
SO_2	0.08	0.34	0.40	0.59	−0.38	1.00			
WS	−0.82[a]	−0.89[a]	−0.86[a]	−0.64[a]	0.96[a]	−0.16	1.00		
AT	−0.75[a]	−0.84[a]	−0.82[a]	−0.58[a]	0.97[a]	−0.36	0.94[a]	1.00	
RH	0.76[a]	0.86[a]	0.85[a]	0.63[a]	−0.97[a]	0.39	−0.94[a]	−0.99[a]	1.00

[a] Correlation is significant at the 0.05 level (2-tailed).

with values of r = −0.82, −0.89, −0.86 and −0.64, while the concentration of ground level O_3 was significantly positively correlated with WS with a value of r = 0.96 at the 0.05 level (2-tailed). The concentrations of pollutants, except ground level O_3, were found to be lower when AT and WS were high as also reported by Ocak and Turalioglu (2008). The ground level O_3 concentration is highly associated with AT and WS during the daytime as it is also influenced by photochemical reactions and therefore affected by sunlight levels (Kiss et al., 2005; Gao and Niemeier, 2008).

The inverse situation was observed with the correlations of the pollutants with RH. The concentrations of PM_{10}, CO, NO_x and NO_2 were significantly correlated with RH at the 0.05 level (2-tailed) with the values of r = 0.76, 0.86, 0.85 and 0.63 respectively, while the concentration of ground level O_3 and RH showed a negative significant correlation with the value of r = -0.97 at the 0.05 level (2-tailed). This is relevant as the level of RH is in inverse correlation with the AT and WS. The concentrations of PM_{10}, CO, NO_x and NO_2 were significantly correlated with one another at the 0.05 level (2-tailed). It was also determined that the presence of CO influenced the concentration of PM_{10} and was closely related to the combustion processes of motor vehicles (Dominick et al., 2012). On the contrary, the concentration of ground level O_3 showed negative significant correlations with the concentrations of PM_{10}, CO, NO_x and NO_2. However, the concentration of SO_2 showed no significant correlations with RH, AT, WS or the other pollutants. Even though the concentration of air pollutants are significantly related to road traffic emission, they are also greatly affected by the local meteorology factor (Kimbrough et al., 2013).

4. Conclusion

This study revealed that vehicular traffic emissions were the major contributors of air pollutants within the industrial area studied. The concentrations of air pollutants at the sampling site illustrate the importance of road traffic emissions as one of the contributors to air pollution in the industrial area. Even though it is well established that industrial activities are the usual source of air pollution, there was no significant industrial air pollutant source in this area, as the type of activities carried out at the Shah Alam Industrial Estate are mostly warehouse, storage, trading, and assembly of products. Very little activity that involves combustion and emission of air pollutants can be found in the area. The concentrations of PM_{10} and CO were significantly higher ($p \leq .05$) near to the road (1 m) compared to the station 100 m away from the roadside. The concentrations of O_3 showed the opposite trend, where the amount of O_3 recorded was at higher concentrations 100 m from the roadside compared to the station located about 1 m from the roadside. The amount of primary pollutants from vehicle exhaust is expected contribute to the concentrations of PM_{10} and CO. The amount of CO and NO_x then contribute to the amount of secondary pollutant, O_3 after they have been transported away from the roadside.

The results demonstrate that the levels of pollutants detected at the sampling area were significantly higher (p ≤ .05) on a working day compared to a non-working day. The correlations between the number of vehicles and concentrations of PM_{10}, CO and O_3 on a working day were 0.62, 0.81, and -0.86 respectively and were significantly correlated at the 0.05 level (2-tailed). The correlations between the concentrations of CO and O_3 and the number of vehicles on a non-working day were 0.97 and 0.79 respectively and both were significant at the 0.05 level (2-tailed). There were significant correlations of pollutants with the number of vehicles travelling the route, indicating that most of the pollutants detected come from vehicular emissions. The concentrations of PM_{10}, CO, NO_2, SO_2 and O_3 from the CAQMS data recorded at nearby DOE's station in Shah Alam also showed that the concentrations of pollutants were affected by the peak hour of vehicles utilising the road, which can be seen through the diurnal pattern. It was evident that the concentrations of pollutants related to the number of vehicles and the distance from the road, which is the point source of the pollutants, and that the pollutants sampled mainly originated from the incomplete combustion of fossil fuels.

Even though the sampling site is a well-known industrial area, the pollutants detected in the area were very much related to the road traffic activity within the industrial area. Although traffic networking is one of the most important factors in supporting the industrial activity, it is also becoming one of the major sources of air pollutants causing environmental issues, including changes to urban and global air quality and climate, direct and indirect health issues, infrastructure damage, and impacts to vegetation. Increasing air pollution also will affect the well-being of the urban population.

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