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LONG-TERM AIR POLLUTION TREND ANALYSIS IN MALAYSIA

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ABSTRACT

Air pollution has become increasingly significant in the last few decades as a major potential risk to public health in Malaysia due to rapid economic development, coupled with seasonal trans-boundary pollution. Over the years, air pollution in Malaysia has been characterised by large seasonal variations, which are significantly attributed to trans-boundary pollution. The aim of this study is to analyse the long-term temporal dynamic (1997–2015) of CO, NO_x and PM_{10} at 20 monitoring stations across Malaysia. Long-term pollutant trends were analysed using the Mann–Kendall test. For potential pollutant source analysis, satellite data and Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) backward trajectories model were employed. In all monitoring sites, we observed that the annual average concentrations of PM_{10} were varied, with large coefficient variations. Meanwhile, CO and NOx were found to be less varied, with smaller coefficient variations, except in certain monitoring sites. Long-term analysis trends for CO attested to insignificant decreasing trends in 11 monitoring stations and increasing trends in seven stations. Meanwhile, NO_x showed no significant trends in most stations. For PM_{10}, five monitoring stations showed increasing trends, whereas 15 other stations showed decreasing trends. HYSPLIT backward trajectory analyses have shown that high seasonal PM_{10} levels in most parts of Malaysia are due to trans-boundary pollution. Large-scale intense biomass burning in Indonesia, particularly during the southwest monsoon, has been identified as the main potential source. Long-term air pollution in Malaysia is characterised largely by trans-boundary pollution and is highly seasonal. In urban areas of Malaysian Peninsula, combinations of trans-boundary pollution and local emission sources were notably identified as important sources. Long-term PM_{10} pollution in Malaysia shows small but significant decreasing trends. Therefore, to ensure that the effect of air pollution on human health is minimised, special attention needs to be focused on short-term pollution episodes, particularly during trans-boundary pollution events and extreme weather conditions such as El Niño.

Keywords: air pollutants, El-Niño, HYSPLIT, biomass burning, trans-boundary pollution.

1 INTRODUCTION

Air pollution is broadly understood as any material of any source within the atmosphere, which exists in either solid, liquid or gas phase that has destructive effects or the ability to modify the natural characteristics of the atmosphere and poses a health risk to living things, or which causes the deterioration of the environment and ecosystem [1,2]. Typically, pollutants come from both natural sources (i.e. plant pollens, wind-blown dust, volcanic emissions and lightning-induced forest fires) and anthropogenic sources (i.e. transportation emissions, industrial emissions and emissions from other processing activities) [3–5]. Common air pollutants include particulate matters (particularly PM_{10} and $PM_{2.5}$), carbon monoxide (CO), ozone (O_3), sulphur (S), sulphur dioxide (SO_2) and nitrogen oxides (NO_x), acid gases, heavy metals, volatile organic compounds (VOCs), solvents, pesticides, radiation and bio-aerosols [6,7].

On the basis of available scientific studies, short- and long-term exposure to air pollutants poses different toxicological impacts on living things [7]. Eye irritation, skin disease, nausea and cardiovascular infection have been affirmed as associated short-term effects of poor air quality [8]. In addition, several studies have linked the long-term effects of air quality exposure to lung inflammation and cardiovascular disease, fatal heart diseases [9–12] asthma [9,11,13,4], the carcinogenic effects of lung cancer [11,15–17], neuropsychiatric complications [15,18,19], ventricular hypertrophy [20,21] and Alzheimer [15,22], neurological

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disorder [22,23], innate immune system [22] and Parkinson's syndrome [22]. Hence, available scientific studies have proven that many of the diseases linked to distortion of immune system and risks of morbidity and mortality are associated with low air quality. High genotoxic potential has been associated with exposure of fine and coarse aerosol particles that reach the alveolar region of the lungs [24]. In Malaysia, respiratory mortality and natural mortality have been found to be significantly associated with daily mean of O_3, CO, NO_2 and PM_{10} [25,26]. The highest relative risk (RR) in the single-pollutant model was observed for PM_{10} and O_3, indicating that an increase in PM_{10} exposure was associated with a maximum increase of 0.99% in natural mortality and a 3.63% increase in respiratory mortality [26].

Malaysia ranked as the third highest country for pollutant emissions in Southeast Asia after Indonesia and Thailand [27]. For the past decades, the major sources of air pollution in Malaysia are power plants (85%), motor vehicles (10%), industrial activity (3%) and other sources (2%) [28]. The increase of demand for motor vehicles between 1996 and 2015 and rapid industrialisation, especially in the western corridor of the Malaysian Peninsula, has caused the increase of air pollutant emissions, thus inevitably affecting local and regional air quality [25,27,29]. Until the 1980s, air pollution was generally regarded as a local issue and confined to nearby emission sources or urban areas, but now several air pollution issues have been reported and become a regional issue as pollutants are transported over long distances and have adverse effects on the environment on a wider scale [30].

The rising trend of trans-boundary air pollution and episodic haze and their associated health impacts is becoming a greater concern in Malaysia [26,30–32]. Seasonally, open biomass burning in neighbouring regions, particularly Indonesia and Indochina, have been known to contribute to the air quality deterioration in Malaysia [29–33]. Severe haze episodes in Malaysia due to trans-boundary pollution, originated largely from Indonesia, were recorded in April 1983, August 1990, June 1991, October 1991, August 1994 and September 1997 [32]. The episode in 1997 was singled out as the worst in Malaysian air quality records by reaching the hazardous level of air pollution index (API) [29,32]. Haze episodes in September to November 2015, also due to trans-boundary pollution from Indonesia, caused low air quality in Malaysia [34], where 34 over 52 air quality monitoring stations recorded API levels of exceeding 200. This is considered the worst haze episode in recent decades [35].

In Malaysia, the southwest monsoon wind and trans-boundary pollution have greatly influenced national air quality [30,31,34,36]. The geographic location of Malaysia, which lies in

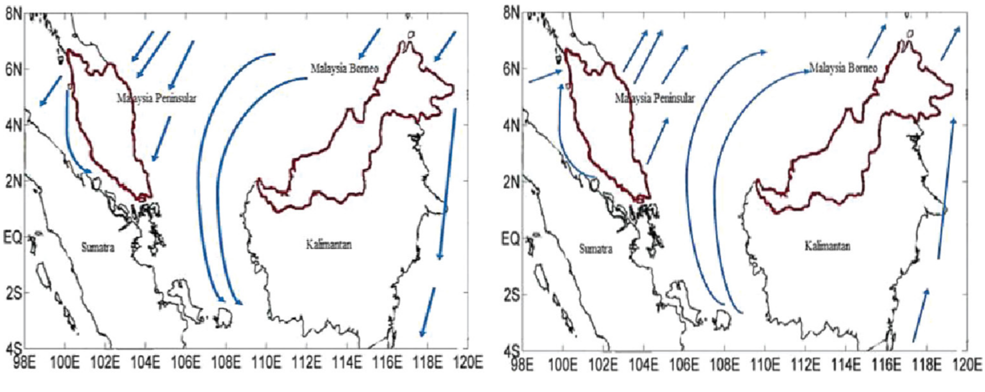

Figure 1: Conceptual model of prevailing wind flow (blue arrows) during NE monsoon (left panel) and SW monsoon season (right panel).

the main pathway of the Southeast Asian pollution outflow (Fig. 1), has caused significant exposure to regional aerosol and pollutant emissions [34,36]. The southern and central areas of the Malaysian Peninsula have been the worst area affected by the trans-boundary haze originating from Sumatra, Indonesia, due to large and intense burning of peat soil and plant residues in releasing high concentrations of particulate matter [34,37]. In urban areas of the Malaysian Peninsula during normal periods, the air quality is characterised by local emissions, mostly emissions from traffic, industries as well as local biomass burning [25,29]. In understanding the air pollution dynamic, this paper is aiming to characterise the long-term temporal dynamic and variations of CO, NO_x and PM_{10} in Malaysia. In supporting this aim and to enhance regional understanding on air pollution variations and its potential sources, assessment of the regional long-term pollution trend and its link with seasonal trans-boundary pollution episodes and El Niño events will be explored.

2 METHODOLOGY

2.1 Site description

The air quality pollutants considered in this study are CO, NO_x and PM_{10}, with data obtained from 20 air quality monitoring stations of a total of 61 monitoring stations in Malaysia. The selection of the 20 monitoring sites is due to the availability of long-term air quality data for all selected pollutants. The selections of the 20 monitoring station are based on regional representation (northern, central, southern and eastern Malaysian Peninsula and Malaysian Borneo) as well as the surrounding land use setting (urban, sub-urban, industrial and rural) as shown in Fig. 2 and Table 1.

2.2 Climatic variations and air quality datasets

Malaysia has a typical tropical climate governed by the regional wind systems, which result from the atmospheric pressure distribution over the region. The seasonal fluctuation of the inter-tropical convergence zone (ITCZ) and the associated trade wind fields in the region

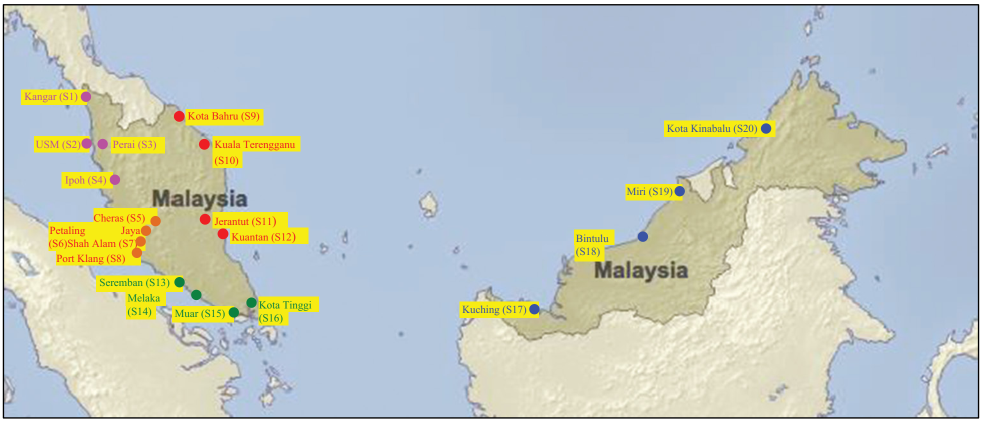

Figure 2: Selected locations of air quality monitoring stations (S1-S20) for the investigation of long-term air quality analysis in Malaysia.

Table 1: Selected 20 air quality monitoring stations (S1-S20) in different regions and site characteristics.

Region	Area status	Location (station)	Coordinate (Lat, Long)
Northern Peninsular Malaysia	Suburban	Kangar (S1)	6.25, 100.11
	Suburban	USM (S2)	5.21, 100.17
	Industrial	Perai (S3)	5.23, 100.24
	Urban	Ipoh (S4)	4.33, 101,04
Central Peninsular Malaysia	Urban	Cheras (S5)	3.06, 101,40
	Industrial	Petaling Jaya (S6)	3.06, 101.42
	Urban	Shah Alam (S7)	3.06, 101.33
	Urban	Port Klang (S8)	3.00, 101.24
Eastern Peninsular Malaysia	Urban	Kota Bahru (S9)	6.09, 102.15
	Urban	Kuala Terengganu (S10)	5.18, 103.07
	Suburban	Jerantut (S11)	3.58, 102.20
	Suburban	Kuantan (S12)	3.49, 103.17
Southern Peninsular Malaysia	Urban	Seremban (S13)	2.43, 101.58
	Urban	Melaka (S14)	2.15, 102.1
	Suburban	Muar (S15)	2.03, 102,35
	Urban	Kota Tinggi (S16)	1.33, 104.13
Malaysian Borneo	Industrial	Kuching (S17)	1.33, 110.23
	Suburban	Bintulu (S18)	3.10, 113.02
	Rural	Miri (S19)	4.25, 114.00
	Urban	Kota Kinabalu (S20)	5.53, 116.02

produces two monsoonal seasons, namely the Northeast Monsoon (NEM) (November to February) and the Southwest Monsoon (SWM) (June to August), which greatly influences regional climatic variations (Fig. 1). The two monsoons are separated by two transitional periods, where the wind conditions are generally light and variable. Seasonal monsoons in the region, particularly in the south ASEAN (Malaysia and Indonesia) subregion, have been known to play important roles in the regional air pollutant transport and dispersion. Most notable cases were the significant role of the southwest monsoon to the large scale of transboundary pollution in the region due to biomass burning in Sumatra [38].

In this study, a long period of air quality data (1997–2015) was obtained from 20 air quality monitoring stations across Malaysia from the Department of Environment (DOE). All air quality monitoring stations were equipped with continuous automatic monitoring equipment designed to collect and measure data continuously during the monitoring periods. CO was measured by Teledyne API Model 300/300E analyser using the non-dispersive, infrared absorption (Beer Lambert) technique. NO_x was measured by Teledyne API Model 200A/200E analyser using chemiluminescence detection technique. Meanwhile, fully automated continuous monitoring of PM_{10} was carried out using a β-ray attenuation mass monitor (BAM-1020). The diurnal, seasonal and annual air pollutant concentrations variations were analysed.

Hourly data were used for the diurnal variations computation, while daily data were used for the seasonal and annual variations.

2.3 Pollutant temporal dynamic characteristics

The inter-annual variation characteristics (temporal dynamic) of air pollutants in Malaysia between 1997 and 2015 as based on trend analysis were investigated. The Mann–Kendall (MK) test was employed, as it is capable of detecting a monotonic trend of a time series with no seasonal or other cycles [34,39]. In assessing the extent of inter-annual variability relative to the pollutant mean concentrations over the period of investigation, the variation coefficient, which is the ratio of the standard deviation (σ) to the mean (μ), was also calculated [39].

2.4 Pollutant Trajectory analyses

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used to evaluate the origin and pathway of air mass transport with high value of pollutant concentration. In any given starting location, this model is capable of generating air mass backward trajectories and is thus very helpful in assessing and understanding an air quality event during the selected period. The model was provided by the US National Oceanographic and Atmospheric Administration (NASA), which can be accessed at http://www.arl.noaa.gov/ready.html. The model was developed as a hybrid between the Lagrangian and Eulerian approach, using a moving frame of reference for the advection and diffusion calculations as the trajectories of an air mass from a given location and at the same time computing the air pollutant concentrations using a fixed three-dimensional grid as a frame of reference [40–42]. Despite the HYSPLIT trajectory model's weaknesses, such as the calculated error of up to 30% (after 24 h) and the non-representation of an air parcel path within the planetary boundary layer (PBL) due to physical processes such as turbulent mixing [41,42], this model is adequate to classify regional-scale air mass motions. To investigate the potential sources of air pollutants from biomass burning, information on regional fire maps was obtained from FIRMS (Fire Information for Resource Management System), which can be accessed at https://firms.modaps.eosdis.nasa.gov/firemap/. The detection of hot spots due to biomass burning in Southeast Asia was based on data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) observation instrument on board the NASA's Terra and Aqua EOS satellites, which passes over the region at least four times daily [43].

3 RESULT AND DISCUSSION

3.1 Dynamic variations of CO, NO_x and PM_{10}

Over the period of investigation (1997–2015), monthly concentrations of CO, NO_x and PM_{10} over the northern and central of Malaysian Peninsula showed large variations (Fig. 3). In the northern region, long-term concentrations of CO (0.96 μg/m^3), NO_x (0.051 μg/m^3) and PM_{10} (57.75 μg/m^3) at Perai station were higher than at the other stations. The monthly concentration averages of CO and PM_{10} in the northern region showed small spatial pattern but large coefficient variation (Table 2). There were small decreasing trends of CO and PM_{10} at a 95% confidence interval in the northern region. Meanwhile, the monthly NO_x average concentration varied spatially with a 16.99%–34.27% coefficient variation. The MK test at 95%

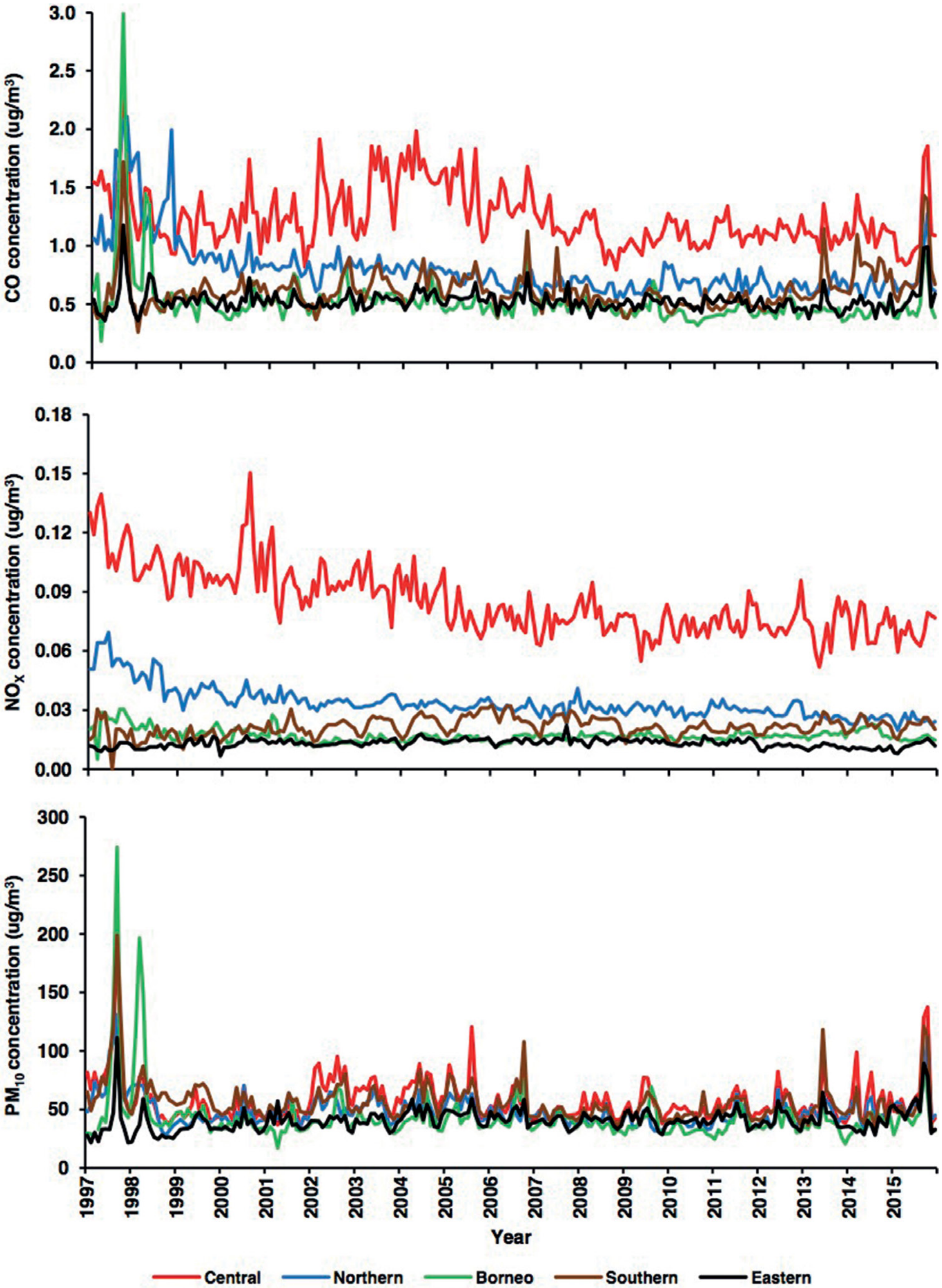

Figure 3: Monthly mean concentrations of CO, NO_x and PM_{10} in each region in Malaysia over the period between 1997 and 2015.

Table 2: Pollutant concentrations (minimum, maximum and mean) (in µg/m^3), coefficient variations (CV) and 95% confidence interval trends for the measurement period between 1997 and 2015 at 20 air quality monitoring stations across Malaysia.

Region	Minimum			Maximum			Mean			CV			95% confidence interval trend		
Norther Pen.	CO	NO$_x$	PM$_{10}$	CO	NO$_x$	PM$_{10}$	CO	NO$_x$	PM$_{10}$	CO	NO$_x$	PM$_{10}$	CO	NO$_x$	PM$_{10}$
• Perai	0.57	0.032	33.03	2.11	0.078	131.00	0.96	0.051	57.75	24.32	16.99	26.09	(–0.002, –0.002)	(–0.000, –0.000)	(–0.050, –0.065)
• Kangar	0.30	0.005	19.00	1.03	0.035	87.00	0.70	0.021	41.52	19.66	33.40	26.65	(–0.001, –0.000)	No trend	(0.000, –0.015)
• USM	0.40	0.012	20.00	1.78	0.054	118.00	0.66	0.027	38.51	22.85	34.27	30.40	(–0.001, –0.001)	(–0.000, –0.000)	(0.000, –0.010)
• Ipoh	0.40	0.017	30.00	1.30	0.047	116.00	0.64	0.026	48.45	17.76	17.09	25.53	No trend	(0.000, 0.000)	(0.025, 0.011)
Central Pen.															
• Port Klang	0.58	0.032	30.00	2.71	0.137	214.00	1.30	0.072	68.79	24.13	21.69	32.84	(–0.002, –0.001)	(–0.000, –0.000)	(–0.037, –0.056)
• Petaling Jaya	0.98	0.076	27.00	2.68	0.314	199.00	1.64	0.125	53.87	23.93	24.64	34.23	(–0.006, –0.005)	(–0.000, –0.000)	(–0.044, –0.058)
• Shah Alam	0.53	0.032	22.00	2.34	0.095	172.00	1.00	0.063	53.61	28.63	15.96	37.61	(–0.001, –0.000)	(0.000, 0.000)	(0.031, 0.011)
• Cheras	0.57	0.032	29.62	2.03	0.105	116.00	1.04	0.065	52.25	24.60	18.46	29.17	(–0.002, –0.001)	(–0.000, –0.000)	(–0.020, –0.042)
Eastern Pen.															
• Jerantut	0.15	0.002	17.00	0.90	0.010	169.00	0.36	0.005	38.13	31.60	26.95	38.01	(–0.000, –0.000)	(0.000, 0.000)	(0.016, 0.000)
• Kuantan	0.09	0.005	17.00	1.08	0.027	104.00	0.40	0.013	33.89	34.03	27.59	31.57	(0.001, 0.001)	(0.000, 0.000)	(00.062, 0.053)
• Kota Bahru	0.41	0.005	17.00	1.71	0.035	92.00	0.78	0.020	41.46	23.55	33.78	26.32	(–0.002, –0.001)	(–0.000, –0.000)	(0.050, 0.041)

Table 2: (*Continued*)

Region	Minimum			Maximum			Mean			CV			95% confidence interval trend		
• Kuala Terengganu	0.31	0.006	24.58	1.19	0.019	84.00	0.55	0.014	50.09	23.55	18.97	20.45	(0.001, 0.000)	(0.000, 0.000)	(–0.027, –0.040)
Southern Pen.															
• Melaka	0.26	0.010	35.00	1.72	0.059	199.00	0.66	0.028	66.90	24.38	31.13	28.39	(0.001, 0.000)	(0.000, 0.000)	(–0.035, –0.049)
• Muar	0.36	0.008	21.00	1.90	0.035	119.00	0.67	0.022	50.75	34.74	24.92	29.74	(0.000, 0.000)	(0.000, 0.000)	(–0.028, –0.046)
• Seremban	0.31	0.010	27.00	2.22	0.029	130.00	0.62	0.021	45.35	37.49	13.68	31.61	No trend	(0.000, 0.000)	(0.001, –0.007)
• Kota Tinggi	0.21	0.001	27.67	0.90	0.020	121.18	0.38	0.010	46.80	36.83	52.23	28.91	(0.002, 0.002)	(0.000, 0.000)	(–0.093, –0.116)
Malaysian Borneo															
• Kuching	0.18	0.005	20.00	3.00	0.052	274.00	0.58	0.020	40.85	48.70	33.64	56.11	(-0.001, –0.000)	No trend	(–0.002, –0.017)
• Bintulu	0.19	0.008	17.00	1.07	0.025	106.00	0.45	0.017	46.88	27.34	16.73	31.42	(0.000, 0.000)	(0.000, 0.000)	(–0.035, –0.053)
• Miri	0.24	0.010	15.00	0.98	0.022	437.00	0.98	0.015	39.63	26.88	17.25	91.99	(–0.001, –0.001)	(–0.000, –0.000)	(–0.031, –0.044)
• Kota Kinabalu	0.21	0.003	19.00	1.80	0.025	188.00	0.46	0.014	39.19	35.95	29.95	40.51	(0.000, 0.000)	(0.000, 0.000)	(–0.032, –0.042)

confidence interval trend also showed decreasing trends at Perai and USM stations, a slightly increasing trend at Ipoh station and no trend at Kangar.

The central region had the highest pollutant concentration in Malaysia. The monthly concentration of air pollutants showed small spatial variations except for PM_{10} (coefficient variation between 29.17% and 37.61%). A small and insignificant trend of CO and NO_x could be observed in all stations in the central region. However, for PM_{10}, a significant increasing trend was observed in Shah Alam, while other stations showed decreasing trends. Petaling Jaya station was considered a pollutant hots pot for CO and NO_x in the country, with the highest average concentrations of 1.64 μg/m^3 and 0.125 μg/m^3, respectively. Meanwhile Port Klang had the highest average concentration of 68.79 μg/m^3, indicating a hot spot area for PM_{10} pollution.

In southern region, the highest mean concentrations of CO, NO_x and PM_{10} were observed at Melaka station with 0.66 μg/m^3, 0.028 μg/m^3 and 66.90 μg/m^3, respectively. The sideway trends of pollutants showed significant spatial variation of pollutants, with large coefficients of variation for CO (24.38%–37.49%), NO_x (13.68%–52.23% and PM_{10} (25.39%–31.61%). The southern region showed decreasing trends of PM_{10} and an insignificant trend of NO_x. Meanwhile, insignificant increasing trends for CO were observed in all stations in the region except Seremban station, which showed no trend.

On the contrary, the eastern region can be considered the least polluted area, though the monthly mean concentrations of CO, NO_x and PM_{10} showed large variations. Kota Bahru showed the highest average concentrations of CO (0.78 μg/m^3) and NO_x (0.020 μg/m^3). The pollutant coefficient variations over the eastern region were greatly varied: CO (23.55%–34.03%), NO_x (18.97%–33.78%) and PM_{10} (20.45%–38.01%). The highest mean concentration of PM_{10} was observed at Kuala Terengganu station with 50.09 μg/m^3. With the exception of Kuala Terengganu station, the PM_{10} pollution trends were increasing in all other stations. For other pollutants (CO and NO_x), there were no significant trends observed in all stations.

Over the Malaysian Borneo region, the pollution levels are relatively low in comparison with the Malaysian Peninsula, though the monthly average concentrations of pollutants varied with large coefficient variations from 31.42% to 91.99% (PM_{10}), 26.88% to 48.70% (CO) and 16.69% to 33.64% (NO_x), respectively. Significant decreasing trends of PM_{10} were observed in all stations at 95% confidence interval trend, though similar trends were not observed for CO and NO_x. In September 1997, this region had the highest concentration of PM_{10} (436.8 μg/m^3) ever recorded in Malaysia, primarily due to the intense biomass burning in Indonesian Borneo of Kalimantan as previously described [31,35,38].

3.2 Associated sources of air pollutants

Air quality data for the period between 1997 and 2015 were further evaluated to determine the pollutant potential sources and also to assess the roles of the monsoons and the El Niño event. The highest pollutant averages in 1997 and 2015 occurred between September and November. The significant emission of dust particles and gaseous pollutants into the atmosphere is attributed to the large biomass burning in the region and coincidence with the long dry spell in the region due to the El-Niño event. During non-El Niño or weak El Niño events, high pollutant concentrations due to trans-boundary pollution from large biomass burning in Indonesia were also observed over the Malaysian Peninsula in September and October between 2011 and 2014. In such cases, strong winds during the southwest monsoon, which generally occur from June to October, accelerated the pollutant transport towards Peninsular

Malaysia, thus enhancing the trans-boundary transport and distribution of pollutants over the region [34].

Analysis of the air mass transport by using backward trajectories in October and November 2015 for all regions in Malaysia identified biomass burning in Sumatera, Indonesia, as an associated source of trans-boundary air pollution. During the southwest monsoon, in most cases, the air mass trajectories come from the same direction and sometimes originated from different locations (Fig. 4). From satellite evidence, thick haze in most part of Malaysian Peninsula during this period was caused by the long-range trans-boundary pollution originated from Sumatera, Indonesia. Measurement records of the highest concentration values of PM_{10} during this period have exceeded the Malaysian Air Quality Guideline Standard (150 $\mu g/m^3$), while in the northern region, Kangar station recorded 338.08 $\mu g/m^3$; central region – Port Klang, 346.43 $\mu g/m^3$; southern region – Seremban, 353.83 $\mu g/m^3$; and eastern region – Kuantan, 275.25 $\mu g/m^3$, respectively. In Malaysian Borneo during this period, PM_{10} pollution levels in all monitoring stations were not as serious as those in Malaysian Peninsula, but records indicate that the highest PM_{10} concentration of 436.77 $\mu g/m^3$ was recorded at Miri monitoring station in September 1997. Based on the calculated backward trajectories during this period in Miri station, the air mass transports originated from different locations in Kalimantan Indonesia. The climatic conditions during this period were extremely dry and large hot spots of biomass burning were detected in the southern area of Kalimantan (Fig. 4). These analyses and assessments affirmed that biomass burning and long-range trans-boundary pollution from Indonesia were largely responsible for the seasonally high pollutant concentrations in all regions in Malaysia as previously mentioned in other studies [25,29–37]. In addition to the long-range transport of air pollutants, additional anthropogenic sources such as the emission from motor vehicles and local industrial activities were also associated with high CO and NO_x especially in urban and industrial areas such as in the central and northern peninsula, as supported by earlier studies at selected monitoring stations [29,31,44].

The occurrence of El Niño phenomenon is common to this region [30,32,34,35,38]. Since 1997, seven El Niño events were recorded, with the strongest intensities in 1997 and 2015 (Fig. 5). Coincident with the occurrence of El Niño events in 1997, 2002, 2009 and 2015, large hot spot areas of biomass burning were detected over south ASEAN (Association of South East Asia Nations), but mostly in Sumatera and Kalimantan. During these events, the persistently high concentrations of PM_{10} and other primary pollutants such as CO and NO_x were notably observed in all regions of Malaysia. These coincident observations were primarily due to long-range trans-boundary pollution from the large and intense biomass burning in Indonesia [30,33]. During the super El Niño events in 1997 and 2015, significantly higher concentrations of PM_{10} than usual were observed in USM, Shah Alam, Jerantut, Seremban and Kuching in 2015 El Niño and Miri in 1997. Higher concentrations of pollutants during the El Niño events were the amplifying effects of this phenomenon [35,38,45]. During El Niño events, the lower atmosphere is extremely dry, coupled with high ambient temperature [30,31,34,45]. These conditions lead to severe drought and has become an important accelerator of large-scale biomass burning in the south ASEAN region [30,45].

4 CONCLUSION

This study has analysed the long-term trends of air pollution in Malaysia using air quality datasets from 20 monitoring sites across Malaysia, which spanned from 1997 to 2015. For the trend analysis, the monitoring stations were divided into five regions, namely the northern, central, eastern and southern of the Malaysian Peninsula and Malaysian Borneo. Based

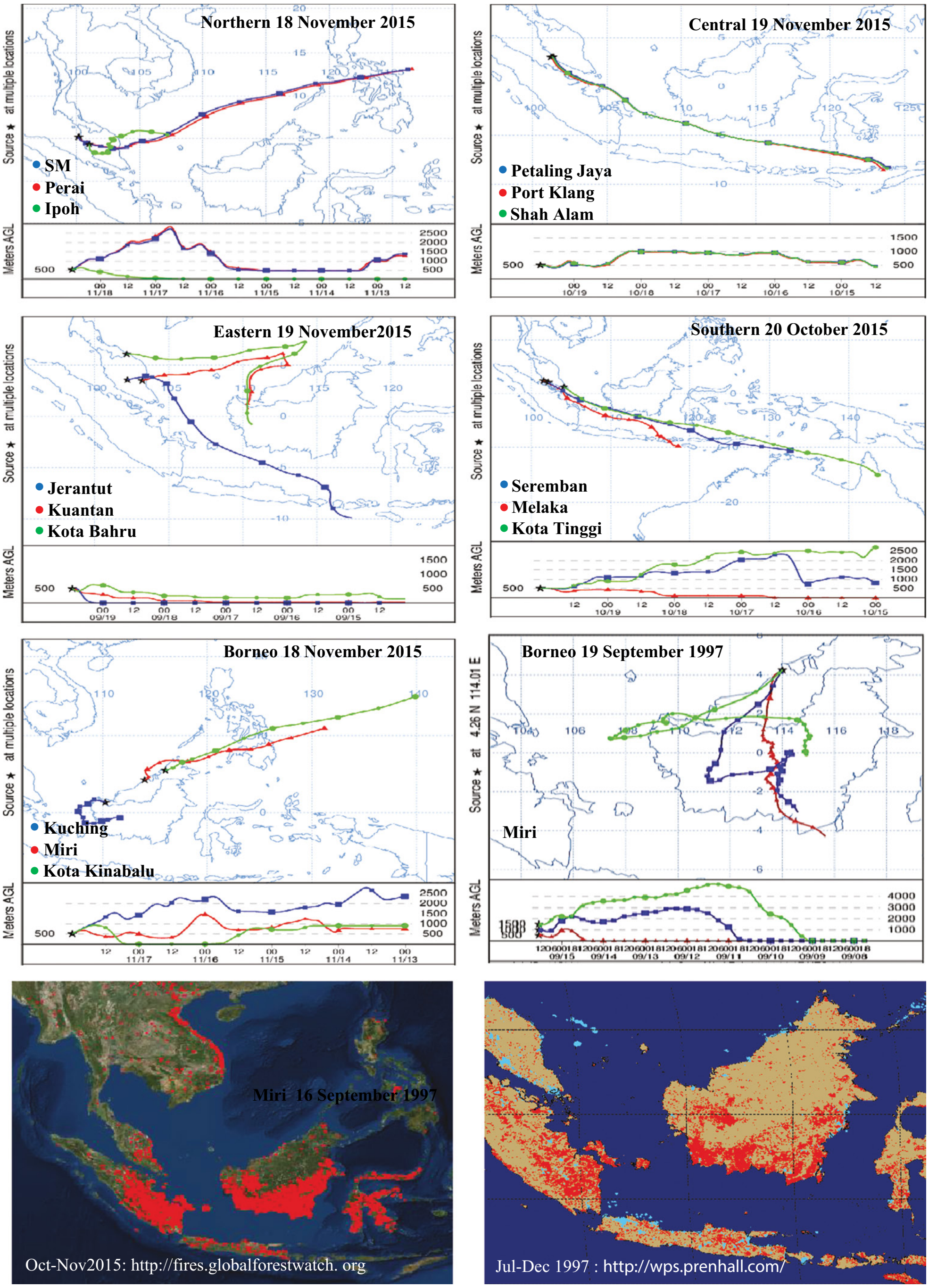

Figure 4: Backward air mass trajectory analysis (first to third panels) and MODIS fire records between October–November 2015 (bottom-left panel) and July–December 1997(bottom-right panel) in Southeast Asia.

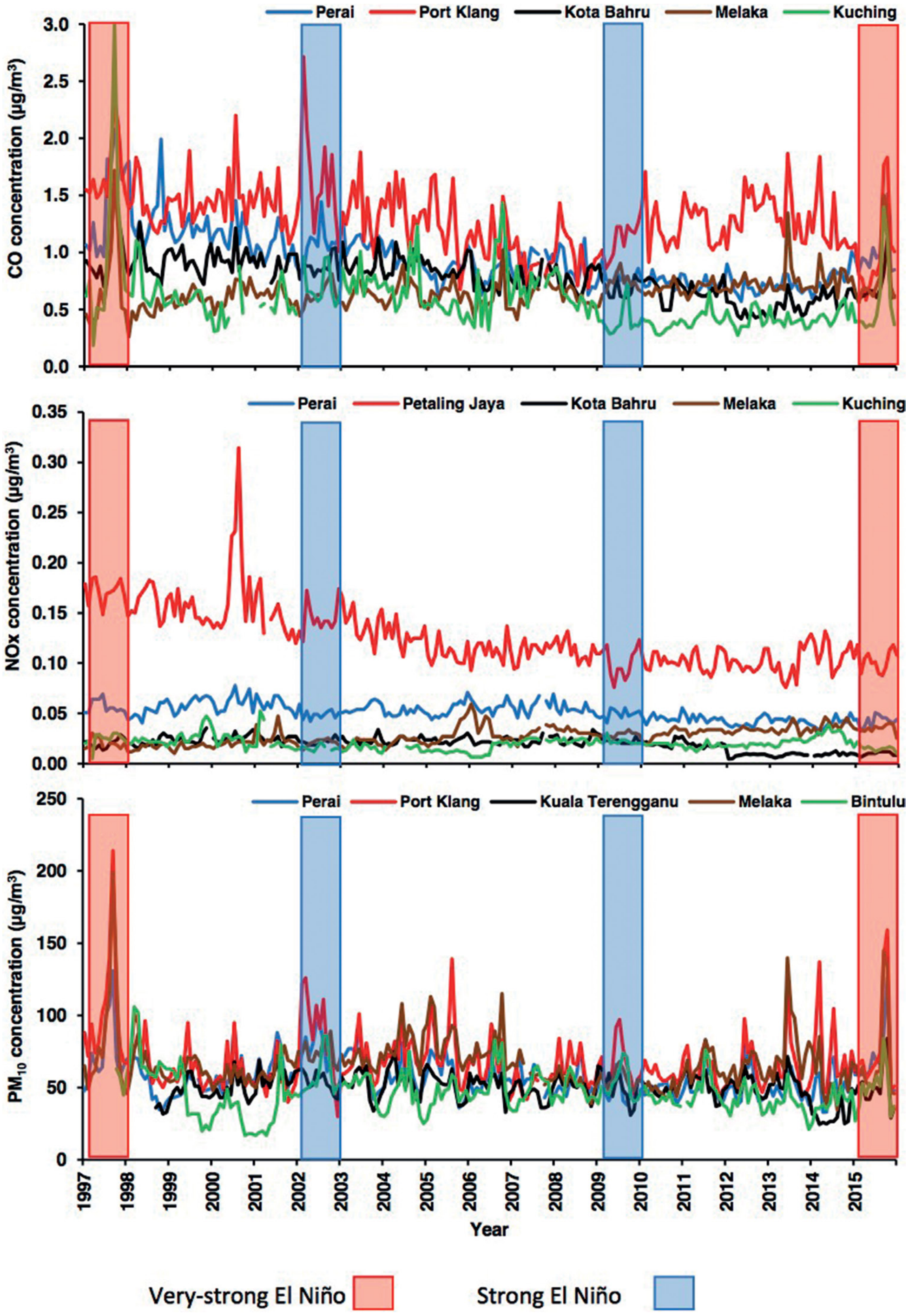

Figure 5: Time-series analysis for selected monitoring stations (1997–2015) with El Niño events.

on the long-term measurements, CO pollution in Malaysia has shown small but decreasing trends in the northern and central regions, while the southern region has shown small but increasing trends. Meanwhile, NO_x pollution has shown increasing trends in the eastern and southern regions but decreasing trend in the central region. For PM_{10} pollution, all regions have shown mixed trends for the entire period of long-term measurement. The highest level of pollution was observed during the southwest monsoon in September 1997 and between September and October in 2015. Based on HYSPLIT model results, biomass burnings in Kalimantan and Sumatera of Indonesia were found to be the associated sources of pollution in Malaysian Borneo and Peninsular Malaysia regions, respectively. This is to conclude that high level of pollution in Malaysia is spatially and temporally varied, with strong influence of long-range trans-boundary pollution due to the large and intense biomass burning Indonesia. The extremely dry season and warm ambient air temperatures during the El-Niño events in 1997 and 2015 played important roles in accelerating forest fires in the region and delayed the precipitation wash-off of pollutants. Notably, the daily highest PM_{10} and CO concentrations at all stations in all the five regions were likely linked with the El Niño events, but this is less likely for NO_x. Local anthropogenic sources, especially motor vehicles and industrial activities in the northern and central regions, were likely the associated sources for the relatively higher average concentrations of CO and NO_x.

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