

Distribution and Temporal Behaviour of O₃ and NO₂ Near Selected Schools in Seberang Perai, Pulau Pinang and Parit Buntar, Perak, Malaysia

(Sifat Taburan dan Masa O₃ dan NO₂ Berdekatan Sekolah-sekolah Terpilih di Seberang Perai, Pulau Pinang dan Parit Buntar, Perak, Malaysia)

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ABSTRACT

Air quality has deteriorated in urban areas as a result of increased anthropogenic activities. Quantitative information on the influence of meteorological conditions on several pollutants in a tropical climate is still lacking. Real-time ozone (O₃) and nitrogen dioxide (NO₂) levels were measured nearby selected schools in Malaysia to examine the impact of meteorological factors on monitoring pollutants. The results showed the overall 10 min average concentrations of the main parameters during school holiday were 24 ppb (O₃) and 33 ppb (NO₂) while during school day the overall 10 min average concentrations were 26 ppb (O₃) and 51 ppb (NO₂). Although there are no minimum requirements for short-term exposure by MAAQG, if compared to 1 h average requirements, all concentrations were still below the suggested values. Regarding spatial distribution, a different trend in pollutant concentration among the schools was observed because of the influence of temperature (AT) and wind speed (WS). The results were verified by Pearson correlation, where significant correlations ($p < 0.01$) were determined between air pollutants and meteorological factors, which were temperature, wind speed and relative humidity. Meanwhile, the distribution of O₃ was moderately correlated with NO₂. However, the results of multivariate analysis indicate that temperature and relative humidity had the most significant influence on the formation of O₃. In summary, the results of this study showed that all precursors and meteorological parameters contribute to the production of O₃. Hence, reducing O₃ precursors, which are emitted by vehicles, is essential to lessening the exposure to O₃.

Keywords: Downwind transport; meteorological parameters; nitrogen oxide; ozone; wet condition

ABSTRAK

Kualiti udara telah merosot di kawasan bandar akibat daripada peningkatan aktiviti antropogen. Maklumat kuantitatif terhadap pengaruh keadaan meteorologi kepada beberapa pencemar dalam iklim tropika masih kurang. Kadar ozon (O₃) dan nitrogen dioksida (NO₂) pada masa sebenar telah diukur berdekatan beberapa sekolah yang telah dipilih di Malaysia untuk menilai kesan factor meteorologi terhadap pencemar yang dipantau. Keputusan menunjukkan kepekatan purata 10 min keseluruhan bagi parameter utama semasa cuti sekolah adalah 24 ppb (O₃) dan 33 ppb (NO₂) sementara semasa hari sekolah adalah 26 ppb (O₃) dan 51 ppb (NO₂). Walaupun tiada syarat minimum untuk pendedahan jangka pendek, jika dibandingkan dengan syarat purata 1 jam, kesemua kepekatan ini masih di bawah nilai yang disarankan oleh Garis Panduan Kualiti Udara Malaysia (MAAQG). Mengenai taburan reruang, perbezaan trend bagi kepekatan pencemar antara sekolah-sekolah diperhatikan, disebabkan pengaruh suhu dan kelajuan angin. Keputusan telah dibuktikan melalui korelasi Pearson, dengan korelasi ketaranya ($p < 0.01$) ditentukan antara pencemar udara dan faktor meteorologi, iaitu suhu, kelajuan angin dan kelembapan relatif. Sementara itu, taburan kepekatan O₃ adalah berkorelasi sederhana dengan kepekatan NO₂. Namun begitu, keputusan daripada analisis multivariat menunjukkan suhu dan kelembapan relatif mempunyai pengaruh yang paling ketara dalam pembentukan O₃. Secara ringkas, keputusan daripada kajian ini menunjukkan bahawa semua prapenanda O₃ dan parameter meteorologi menyumbang kepada penghasilan O₃. Justeru itu, pengurangan prapenanda O₃ yang dihasilkan oleh kenderaan adalah sangat penting dalam mengurangkan pendedahan terhadap pencemaran O₃.

Kata kunci: Keadaan lembap; nitrogen dioksida; ozon; parameter meteorologi; pembawaan angin

INTRODUCTION

Urban air pollution is a serious environmental problem that threatens human health and well-being as reported by many researchers from all over the world (Beauchamp et al. 2004; Mayer et al. 1999; Unal et al. 2003). Ground-level ozone (O₃) is a noxious secondary air pollutant that is produced

by a series of complex photochemical reactions between its precursors, such as nitrogen oxides (NO_x) or volatile organic compounds (VOCs) and incoming solar radiations (Ghazali et al. 2010; Seinfeld & Pandis 2006). Nitrogen dioxide (NO₂) is generally produced by anthropogenic activities, such as combustion of fossil fuels and biomass

burning. O_3 and NO_2 are always associated with negative impact which gave adversely affect to human health, crop yield and sensitive materials. Ozone is a major constituent of photochemical smog and and plays significant roles as greenhouse gas (Abdul Wahab et al. 2005; Kleanthous et al. 2014). Furthermore, O_3 and NO_2 also play critical role in tropospheric chemistry since it is principal precursors to hydroxyl radical (OH) which controlling oxidizing power at lower atmosphere (Alghamdi et al. 2014).

Formations and variations in O_3 and NO_2 concentrations are regulated by various processes, such as photochemistry, physical and chemical pollutant removal, dispersion and transportation (Alghamdi et al. 2014). All emitted pollutants are dispersed and diluted in the atmosphere and these processes are strongly influenced by meteorological conditions, such as temperature (AT), UV light, wind speed (WS), wind direction (WD) and relative humidity (RH) (Ghazali et al. 2010; Kovac-Andric et al. 2009; Toh et al. 2013). Several studies showed that intense solar radiation, high temperature, minimal rainfall, low wind speed and low relative rainfall also promote higher O_3 concentrations (Kovac-Andric et al. 2009; Latif et al. 2012; Tawfik & Steiner 2013; Toh et al. 2013).

Malaysia is currently experiencing rapid urbanization and economic growth as it strives to become an industrialized nation. Increased anthropogenic activities such as industrialization, urbanization and transportation significantly affect the air quality of tropical countries such as Malaysia. The O_3 variations in tropical countries do not follow the same trend as temporal countries, which have four prominent seasons with maximum concentrations measured during summer. Diurnal variations for UVB in tropical climates that influence air temperature and high relative humidity may affect the diurnal variability of O_3 concentration compared with that in temporal countries. The ambient concentrations of O_3 and NO_2 are expected to be higher during school days compared with those during school holidays because of high traffic volume.

Exposure to these pollutants repeatedly may give adverse effects to human health especially to schoolchildren. Thus, the objective of this study were to determine the differences of the concentrations between school holidays and school days as well as to investigate the influences of meteorological parameters on O_3 and NO_2 concentrations for both school phases at selected schools in a tropical region, which is climatically different from other regions.

MATERIALS AND METHODS

SITE DESCRIPTION

Penang is located in the peninsular of Malaysia by the Straits of Malacca. It is divided into two parts, namely, Seberang Perai (753 km²) and Penang Island (293 km²). Penang is also known as a highly urbanized and industrialized area in Malaysia. In 2013, the total human population and number of motor vehicles in Penang were 1,647,716 (Department of Statistics Malaysia 2013) and 2,408,715 (Road Transport Department Malaysia 2013), respectively. Meanwhile, Parit Buntar is a small town located on north of Kerian District and bordered by Bandar Baharu, Kedah and Nibong Tebal, Penang. Parit Buntar is now greatly develop especially on transportation sector. Thus, major concerns regarding pollutant levels are taken seriously because of their adverse effects on human health and the environment. Sampling was carried out near four school buildings located in different areas. These areas were selected based on their population and traffic volume. In areas with high population and traffic volume, a large number of pedestrians are expected to use the pedestrian facilities near the area (Dueñas et al. 2004). Thus, these individuals may have been exposed more to pollutants and hazards caused by the traffic. The distributions and descriptions of the selected schools in Penang are shown in Figure 1 and Table 1.

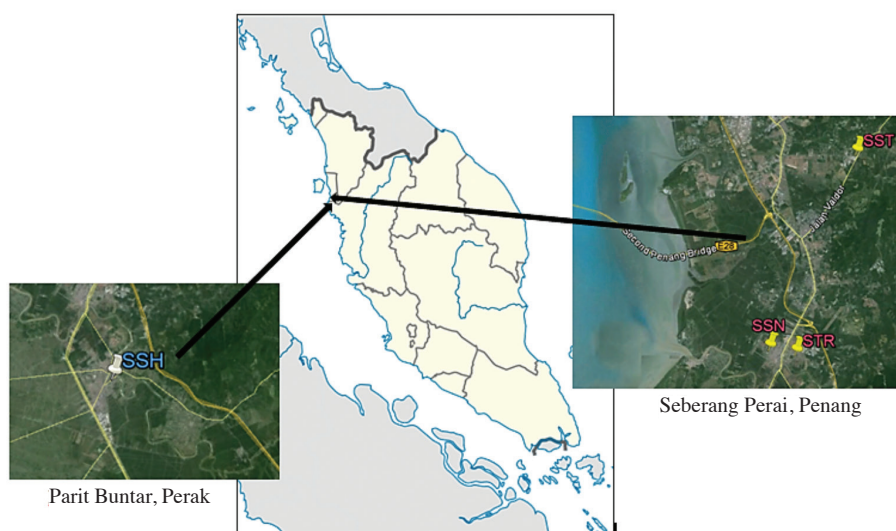


FIGURE 1. Site distribution of selected schools in Seberang Perai, Penang and Parit Buntar, Perak (not to scale)

TABLE 1. Description of selected schools in Seberang Perai, Penang and Parit Buntar, Perak

Site Location	Schools ID	Coordinate	Location
SJK (C) Sin Hwa	S1	5° 7' 35.2416"N 100° 29' 31.1388"E	Town and commercial area
SMK Seri Nibong	S2	5° 10' 17.601"N 100° 28' 15.7008"E	Residential and commercial area
SK Seri Tasek	S3	5° 17' 4.1712" N 100° 30' 11.4012"E	Rural and industrial area
SMK Tunku Abdul Rahman	S4	5° 10' 8.241"N 100° 29' 10.8306"E	Industrial and residential area

DATA SAMPLING

In the first phase, data sampling were collected during school holiday. Data sampling was carried out during school holidays from November 2014 to January 2015. Data were collected for 12 h from 7:00 am to 7:00 pm. Data during school holiday were used to represent the background concentrations on each selected schools. For the second phase of monitoring, data samplings were collected during school day for five days on weekday (Monday to Friday). Data sampling during school day were represented as the actual concentrations of these selected schools. Duration of data monitoring were different based on the school hours. Data were collected on the roadside of the selected schools to determine the air pollutant concentrations that pedestrians were exposed to. Five parameters were considered in this study: O₃, NO₂, AT, RH, and WS. O₃ and NO₂ were measured using Aeroqual S500, while meteorological parameters were obtained employing the E-Sampler 9800. Based on the results from the survey that were reported elsewhere, the average time that most of the students stay by the roadside were 10 min before they were picked up by their parents or guardians after school. Therefore, 10 min average data was analysed to observe the short-term exposure of gaseous pollutants to the schoolchildren.

Box and Whisker plot was employed to graphically describe the mean, median, lower and upper quartile, as well as the maximum and minimum values of the parameters. The daily variations of O₃, NO₂ and meteorological parameters were used to provide important information regarding O₃ and NO₂ concentrations, as well as the effect of meteorological parameters on O₃ formation.

The spatial variability of O₃ and NO₂ in all the selected schools was assessed using coefficients of divergence (COD). COD values indicate the differences between the absolute concentrations of pollutants at the monitoring sites (Wang et al. 2011; Wilson et al. 2005). COD provides the degree of uniformity between the simultaneously sampled sites *j* and *k*, as shown in (1).

$$\text{COD } I, k = \sqrt{\frac{\sum_{i=1}^p \left(\frac{x_{i,j} - x_{i,k}}{x_{i,j} + x_{i,k}} \right)^2}{p}}, \quad (1)$$

where *x_{i,j}* and *k* are the measured concentrations at sites *j* and *k* over the sampling period; and *p* is the number of observations. A small COD (*r* < 0.2) indicates similar pollutant concentrations between two sites, whereas a value approaching unity indicates a significant difference in absolute concentrations and subsequent spatial non-uniformity between the sites.

Pearson correlation coefficient was employed for univariate analysis to measure the linear association and the strength and direction of the relationship between selected variables and a dependent variable (Awang et al. 2015; Elbayoumi et al. 2014). Equation 2 shows equation for calculating *r*.

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}, \quad (2)$$

where *x* and *y* are selected variables and \bar{x} and \bar{y} are the means of the variables.

Multivariate analysis was performed to assess the main factors associated with O₃ and NO₂ levels. For statistical analysis, SPSS (version 22) was used. Statistical significance was taken as *p* ≤ 0.01. Through these analyses, the variation and influence of meteorological factors on O₃ and NO₂ levels were determined.

RESULTS AND DISCUSSION

CHARACTERISTICS OF POLLUTANT LEVELS

The results for box and whisker plots of O₃ and NO₂ concentrations at four schools are illustrated in Figures 2 and 3. During school holiday, the ranges of O₃ concentrations were 1-54 ppb for S1, 4-47 ppb for S2, 5-42 ppb for S3 and 9-48 ppb for S4. Meanwhile, the ranges of NO₂ concentrations were 9-66 ppb for S1, 5-66 ppb for S2, 24-78 ppb for S3 and 13-48 ppb for S4. During school day, O₃ concentrations were in the range between 3-55 ppb for S1, 3-38 ppb for S2, 2-35 ppb for S3 and 5-52 ppb for S4. As for NO₂ concentrations, the ranges were between 28 and 65 ppb for S1, 33-75 ppb for S2, 41-100 ppb for S3 and 36-58 ppb for S4 (Figure 2).

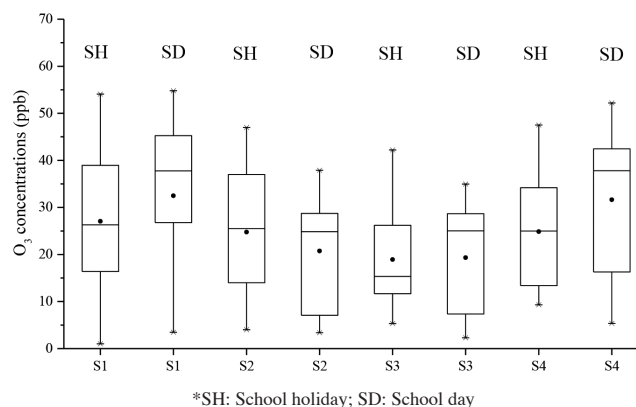


FIGURE 2. Box and whisker plot of O₃ concentrations at four schools during school holiday and school day

During school holiday, the highest 10 min average concentrations of O₃ were observed at S1 (27±15 ppb) followed by S4 (25±11 ppb), S2 (25±13 ppb) and S3 (19±10 ppb). Although NO₂ concentrations recorded were slightly different, O₃ concentrations in S1 were significantly higher compared with that of S2. High O₃ concentrations may be attributed to WS because wind carries pollutants from the source to other areas as shown in Table 2 (Gorai et al. 2015). Highest 10 min average concentrations of O₃ were also observed at S1 during school day's data monitoring with the value of 32±16 ppb followed by S4 (32±16 ppb), S2 (21±11 ppb) and S3 (19±11 ppb). Greater O₃ concentrations were expected during school day due to increment of traffic volume. Primary pollutants that were emitted from vehicles exhausts will be significantly higher. These primary pollutants that are also known as O₃ precursors will then react with sufficient amount of solar radiation to form O₃. Ratio of increment for this pollutants were 1.20 (S1), 1.02 (S3) and 1.27 (S4). However, O₃ concentrations were slightly lower for S2 during school day compared to school holiday with the ratio of 0.88. This result contrasts with the expectation of higher O₃ concentrations recorded since traffic volume were higher during school day. This phenomenon occurred due to high

particulate event during monitoring days at S2. Atkinson et al. (2012) explained that there was a negative correlation between PM₁₀ and O₃. Suspension of particulate matters in atmosphere prevents UV light to penetrate to the ground. Thus, solar radiation available for ozone formation at the surface was significantly lower compared to normal condition (Lee et al. 2004) (Figure 3).

As for NO₂ concentrations during school holiday, this pollutant tends to achieve its peak during morning and evening peak hour due to people who were going to and returning from work. The highest 10 min average concentration of NO₂ was recorded at S3 (41±12 ppb), followed by S4 (31±8 ppb), S2 (30±12 ppb) and S1 (29±15 ppb). This pollutant was higher at S3 compared to other areas due to the anthropogenic activities located in a close proximity mainly from industrial and transportation (Awang et al. 2015; Banan et al. 2013). However, there was depletion of NO₂ levels for S1, S2 and S3 during evening peak hour when there should be an expectation to have high NO₂ levels due to the availability of the sources for this pollutant. High RH shown in Table 2 results in low NO₂ concentration because of the cleansing activity of this pollutant caused by rainwater. Similar to O₃ concentrations, increments of this pollutant were also observed throughout

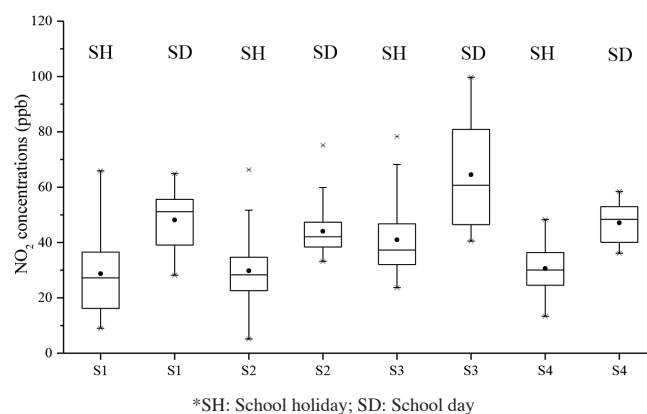


FIGURE 3. Box and whisker plot of NO₂ concentrations at four schools during school holiday and school day

TABLE 2. Average of meteorological parameters in each selected sites

Meteorological parameters	S1		S2		S3		S4	
	SH	SD	SH	SD	SH	SD	SH	SD
AT	33.9	33.7	33.9	32.1	31.0	32.3	33.5	34.0
RH	67.3	64.2	70.4	66.9	75.3	65.5	63.1	62.8
WS	1.1	1.1	0.7	0.8	0.8	0.9	1.2	0.7

*SH: School holiday; SD: School day

monitoring during school days with the highest 10 min average concentrations of 65 ± 18 ppb which was also recorded at S3 followed by S1 (48 ± 10 ppb), S4 (47 ± 7 ppb) and S2 (44 ± 9 ppb). Ratio increment of NO_2 at these four sites was 1.68 (S1), 1.48 (S2), 1.57 (S3) and 1.54 (S4). NO_2 levels were much higher on morning, afternoon and evening peak during school days period due to increment of traffic densities in all selected sites thus caused increasing of this pollutant (Rahman et al. 2015).

Malaysian Ambient Air Quality Guidelines (MAAQG) recommends the minimum requirement for outdoor air quality to avoid the adverse effects of pollutants on human health and the environment. The recommended minimum requirements for O_3 are 100 ppb as the 1 h average and 60 ppb as the 8 h average. Meanwhile, the minimum requirements recommended by MAAQG for NO_2 are 170 ppb as the 1 h average and 40 ppb as the 24 h average. However, for this study, the 10 min average is used to analyze the exposure of pedestrians, mainly schoolchildren where most of them were exposed to ambient air approximately in 10 min nearby roadside before being picked up by parents or guardians after the school session ended based on the survey conducted which were reported elsewhere. The results showed that the overall 10 min average concentrations of the main parameters during school holiday were 24 ppb (O_3) and 33 ppb (NO_2), meanwhile during school day the overall 10 min average concentrations were 26 ppb (O_3) and 51 ppb (NO_2). Low O_3 and NO_2 concentrations were expected since the data were obtained at the sites during school holidays, where traffic volume were lower compared to during school days. Even though there is no minimum requirements for short-term exposure by MAAQG, if compared to 1 h average requirements for O_3 and NO_2 , both concentrations during school holidays and school days were still below the suggested values. A lower value than the recommended value of MAAQG does not imply that short-term exposure to these gasses pollutants does not have adverse effects. Atkinson et al. (2012) stated that short-term exposure to O_3 corresponds to a small but significant increase in daily mortality.

DAILY VARIATION

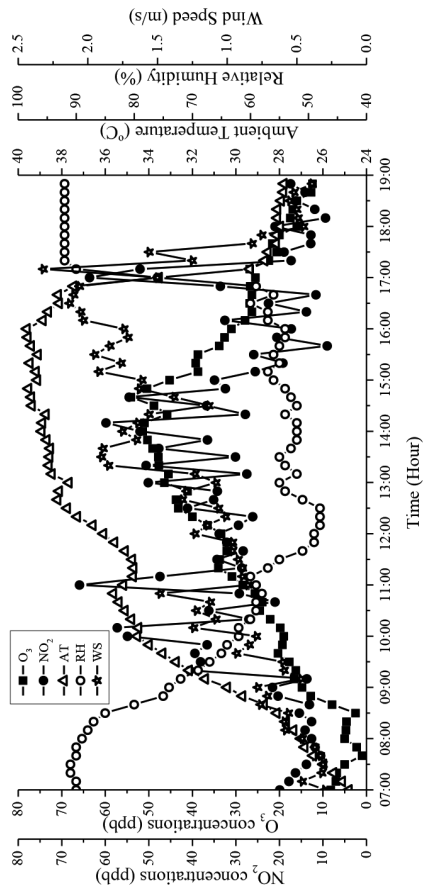
Daily variation of O_3 and NO_2 , as well as meteorological parameters which are AT, RH and WS, during school holidays and school days are graphically presented in Figures 4 and 5, respectively. O_3 formation was driven by

its precursors and sunlight. As observed in Figures 4 and 5, all sites exhibited high levels of O_3 during afternoon at around 1:00 pm to 3:00 pm because of maximum AT and solar radiation reaching its maximum during this period. This trend was also observed in other studies such as by Awang et al. 2015; Banan et al. 2013; Duenas et al. 2004; Rahman et al. 2015). Meanwhile, NO_2 concentrations are more driven by the sources of pollutants. According to the profiles, during school holiday, higher NO_2 concentrations were measured in the morning and evening because of the influenced by high traffic volumes where most of people are going to and back from work during this time without the presence of schoolchildren. Latha and Badarinath (2004) stated that high concentrations of NO_2 during morning and evening can be due to anthropogenic emissions, boundary layer processes, chemistry and local sources and wind profile. However, traffic patterns were different in all schools during school days. NO_2 concentrations were greater based on schools' hour when parents or guardians sent or picked up their children from schools.

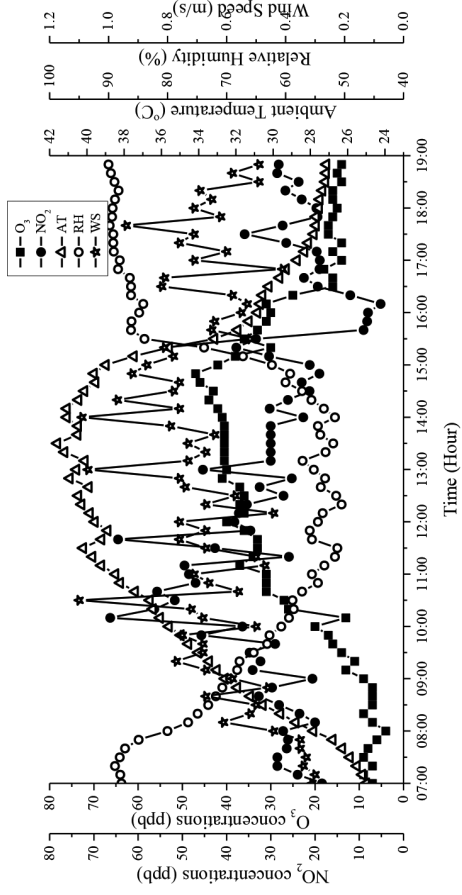
Even though the trend of O_3 and NO_2 concentrations were almost similar in all sites, variations were observed because of the effect of meteorological conditions. NO_2 concentrations were likely influenced by the instantaneous emission from anthropogenic activities mainly from vehicles while O_3 concentrations were proximately associated with the overall pollutants and meteorological conditions (Shen et al. 2010). During school holiday, there were similarities in all sites for O_3 and NO_2 trends where they were positively significant with AT and negatively significant with RH. Since O_3 levels are usually corresponding to temperature and solar radiation (Dawson et al. 2007; Stathopoulou et al. 2008; Swamy et al. 2012), higher O_3 levels during noon were expected. However, at S3, O_3 concentrations were observed to reduce during noon starting from 1.00 pm due to the rainfall. NO_2 concentrations were also observed to reduce in the evening in S1, S2 and S3. This phenomenon indicates that rainfall helps reduce pollutants by wet deposition (Lazaridis 2011). Low O_3 concentrations should be expected because of low number of ozone precursors in the area.

During school days, at S3, the measured O_3 concentrations were always lower than NO_2 throughout data sampling. However, NO_2 concentrations exhibited a different trend compared with that of WS. This observation indicates that the high NO_2 concentrations in this site were not significantly correlated with WS. This condition

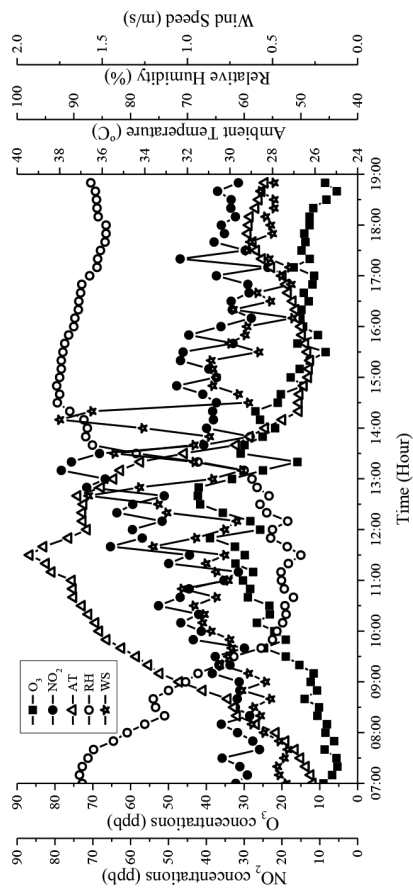
(a) S1



(b) S2



(c) S3



(d) S4

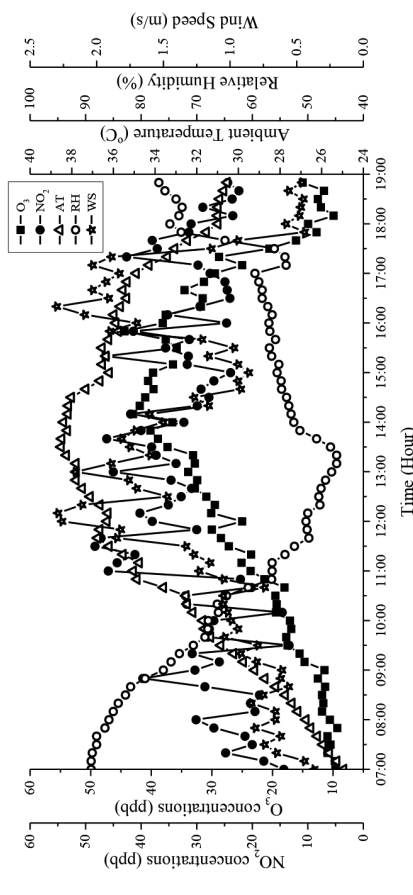


FIGURE 4. Daily variations of O_3 and NO_2 as well as meteorological parameters during school holiday

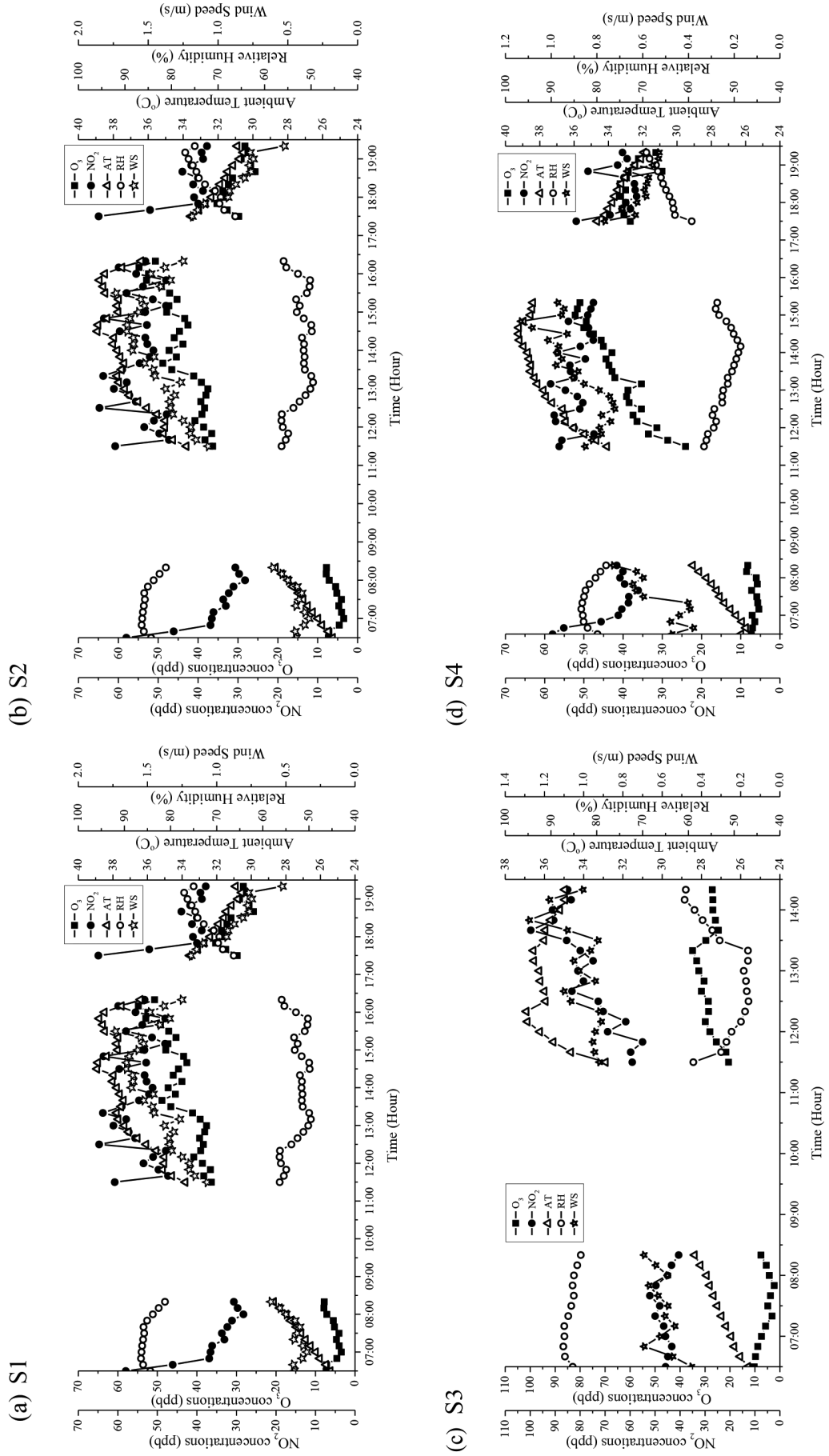


FIGURE 5. Daily variations of O_3 and NO_2 as well as meteorological parameters during school day

happened due to pollutant sources originally come from this area. As mentioned earlier, S3 is located in close proximity with industrial area with greater traffic volume. Thus, the pollutants from these sources contributed to the condition of this site. The recorded data showed that WS exhibited a similar pattern as O₃. This observation verifies that increased of O₃ concentrations are positively and significantly correlated with WS. Lal et al. (2000) mentioned that surface wind direction is directly influences high O₃ levels, but they also responsible for the diurnal variations of the primary pollutants. In summary, the O₃ levels are strongly depending on wind effect (Banan et al. 2013).

SPATIAL VARIABILITY

COD is a statistical technique employed to measure the magnitude of differences between sites. The summary of COD values calculated for O₃ and NO₂ concentrations are shown in Tables 3 and 4. The COD values for O₃ concentrations between S2 and S4 as well as S1 and S2 are smaller than 0.2. These differences show the spatial homogeneity between sites, a state that explains the almost identical concentrations. S2 and S4 are located at residential area where high traffic volume is expected to become the major source of air pollutants. Relatively high divergences were observed between other sites with COD values of 0.2054, 0.2344, 0.2589 and 0.2935 for differences between sites S1 and S4, S2 and S3, S3 and S4, as well as S1 and S3, respectively. COD values approximately higher than 0.2 indicate a heterogeneous spatial distribution between these sites.

As for NO₂ concentrations, all COD values were found to be higher than 0.2 between these sites. This indicates that there were high significantly differences between S1, S2, S3 with S4 during 10 min data monitoring. The lower COD value was recorded between S3 and S4 with 0.2066, meanwhile higher COD value was recorded between S1 and S3 with 0.3123. Even though S1 located in a town area, S3 recorded higher NO₂ concentrations rather than at S1. Location of

S3 which exposed to more nearby anthropogenic sources mainly industrial as well as transportation lead to greater levels of this pollutant in this area.

CORRELATIONS BETWEEN INDOOR VARIABLES AND METEOROLOGICAL PARAMETERS

Table 5 presents the Pearson correlation matrix between O₃, NO₂ and meteorological parameters. Based on the results for both during school holidays and school days, O₃ is significantly and positively correlated with NO₂, AT and WS except for RH, where a significantly negative correlation was observed. During school holiday, the highest magnitude was recorded between O₃ and AT ($r=0.905, p<0.01$), followed by WS ($r=0.824, p<0.01$), RH ($r=0.797, p<0.01$) and NO₂ ($r=0.635, p<0.01$). Meanwhile, during school days, the highest magnitude was also recorded between O₃ and AT ($r=0.991, p<0.01$), followed by RH ($r=0.855, p<0.01$), WS ($r=0.843, p<0.01$) and NO₂ ($r=0.468, p<0.01$). A magnitude value that is close to 1.00 indicates an almost similar temporal behavior between parameters. Therefore, according to the r-value, O₃ was highly correlated with AT, RH and WS meanwhile O₃ formation was moderately correlated with NO₂.

The positive correlation between O₃ with AT and WS were expected to occur since sunlight may initiate the oxidation of O₃ precursors, which leads to O₃ formation (Jenkin & Clemitshaw 2000). Hassan et al. (2013) stated that downwind effect may also significantly affect O₃ concentrations. The movement of gaseous pollutants, particularly O₃ precursors, from one area to another often results in high levels of O₃ concentration because of photochemical reaction. However, the positive correlation between O₃ and NO₂ was not expected because NO₂ is known as one of O₃ precursor. Increased O₃ levels are associated with a drop of NO₂ due to oxidation of this precursor (Awang et al. 2015). RH corresponds to the wet condition of the area. Wet condition or high RH will reduce O₃ formation because of insufficient sunlight to driven O₃ formation. Thus, RH was expected to be negatively correlated with O₃.

TABLE 3. Summarize of COD values of O₃ concentrations between sites

	S1	S2	S3	S4
S1	1	0.1733	0.2935	0.2054
S2		1	0.2344	0.1666
S3			1	0.2589
S4				1

TABLE 4. Summarize of COD values of NO₂ concentrations between sites

	S1	S2	S3	S4
S1	1	0.2730	0.3123	0.2524
S2		1	0.2590	0.2298
S3			1	0.2066
S4				1

TABLE 5. Pearson correlation matrix of O₃, NO₂ and meteorological parameters

School holiday					
	O ₃ (ppb)	NO ₂ (ppb)	AT (°C)	RH (%)	WS (m/s)
O ₃ (ppb)	1	0.635**	0.905**	-0.797**	0.824**
NO ₂ (ppb)		1	0.789**	-0.827**	0.500**
AT (°C)			1	-0.968**	0.755**
RH (%)				1	-0.650**
WS (m/s)					1
School day					
	O ₃ (ppb)	NO ₂ (ppb)	AT (°C)	RH (%)	WS (m/s)
O ₃ (ppb)	1	0.468**	0.991**	-0.855**	0.843**
NO ₂ (ppb)		1	0.654**	-0.744**	0.682**
AT (°C)			1	-0.974**	0.919**
RH (%)				1	-0.895**
WS (m/s)					1

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

FACTORS AFFECTING O₃ AND NO₂ CONCENTRATIONS

Table 6 shows the results of the multivariate analysis of factors that affect O₃ and NO₂ concentrations, which are mainly meteorological parameters for all the monitoring sites.

During school holidays, O₃ concentrations were significantly influenced by AT and RH ($p < 0.01$). AT was positively correlated with O₃ concentrations and negatively correlated with RH because O₃ production

requires sufficient amount of solar radiation. However, O₃ formation was insignificantly influenced by WS. These results also found during school days where only AT and RH were significantly influenced the production of O₃. As for NO₂ concentrations during school holiday, only RH significantly influenced the increase of NO₂ levels at the monitoring sites. Meanwhile, AT and WS were found to be insignificant. RH was negatively correlated with NO₂ levels. During high RH, the precipitation of rainwater occurs,

TABLE 6. Multivariate analysis of factors affecting O₃ and NO₂ concentrations for overall monitoring sites

School holiday		
	B (Standardized coefficient)	Significance
O ₃ concentrations		
AT	1.859	0.000
RH	1.083	0.000
WS	0.123	0.042
Adjusted R ²		0.918
NO ₂ concentrations		
AT	-0.099	0.783
RH	-0.951	0.003
WS	-0.043	0.720
Adjusted R ₂		0.673
School Day		
	B (Standardized coefficient)	Significance
O ₃ concentrations		
AT	1.754	0.000
RH	0.830	0.000
WS	-0.027	0.829
Adjusted R ²		0.876
NO ₂ concentrations		
AT	-1.901	0.000
RH	-2.120	0.000
WS	0.532	0.010
Adjusted R ₂		0.679

which carry the pollutants to the ground. This phenomenon decreases the pollutant level in the atmosphere (Rahman et al. 2015). However, varied from school day's data monitoring, AT also gave a significant influence to NO_2 levels. AT was negatively correlated with NO_2 levels because of O_3 formation. Solar radiation initiated oxidation of O_3 precursors particularly NO_2 to produce O_3 (Jenkin & Clemitshaw 2000).

CONCLUSION

The objective of this study were to determine the differences of the concentrations between school holidays and school days as well as to investigate the influences of meteorological parameters on O_3 and NO_2 concentrations for both school phases at selected schools in a tropical region, which is climatically different from other regions. The results showed the overall 10 min average concentrations of the main parameters during school holiday were 24 ppb (O_3) and 33 ppb (NO_2) while during school days, the overall 10 min average concentrations were 26 ppb (O_3) and 51 ppb (NO_2). The results also showed individual concentrations to determine the differences between school holidays and school days. The results indicated that all sites recorded higher O_3 concentrations during school days except for S2 where the concentrations were slightly lower than during school holiday due to the high particulate event during data monitoring. The maximum ratio of concentrations differences was recorded at S4 with 1.27. Meanwhile, NO_2 concentrations at all sites were higher during school days with the maximum ratio recorded at S1 (1.68). According to the Pearson correlation coefficient, O_3 was highly correlated with AT, RH and WS. Meanwhile, O_3 was moderately correlated with NO_2 . These results verify that NO_2 and meteorological parameters are crucial in O_3 production. A sufficient amount of solar radiation and O_3 precursors are needed in O_3 formation. Hence, reducing O_3 precursors, which are mainly emitted by vehicles, is essential to lessen the exposure of pedestrians to O_3 .

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