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Variation of Ground-level Ozone in the West Coast of Peninsular Malaysia

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Abstract

Hourly air pollutants data and weather parameters over the time period of 2008-2012 were obtained from the Air Quality Division, Department of Environment (DOE) Malaysia. The main aim of this study is to examine the variations of ground-level ozone in the west coast of Peninsular Malaysia. Shah Alam recorded the highest number of hours and days of ozone concentration above the threshold limit that was suggested by the Recommended Malaysian Air Quality Guidelines (RMAQG) with a maximum concentration of 0.158 ppm. The highest ozone concentration recorded in Petaling Jaya and Nilai were 0.12 ppm and 0.115 ppm respectively. The diurnal pattern shows that the maximum concentration was observed in the afternoon, which is the peak occurred between 2 p.m. to 4 p.m. and a minimum reading was recorded early in the morning and night-time. Analysis of ozone concentration and its precursors showed that the amount of Ultraviolet B (UVB) and the concentration of nitrogen dioxide had impacted the ozone photochemistry through the titration processes. The results show that there are visible seasonal patterns in the ground-level ozone among the three stations. The high concentration of ozone is usually observed between January to April (end of northeast monsoon that bring hot temperature from Cambodia) whereas the wind direction during different monsoons was found out to influence the concentration of surface ozone.

Keywords: Ground level ozone; Surface ozone; Nitrogen oxides; Temporal analysis; Spatial analysis

INTRODUCTION

Ozone (O_3) can be found both in the Earth's upper atmosphere (stratosphere) and at the ground level (troposphere). Tropospheric ozone is a secondary pollutant that is formed by chemical reactions between the volatile organic compounds (VOCs) and the nitrogen oxides (NOx) with the presence of sunlight and heat (Theapiriyakit *et al.*, 2017). Ozone is known as one of the major pollutants and one of the factors that influences global warming. Surface ozone is classified as the third most significant greenhouse gas and had a major role in the atmospheric chemistry by controlling the oxidizing capacity of the atmosphere (Nishanth *et al.*, 2012).

Surface ozone is a primary product of photochemical smog and always related to negative impacts toward human health, growth of vegetation and the lifetime of materials. Ozone can cause impairment to lung tissue, plants and other living things. High concentrations of ozone can cause cardiovascular and respiratory dysfunction (Yahaya *et al.*, 2017; Jerrett *et al.*, 2009; Yang *et al.*, 2014). It also damage plants via membrane destruction of leaves, hence disrupting the photosynthesis processes and reduces the yield (Chaudhary and Agrawal, 2015). Some of the studies had proved that ozone reduce the yield of certain food crops such as paddy-grown rice and grain (Amin, 2014; Van Dingenen *et al.*, 2009; Wang and Mauzerall, 2004). Furthermore, high ozone concentration also damage materials, such as surface coatings and rubber good. To date, surface O_3 is considered as the most damaging air pollutant in terms of adverse effects on human health, vegetation, crops and materials in Europe (Sicard *et al.*, 2016; Screpanti and De Marco, 2009).

Ground-level ozone is formed by photolysis reaction of NO_2. Oxidized hydrocarbons (a class of VOC) reacts as an initiator to the reaction that produced NO_2 from NO (Yahaya *et al.*, 2017; Ghazali *et al.*, 2010). NO is originated from the vehicles emission. Then, NO_2 will undergo the photolysis process and releases O to be uptake by the O_2 molecules to form O_3. These reactions produces NO_2 without using the O_3, hence can lead to accumulation of O_3 concentration at the ground-level (Teixera *et al.*, 2009). These complex photochemical formation of O_3 concentration is regulated by both natural and anthropogenic emissions and also by the meteorological conditions (Abdul-Wahab and AlAlawi, 2002). Tropospheric ozone is largely dependent on meteorology (Yahaya *et al.*, 2017; Ghazali *et al.*, 2010; Luo *et al.*, 2000). The accumulation and dispersion of ozone is dependent on the stability of ambient air together with the wind speed and wind direction. High concentration of ozone are usually associated with the slow-moving, high pressure weather systems (Gorai *et al.*, 2015). As surface ozone is a products of photochemistry reaction of NOx, CO and VOC, high intensity of sunlight, cloud cover, wind speed and water vapor concentration were all the factors that enhance the reaction.

Since surface ozone is a complicated secondary pollutants that is very unsafe to human, plants and environment, the concentration of ground-level ozone need to be studied thoroughly so that the seasonal peak of surface ozone can be analysed. The main goal for this study is to have a better understanding on surface ozone variation, temporally and spatially, in the westcoast of Peninsular Malaysia and to provide thorough information on the trend and characteristic of the ground-level ozone.

MATERIAL AND METHODS

In this study, hourly O_3 concentration and its precursors along with the meteorological parameters data were sorted by locations, years, month, and day. The chosen study areas are Shah Alam and Petaling Jaya in Selangor, and Nilai in Negeri Sembilan. The monitoring records from 2008 to 2012 were used to study the characteristics of O_3 concentration during that period. The hourly O_3 monitoring records, traces gases and meteorological dataset were made available by Department of Environment (DOE).

Data Collection

Five years of hourly ground level ozone concentration and its precursors together with weather parameters from 2008 to 2012 were obtained from air quality monitoring in Shah Alam, Petaling Jaya, and Nilai from Department of Environment (DOE). The dataset was recorded as part of Malaysian Continouos Air Quality Monitoring (CAQM) by using the β-ray attenuation mass monitor (BAM-1020) manufactured by Met One Instrument Inc (Afroz *et al.* 2003).

This study emphasized on the three important locations in westcoast, Peninsular Malaysia namely Shah Alam, Petaling Jaya, and Nilai. Shah Alam is one of the major cities in Klang Valley, situated within the Petaling Jaya district and a small part of neighbouring Klang District. The city is mostly occupied with housing areas. The total area is about 232.3 kilometers square and the population is about 730,000. This station represents urban areas that is located in one of the school that is surrounded by a few residential areas.

Petaling Jaya is a major Malaysia city with an area of approximately 97.2 kilometers square. This city is originally develop as a satellite township surrounded by the Malaysian capital, Kuala Lumpur. The population is about 550,000 residents. Petaling Jaya station stand for industrial area, however, it is also surrounded by residential and commercial areas making the area very condensed.

Nilai is located in Seremban District, Negeri Sembilan. This station has undergone a state of socioeconomic development. It is surrounded by industrial and commercial areas. The population of this area is about 38,000 people.

Data Analysis

For descriptive statistics, the analysis include mean, maximum, minimum, and standard deviation. Meanwhile, for boxplot analysis, it compromises of minimum, and maximum concentration, median and lower and upper quartile, to observe wether a data is symmetric or skewed.

For temporal characteristics, diurnal plot and pearson correlation were used to evaluate the data. Diurnal plot is done using average of hourly values of the chosen time period on 24 h scale. Pearson analysis were done by using continous measurements of O_3 concentration, traces gases and weather parameters, to observe the association between them. This is done using the Statistical Package for Social Science (SPSS) version 22.

For spatial characteristics, windrose diagram, trajectory analysis, and contour analysis were used. Windrose diagram is generated by using Hydrognomon 4 software. Backward trajectory was done using Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) Model developed by the National Oceanographic and Atmospheric Administration (NOAA) Air Resource Laboratory (ARL) (Draxler, 1999). The trajectories was observed at 2300 UTC for 500 m above ground level and developed for 72 hours according to the monsoon occur in peninsular Malaysia, which is the southwest monsoon and the northeast monsoon as well as the two intermonsoon. Contour analysis was generated using the internet based software called Plot.ly version 2.0.

RESULTS AND DISCUSSION

Temporal characteristics

Table 1 shows the descriptive statistics of the hourly ozone concentrations from 2008 to 2012 for the three monitoring stations. The full dataset without missing observation per year is 8760. For leap year, the additional one day (24-h) was omitted. The For Shah Alam, the maximum reading was 158 ppb in 2011. For Nilai, the highest maximum reading was 115 ppb in 2010 whereas in Petaling Jaya, the highest recorded concentration was 125 ppb in 2009. Overall, it can be seen that Shah Alam exhibited the highest O_3 concentration, followed by Petaling Jaya meanwhile the maximum concentration in Nilai was the lowest compared to the other two stations.

Shah Alam and Petaling Jaya are located in the Klang Valley, which is the commercial and industrial hub in Malaysia. Shah Alam is not only situated in large residential areas but it is also close to industrial areas. The location of the monitoring station is in the residential area and downwind to the city center, that may

Table 1. Descriptive Statistics of Ground Level Ozone

		Descriptive. Statistics (Unit: ppb)				
Station	**Year**	**N**	**Min**	**Max**	**Mean**	**Std. Deviation**
Shah Alam	08	8024	1	149	19.7	23.7
	09	8076	2	145	20.8	23.3
	10	7994	1	148	20.0	23.0
	11	7948	1	158	17.8	21.6
	12	8205	1	119	16.8	19.6
Nilai	08	8278	1	112	12.9	14.1
	09	8291	1	101	14.9	16.2
	10	8292	1	115	20.0	17.0
	11	8281	1	107	14.9	16.2
	12	7939	2	84	12.0	14.2
Petaling Jaya	08	7977	1	120	02.2	16.8
	09	8215	1	125	13.9	18.0
	10	8299	1	103	13.5	17.7
	11	8286	1	116	12.9	16.6
	12	8283	1	101	11.9	15.0

lead to the influence of ozone precursors such as NO_x in this study area. The oxidation of NO during the day produces NO_2, which increases the amount of ozone at this station. Other than that, green areas that surrounded that city slightly contribute to the quantity of another precursor, which is volatile organic carbon. The high amount of NmHC may indicate that VOC had contributed to the amount of ozone during the daytime.

Figure 1 shows the diurnal variation of the ozone concentration in Shah Alam, Petaling Jaya and Nilai. The ozone diurnal variation of each site displayed a similar shape, but the degrees of the deviations were varied. The diurnal pattern of ozone concentration for each site was observed to have a maximum concentration in the afternoon and a minimum reading in the night-time and early morning. This result is consistent with the previous findings (Awang *et al.,* 2015; Banan *et al.,* 2013; Latif *et al.,* 2012). The distribution of the ozone concentrations for the three sites showed a similar pattern of skewness, which is skewed to the right. It indicated that the possibilities of O_3 concentration to have extreme events through out a year that exceeded the limit of Recommended Malaysia Air Quality Guidelines (RMAQG) that is 0.06 ppm. The higher variation of O_3 concentration during daytime compared to night-time was due to the amount of higher solar radiation intensity during the day, which helped powering the photochemical reactions of producing surface ozone.

The highest ozone peak was observed at Shah Alam, followed by Petaling Jaya and Nilai. Minimum ozone concentrations was observed during the night-time and early in the morning. The lowest concentrations consistently measured at 8 a.m. This scenario happened due to the titrations of NO. During the morning hustle hours, normally occurred from 6 a.m. to 9 a.m., high concentrations of NO are being released from the vehicles emission (Jiménez-Hornero *et al.,* 2010; Reddy *et al.,* 2011). This lead to reactions of oxidized hydrocarbons (from vehicles emission) and NO to produce NO_2. Once the intensity of sunlight is enough for photolysis reactions of NO_2, the reaction take place and the ground-level ozone is produced. As the results, ozone concentrations rise gradually just after the sun rises and reaches its maximum levels between 2 p.m. to 4 p.m. After that, ozone concentrations decrease progressively until evening and keep decreasing more gradually, maintained at low values overnight. This is due to the lack of solar radiation and chemical loss via NO titration and deposition. In addition, further reduction was also cause by reaction between ozone and nitrogen dioxide, which produced dinitrogen pentoxide (N_2O_5) and nitric acid (HNO_3) (Tiwary and Colls, 2009).

Table 2 indicates the recorded monitoring records of O_3 concentrations that exceeding 0.1 ppm, a maximum limit suggested by the Recommended Malaysian Air Quality Guidelines, RMAQG for ambient air. Shah Alam recorded the highest number of hours and days of O_3 concentration above the threshold limit with a maximum concentration of 0.158 ppm. Although Shah Alam and Petaling Jaya are located within the more populous and urban-industrial area, the exceedances patterns are not alike (Ahamad *et al.,* 2014). Petaling Jaya had 36 h of exceedances, whereas the lowest total hours was recorded in Shah Alam for 13 h. According to Latif *et al.,* (2012), the number of hours and days of O_3 concentrations above the stipulated value were noticed as being less at the stations in the city centre and busy areas, which is Petaling Jaya, as well as those remotely located from the city centre, such as Nilai. This could be happened because of the titration of NO. The increase in NO titration eventually promotes the reduction of O_3 concentrations.

Overall results showed that the concentration of O_3 is dominant in the areas outside the city centre, which is Shah Alam as Shah Alam station are located within large housing areas that is more urban-suburban in nature. Petaling Jaya station is urban-traffic in nature as the monitoring station is sited next to a busy inter-section; hence it is more influenced by heavy traffic conditions that released high amount of NO from motor vehicles causing O_3 titration. Nilai has the lowest number of exceedances among other stations, as the station is more sub-urban in nature.

Figure 2 shows the diurnal concentrations (monthly averaged) of O_3, NO_2 and UVB. Although these plots are not capable to completely represent the association between ozone and its precursors, they can provide an informative comparison for the behavior of the pollutants. The study of diurnal variations of ozone and its precursors would provide information on the sources and transport of ozone as well as the effects of its chemical formation or destruction. The shapes of ozone cycles are strongly affected by the levels of its precursors and the meteorological conditions (Papanastasiou *et al.*, 2007). From figure 2, it can be seen that the variation of each site exhibited a similar pattern. Ozone production was from photochemical reactions; thus the diurnal characteristic of ozone concentrations demonstrated an increasing trend after sunrise, reaching the maximum around noon, and minimum concentrations were observed at night.

The magnitude and trends of NO_2 concentrations are similar among the three stations. In Malaysia, the usual NO_2 diurnal variations in Malaysia show two significant peaks in the early morning which is between 9 a.m. to 10 a.m. and in the evening which is in between 8 p.m. to 10 p.m. The magnitude of second peak was higher because the emission amount was more intensed and the prevailing meteorological parameters were less contributing. The typical diurnal patterns of NO_2 concentration trends were observed relatively high at night and the peak concentrations in the morning are attributed to vehicle emissions (Banan *et al.*, 2013).

Table 2. Table of Exceedances

Station	2008			2009			2010			2011			2012		
	Total Hours	Total Days	Max O_3	Total Hours	Total Days	Max O_3	Total Hours	Total Days	Max O_3	Total Hours	Total Days	Max O_3	Total Hours	Total Days	Max O_3
Shah Alam	82	45	0.149	81	44	0.145	48	33	0.148	40	24	0.158	13	10	0.119
Nilai	2	2	0.112	1	1	0.101	8	5	0.115	2	1	0.107	N/A	N/A	0.084
Petaling Jaya	9	7	0.12	17	10	0.12	4	3	0.103	5	3	0.116	1	1	0.101

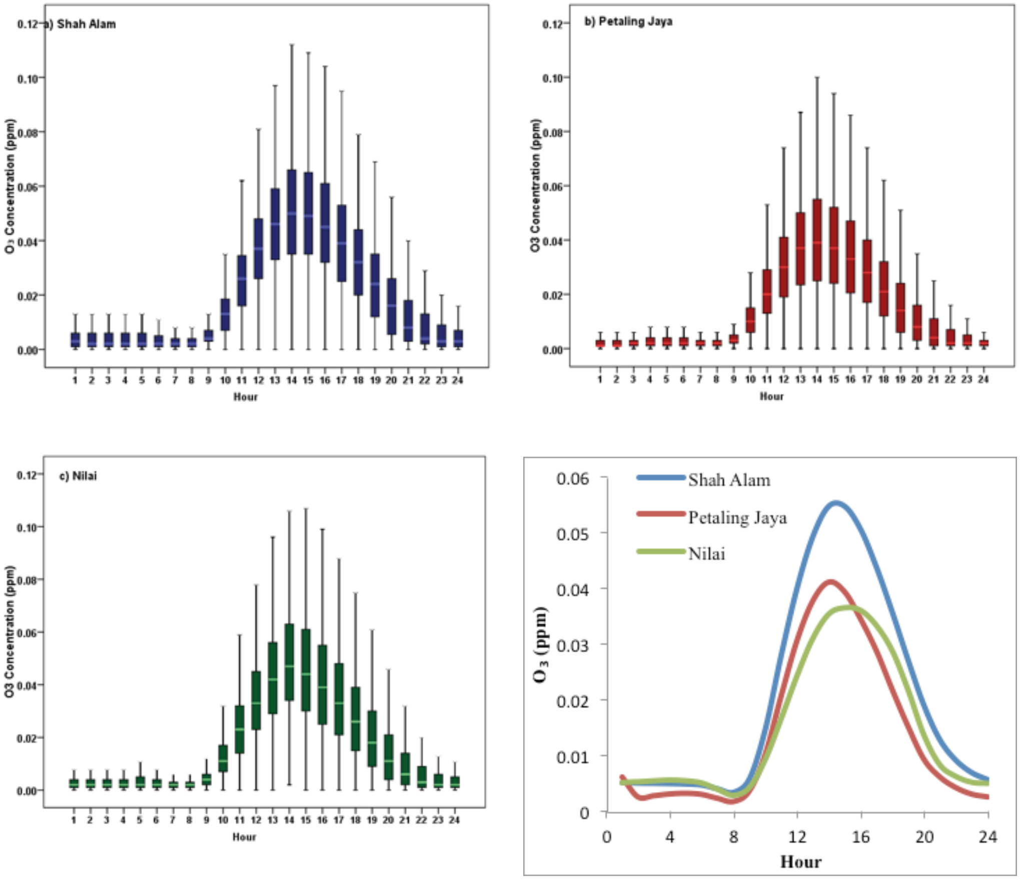

Figure 1. Diurnal Variations of Ground Level Ozone

Sunlight is the essential ingredient for completing the photochemical reactions for ozone formation. UVB radiations are dissimilar according to location, season, time of the day, and weather conditons (Lee *et al.,* 2010). The results of this study demonstrated that the pattern of diurnal ozone concentration was almost the same to the intensity of UVB. Malaysia receives sunlight at around 7 a.m. The increase in sunlight intensity directly increases the temperature and, at the same time, promotes the photochemical reactions of producing O_3. In this study, the maximum UVB radiation was measured between 2 p.m. to 4 p.m., which is also the period of highest ozone concentrations recorded. This was observed in Shah Alam and Nilai. Meanwhile for Petaling Jaya, there were no measurement records available for UVB; hence no comparison can be made.

Table 3 shows the Pearson correlation matrices of the variables in the study areas. Ozone concentrations were correlated with NO_2, CO, NmHC, PM_{10}, wind speed and temperature for Shah Alam. For Petaling Jaya, ozone concentrations were correlated with PM_{10}, CO, SO_2, humidity, wind speed and temperature. Meanwhile, for Nilai, ozone concentration was correlated with PM_{10}, NO_2, SO_2, solar radiation, humidity and temperature. NO_2, CO, and NmHC are known as the

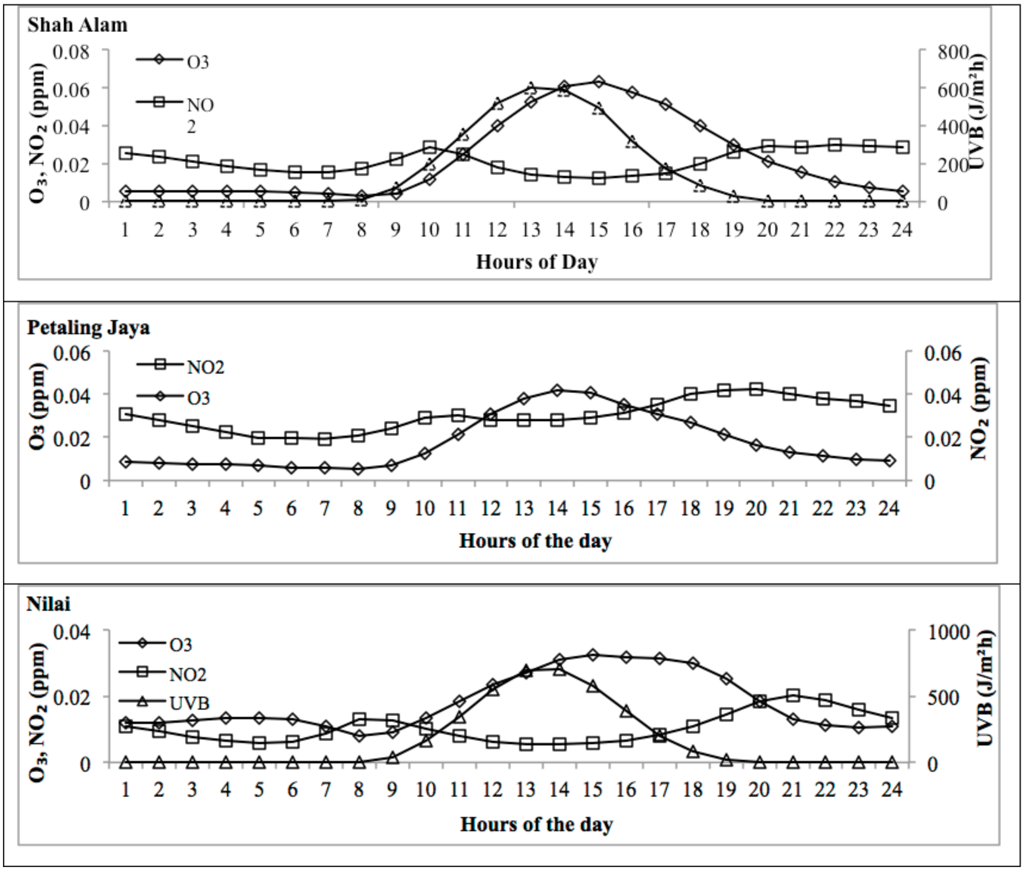

Figure 2. Diurnal plots of O_3 and NO_2 concentrations, and incoming solar radiation in January

precursors of ozone, demonstrating that a rise in ozone concentration is related with a rise or drop in the concentration of these pollutants. Meanwhile, PM_{10} is one of the most prominent criteria pollutants because it can alter the photolysis rates of several traces gases. High concentration of PM_{10} in ambient atmosphere can trigger light scattering of solar radiations and decrease the intensity of the solar radiation that reached the ground level (Bian and Zender, 2003). Photochemical reactions stopped and diminished ozone concentrations when solar intensity is reduced. The negative correlation between the ozone concentration and humidity is associated by the direct relationship between humidity and rainfall or wet condition. High humidity condition increased ozone destruction as a result of the drop in photochemical efficiency and the rise in wet position process (Kovac-Andric *et al.*, 2009).

Spatial Characteristics

Malaysia experiences four different monsoonal changes every year that were characterized by the; 1) northeast monsoon from November to March; 2) the first inter-monsoon from April to May; 3) the southwest monsoon from June to August and; 4) the second inter-monsoon from October to November (Md Yusuf *et al.*, 2010). Figure 3 shows the wind rose diagram during the monsoonal changes throughout the year for Shah Alam, Petaling Jaya, and Nilai. During southwest monsoon, it can be seen that the wind is from the southwest i.e. sumatra meanwhile during the northeast monsoon, the wind is from northeast of the peninsular Malaysia including Indochina and the South China Sea. For the first inter-monsoon and second inter-monsoon, the wind is mostly from the north and the northeast. It was found out that even the indigenous wind direction, such as sea breezes, still effect the movement of air pollutants, including the ozone precursors, from the busy areas to the residential areas. From the wind rose diagrams, it can be seen that Nilai has the strongest wind among the station which is might be the reason why Nilai has the lowest ozone concentrations exceedances, as the wind transmitted the pollutions away. Shah Alam and Petaling Jaya also show a strong wind from south and southwest during the southwest monsoon. The primary winds at these stations clearly indicated that air came from the coastal areas. Sea breeze circulation has ability to increase concentration of ozone in the highly occupied areas (Cheng, 2002; Oh *et al.,* 2006).

Studying the trajectories analysis was employed to better understand the long-range air transport. Figure 4 (a) shows that the southwest monsoon air trajectory was coming from Sumatra. Figure 4 (b) shows the air transport from the east coast of Indo-China across the South China Sea. The northeasterly winds are typically known to cause surface circulation during the winter monsoon. The polluted central outflow air mass over East Asia usually has a high concentration of ozone and carbon oxide (Lam *et al.,* 2001). Figure 4 (c) and (d) are the trajectories during the first inter-monsoon and the second inter-monsoon respectively, both showing the irregular directions. During this time of the year, the weather is considered by the monsoon transition with the weakest atmospheric circulations. During the spring, the equatorial regions received great radiation due to the hemispheric crossing of the sun which affecting higher intensity of solar radiation that has the capability to increase the ozone concentration due to the photochemical reactions.

Figure 6 shows the contour plots of monthly variations of ozone concentrations from 2008 to 2012 in the three study areas. The contour plot graded the concentration of ozone according to the higher concentrated time to the less concentrated. For Shah Alam, the ozone concentrations recorded a peak concentration at 0.06 to 0.08 ppm from 1 p.m. to 5 p.m, meanwhile for Petaling Jaya the ozone concentrations was at peak concentration of 0.04 to 0.06 ppm from 1 p.m. to 5 p.m. At Nilai, the ozone concentrations was observed highest at 0.04 to 0.05 ppm from 2 p.m. to 6 p.m. From the plot, even during the peak hour, the magnitudes for the 3 monitoring stations were different. Shah Alam had the highest peak value, followed by Petaling Jaya and lastly, Nilai. However, the peak hours for all the areas were between 1 p.m. to 6 p.m.

From this plot, it also can be seen that the highest daytime average ozone concentrations were observed between January and May in the three stations, whereas the lowest concentrations were observed between June and August. These observations are consistent with the results of the regional analysis satellite ozone data and also consistent with the previous study done in the Klang valley and the port cities in Malaysia (Latif *et al.,* 2012; Ahamad *et al.,* 2014; Awang

Table 3. Pearson correlation matrix of O_3 concentration with the traces gases and the weather parameters

		O_3	NO_2	SO_2	CO	NMHC	PM_{10}	T	RH	WS	UVB
Shah Alam	O3 (ppm)	1	0.573**	0.016	0.206**	0.595**	0.349**	0.113**	-0.093*	-0.295**	-0.012
	NO2 (ppm)		1	0.203**	0.002	0.572**	0.284**	-0.223**	0.252**	-0.260**	-0.203**
	SO2 (ppm)			1	0.008	0.074	0.258**	-0.052	0.121**	0.182**	-0.073
	CO (ppm)				1	0.050	0.438**	0.600**	-0.530**	-0.265**	0.210**
	NmHC(ppm)					1	0.378**	-0.146**	0.147**	-0.213**	-0.173**
	PM10 (μg/m³)						1	0.180**	-0.164**	0.022	-0.090*
	T (°C)							1	-0.919**	-0.099*	0.669**
	RH (%)								1	0.148**	-0.556**
	WS (m/s)									1	-0.005
	UVB (J/m²h)										1
Petaling Jaya	O3 (ppm)	1	-0.013	-0.083**	-0.153**		0.158**	0.397**	-0.459**	-0.290**	
	NO2 (ppm)		1	.431**	0.815**		0.441**	-0.133**	0.190**	-0.094**	
	SO2 (ppm)			1	0.440**		0.296**	0-.006	0.070**	0.098**	
	CO (ppm)				1		0.437**	-0.092**	0.188**	0.017	
	PM10 (μg/m³)						1	0.149**	-0.090**	0.057**	
	T (°C)							1	-0.771**	0.139**	
	RH (%)								1	-0.117**	
	WS (m/s)									1	
Nilai	O3 (ppm)	1	-0.163**	0.199**	-0.019	-0.040	0.222**	0.522**	-0.402**	0.011	0.202**
	NO2 (ppm)		1	0.068*	0.462**	0.568**	0.314**	-0.555**	0.586**	-0.347**	-0.514**
	SO2 (ppm)			1	0.009	0.114**	0.243**	0.136**	-0.051	0.068*	0.004
	CO (ppm)				1	0.448**	0.618**	-0.260**	0.257**	-0.196**	-0.320**
	NmHC (ppm)					1	0.391**	-0.239**	0.281**	-0.192**	-0.309**
	PM10 (μg/m³)						1	-0.039	0.077*	-0.004	-0.256**
	T (°C)							1	-0.862**	0.122**	0.697**
	RH (%)								1	-0.344**	-0.699**
	WS (m/s)									1	0.298**
	UVB (J/m²h)										1

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

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

Where, T – Temperature; RH – Relative Humidity; WS – Wind Speed;

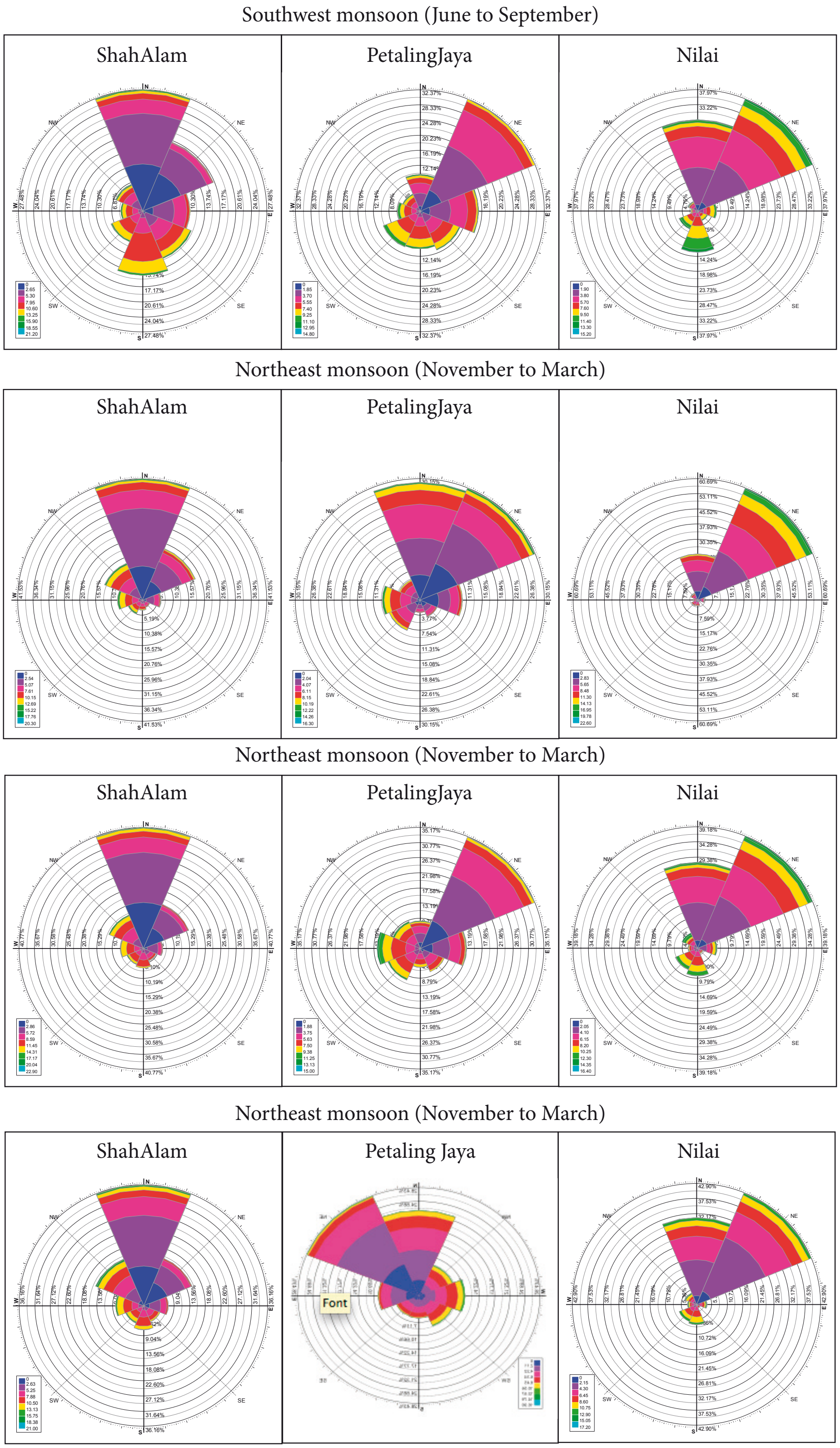

Figure 3. Wind roses diagram for the three stations according to the monsoon (2008-2012).

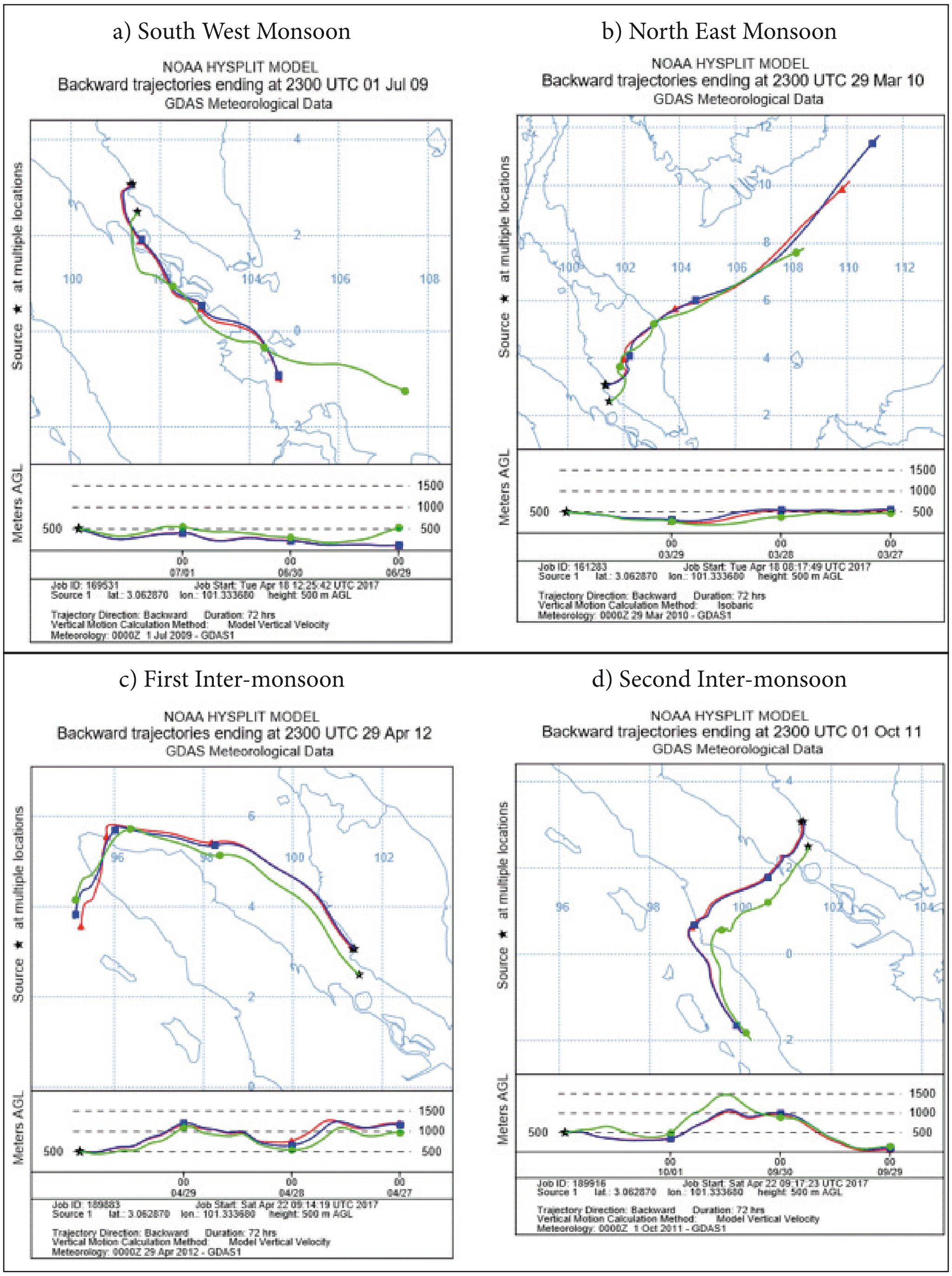

Figure 4. The trajectories of the three stations according to the monsoon. a) Southwest Monsoon (July 2009) b) Northeast Monsoon (March 2010) c) First Inter-monsoon (April 2012) d) Second Inter-monsoon (October 2011)

et al., 2015). It is reported that the seasonal patterns of ozone concentration in China demonstrated an annual maximum in March and a minimum in October.

The monthly variation of ozone was high between January and May, which was during the northeast monsoon and the first inter-monsoon. These periods are generally associated with the wet season and supposed to have lower pollutant concentration. However, these periods also know as winter-spring transition. A high ozone concentration was found out in the month of March when the northeasterly monsoon winds weakens. It is suggested that this happen when the long-range transport of ozone from the ozone sources from East Asian continent and Indo-China across the South China Sea. Hence, indicating the importance of ozone production from the precursors in the polluted maritime air masses. South China Sea is a photochemically active area and understanding the chemical transformation of pollutants emitted from the Asian mainland is crucial (Wang *et al.,* 2001). Thus marine boundary layer processes could provide an important understanding to the variation of ozone and its precursors.

CONCLUSION

Surface ozone is one of the air pollutants that need to be monitored closely since it is becoming one of the major pollutants worldwide. Exposure assessment of ozone concentration need to be done together with the spatial characterization hence the thorough understanding of this secondary pollutant can be achieved . In this study, three important city in Malaysia namely Shah Alam, Petaling Jaya and Nilai were selected. Shah Alam and Petaling Jaya are the two most busy cities in Klang Valley whereas Nilai is the new socio-economic city that transform this remote area into a large industrial and commercial regions.

The diurnal cycle of ozone concentration had a midday peak between 2 p.m. to 4 p.m. and lower night-time concentrations. The diurnal pattern of the ozone concentration is strongly influenced by meteorological conditions and principal levels of its precursors, NO_x and CO, as well as the titration processes. This finding was also agreed by the results of pearson correlation analysis, as the meteorological parameters loaded heavily in the first components in the analysis. It was also shown that NO_2, PM_{10}, CO, and NmHC directly effected the ozone concentrations.

The seasonal dispersal of ozone concentration was mostly influenced by the seasonal wind direction and the locations of the sampling stations. The maximum ozone concentrations were recorded between January to May especially in Shah Alam that exceeded the values of National Ambient Air Quality Standard for ozone that is 0.07 ppm for 8-h average. Even though, Petaling Jaya is more busy and condensed compared to Shah Alam, that is urban-suburban in nature, high ozone concentration was recorded here. There might be a few reason of this occurence. First, ozone is highly associated with NO prior to its formation. NO is produced by vehicles emission and usually was found in densely populated areas such as Petaling Jaya. The movement of air from a city centre will bring high amounts NO_x, to the downwind areas. Secondly, it maybe due to the solar intensity and the accomponied meteorology parameters of the areas. Higher solar radiation promote the formation of surface ozone. However, the densely populated areas with high building lessen the ability of solar to reach the ground level.

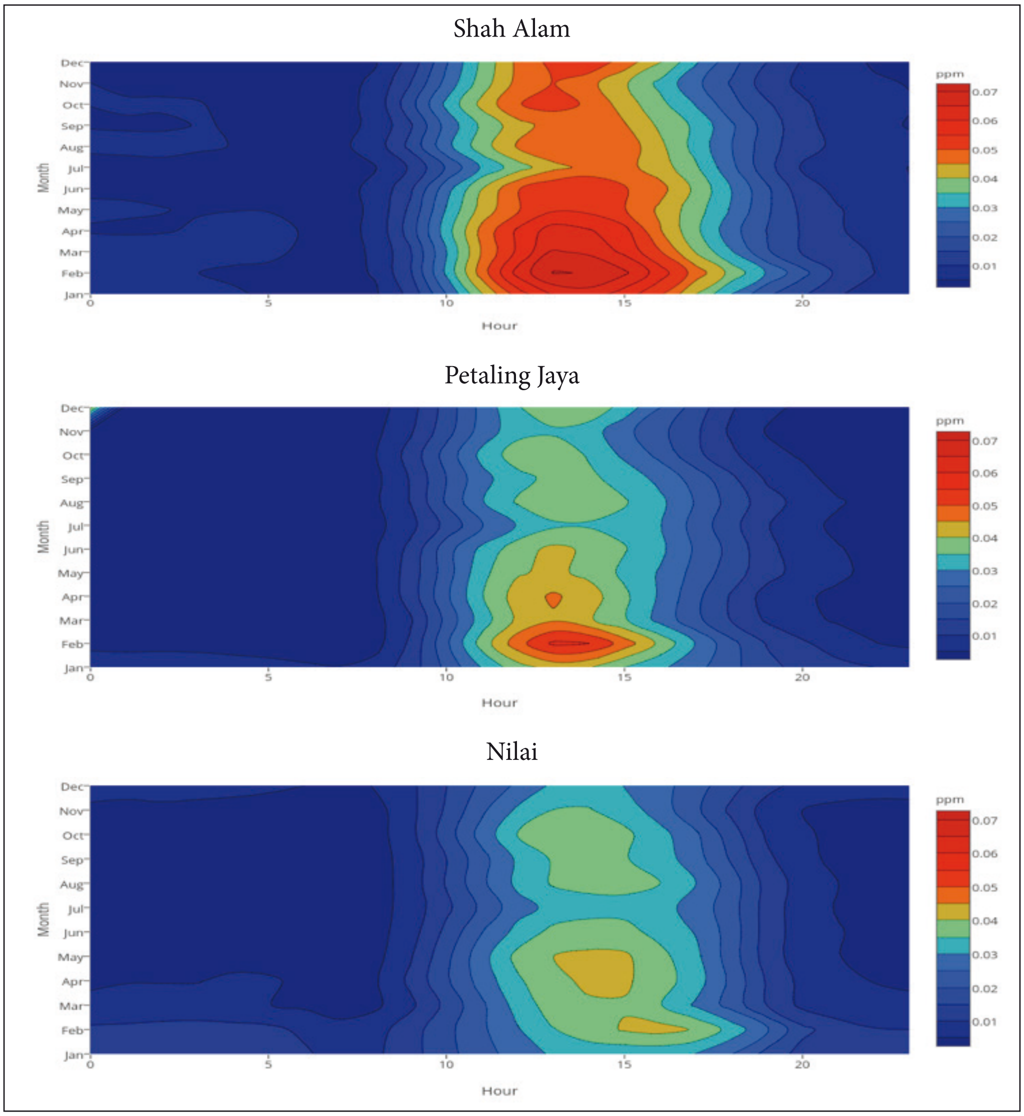

Figure 6. Contour plots of monthly variations of ozone concentrations (2008-2012) in Shah Alam, Petaling Jaya, and Nilai

The findings in this study suggest that the ozone concentration in this less busy area was quite crucial with more than a month of total counted days that the concentration of ozone exceeded the value of 0.10 ppm. Hence, a structured mitigation plan need to be startegized to control this pollutant. The abatement of ozone precursors especially NO_x need to be done to reduce drastically the formation of surface ozone. Further study on ozone precursor, such as NmHCs is needed to be investigated further as there is no clear indication that NmHCs contribution to the level of ozone concentration. Other than that, further investigation is needed on the meteorological parameters such as solar radiation intensity and cloud cover due to complexity of ozone photochemistry and lagged response to meteorological parameters. Long-range transport and oceanic air, some how had shown some relationship with the variations of ozone and its precursors.

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