Title: Investigation of association between smoke haze and under-five mortality in Malaysia, accounting for time lag, duration, and intensity

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Abstract

Background:

Studies on the association between smoke haze (hereafter “haze”) and adverse health effects have increased in recent years due to extreme weather conditions and increased occurrence of vegetation fires. The possible adverse health effects on under-five children (U5Y) is especially worrying due to their vulnerable condition. Despite continuous repetition of serious haze occurrence in Southeast Asia, epidemiological studies in this region remained scarce. Furthermore, no study had examined the association accounting for three important aspects (time lag, duration, and intensity) concurrently.

Objective:

This study aimed to examine the association between haze and U5Y mortality in Malaysia, considering time lag, duration and intensity of exposure.

Methods:

We performed a time-stratified case-crossover study using a generalized additive model to examine the U5Y mortality related to haze in 12 districts in Malaysia, spanning from 2014 to 2016. A “haze day” was characterized by intensity (based on concentrations of particulate matter (PM)) and duration (continuity of haze occurrence, up to 3 days).

Results:

We observed the highest but non-significant odds ratios (ORs) of U5Y mortality at lag 4 of Intensity-3. Lag patterns revealed the possibility of higher acuteness at prolonged and intensified haze. Stratifying the districts by 95th-percentile of PM distribution, the “low” category demonstrated marginal positive association at Intensity-2 Duration-3 (OR: 1.210 (95% confidence interval: 1.000, 1.464)).

Conclusions:

We found null association between haze and U5Y mortality. The different lag patterns of the association observed over different duration and intensity suggest consideration of these aspects in future studies.

Keywords: Fire; Smoke; Haze; Children’s health; Mortality; Southeast Asia

Key messages:

- Smoke haze due to vegetation fires is a major public health concern in the Southeast Asian region.
- We observed null association between smoke haze and under-five mortality in Malaysia (2014-2016), with haze events defined by considering the duration, intensity, and time lag.
- Lag pattern varied over different duration and intensity; more acute odds ratios (ORs) of under-five mortality were observed at longer duration and higher intensity.
- Upon stratification into "low" and "high" areas with cut-offs at 95th-percentile of particulate matter (PM10) distribution, "low" areas demonstrated higher ORs of under-five mortality on haze days with Intensity-1 and Intensity-2, while "high" areas demonstrated the opposite pattern.

Introduction

Smoke haze (hereafter "haze"), an extreme air pollution event during which visibility is lowered due to smoke plumes released from vegetation fires, has caught international attention due to the increasing occurrence, intensity, and duration of such fires[1,2]. These fires can be exacerbated due to human factors[3,4] favored by climate conditions[3,5,6], while the main contributing factors may vary in different regions[5]. In the Southeast Asian region, severe smoke haze episodes have been occurring once every few years, accompanied by climate events such as El-Niño[7,8], and sometimes Indian Ocean Dipole[3,4]. In addition to local air pollution, such episodes have deteriorated the air quality across countries in the region[9,10].

Smoke plumes released from vegetation fires contain a complex mixture of harmful air pollutants, such as particulate matter (PM), inorganic gases, and hydrocarbons[11]. Over the past decades, Southeast Asia has had experienced several severe haze episodes[3] due to forest and peatland fires[12]. Amidst these major episodes, studies on the health effects of haze in the Southeast Asia remain scarce[13,14]. These studies were mostly conducted in Malaysia[15–17], Singapore[18], Indonesia[19] and Thailand[20], but only few which included children category (age 0-14[16,20], 0-18[15]) and one which examined the association in infants (age <1)[17]. While a majority of the studies from North America[21–26], Europe[27] and Australia[28–33] showed significant positive associations between haze and adverse health outcomes, there are still apparent inconsistencies[34].

Evidence from previous studies have revealed the health effects of haze in populations over different age groups. Whereas most of the studies have reported increased risk of respiratory and cardiovascular health effects among population of all ages[22,25], elderly[22,23], and adults[28], several studies also demonstrated the importance to look into health risks among children[16,22,35], especially the younger ones[36], due to their under-developed physical and immunological conditions, and complex immune maturation during childhood[37]. The WHO (World Health Organization) reported the global under-five (U5Y) mortality rate of 39 deaths per 1000 live births in 2018[38]. In that year, 5.3 million deaths were of U5Ys, which accounts for a large proportion (85%) of global children (ages 0-14 years) mortality[38]. Adverse health effects among the U5Ys due to exposure to air pollution[39,40] and biomass burning pollutants[41] have been reported in some studies, but the health effects related to haze remains unclear.

There are several approaches in investigating the health effects related to haze. These include defining a specific period as a haze episode, and compare the health effects with before or after this period[22], or defining haze days based on PM concentrations (absolute measures[16] or percentiles[32] of PM distribution). Some studies examined by haze intensity[27] and duration[23,27,35]. There has been no study which examined the association by accounting for duration, intensity, and time lag concurrently. Furthermore, time lag is commonly used to show the lagged effects of exposure to air pollution[42], but it could not clarify the effects of temporal continuity of haze occurrence.

The present study aimed to examine the association between haze and U5Y mortality in Malaysia, accounting for time lag, duration, and intensity of exposure. Haze days were defined according to intensity (PM10 (PM with $\leq$10μm in diameter) concentration) and duration (continuity of haze occurrence).

Methods

Study settings

Malaysia consists of 16 states (13 states and 3 federal territories) which are sub-divided into administrative districts. This study included a total of 12 districts (**Figure 1**), which were selected based on the population size ($\geq$500 000) and available monitoring station, from 2014 to 2016. Although 13 districts fulfilled the selection criteria, one district (Kota Kinabalu) was excluded because the PM10 concentration in this district throughout the study period was below 100µg/m^3 (maximum: 92.5µg/m^3) – "haze day" could not be defined for Intensity-3 and Intensity-4. Population information based on population census 2016 was used[43]. A bootstrapping method was applied to obtain the overall U5Y mortality rate of the 12 districts, with 95% confidence intervals (CIs).

Data

We used U5Y mortality data which were obtained from the Family Health Development

Division, Ministry of Health Malaysia. Causes of death were classified based on International Classification of Diseases, 10th Revision (ICD-10). All natural deaths (hereafter “all-cause”) (ICD-10: A00-R99) were included; we excluded deaths of accidental/traumatic, and external causes (ICD-10: S00-Y98).

We obtained the air pollutant data from the Air Quality Division, Department of Environment Malaysia. Data from the monitoring station in each district were used (**Figure 1**). We averaged the hourly PM10 data into daily (24-hour) mean concentration, whereby data on days with 4 or more hours of missing values were regarded as missing data. For these days, before-after-mean imputation method was applied to impute the daily PM10 concentration. The number of days with missing data were relatively small (ranged 2.1-7.4%). For districts whereby more than one monitoring stations are available, Pearson’s correlation and time trend of PM10 concentrations were examined. Our examination revealed relatively high correlations (lowest at r=0.87) (data not shown) between the stations, and the station with least missing data was selected. Data for sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO) were obtained from the same monitoring stations. An exception of CO data for station CA0011; CO data from station CA0025 (the nearest station to CA0011) was used due to incomplete data of CO from station CA0011.

We obtained daily mean temperature and relative humidity (RH) data from the Department of Environment Malaysia. These data were averaged over the whole state of each district.

Data on influenza for Malaysia were extracted from the FluNet (www.who.int/flunet), Global Influenza Surveillance and Response System (GISRS) of the WHO. A week was defined as an influenza epidemic week when the influenza cases within that week were more than the 90th percentile of the total distribution throughout the study period per district.

Definition of haze day

A day was defined as haze day based on duration and intensity of PM10 concentration. Haze day definition based on PM10 concentration at 100µg/m^3 has been used in previous study in Malaysia[16]. However, we also considered the guidelines and standards for PM10, both global and local; WHO guidelines (50µg/m^3), current Malaysia National Ambient Air Quality Standard (NAAQS) (100µg/m^3), and Malaysia NAAQS in 2015 (150µg/m^3). As this is the first study to examine health effects of haze considering duration and intensity in addition to time lag, we decided to include Intensity-2 using "PM10>75µg/m^3", which is a level in between the WHO guideline and Malaysia NAAQS.

Thus, we defined the intensities as: Intensity-1 (PM10>50μg/m^3), Intensity-2 (PM10>75μg/m^3), Intensity-3 (PM10>100μg/m^3), and Intensity-4 (PM10>150μg/m^3).

Duration up to three consecutive days were defined for days with PM10 exceeding 50μg/m^3. Each first day with PM10>50μg/m^3 was labelled as "Duration-1"; two consecutive days as "Duration-2", and three or more consecutive days as "Duration-3".

Statistical analysis

We used a time-stratified case-crossover design, which allows adjustment for long-term trends and seasonality. We matched the day-of-week from each month and year as a stratum to match controls for each case[44]. We applied a generalized additive regression model (GAM) with Poisson distribution, and treated district as random effects. Temperature and RH were adjusted for in the model. Based on AIC value and Chi-square test in ANOVA, we did not include influenza epidemic variable in the main model. After examining the health effects based on the definitions, we also examined the lag pattern at each Duration and Intensity. Two types of lag structures were examined: (i) single lag, and (ii) moving average lag, up to 7 days.

All analyses were performed using R (R Core Team 2018). Results are presented as odds ratio (OR), with 95% CI, of U5Y mortality at each Duration and Intensity of haze days.

Sensitivity analysis

We conducted a few sensitivity analyses to examine for robustness of our results. First, we included each pollutant into the main model one at a time. Second, we adjusted for influenza epidemic week. Third, we categorized districts with 95th percentile of PM10 concentration >100µg/m^3 as “high”, while those without as “low”, to examine whether such distribution would modify the effects of haze day on U5Y mortality.

Results

The Children Statistics, Malaysia 2017 recorded 2.6 million U5Y children; these represent around 8.2% of the total population in Malaysia[45]. A total of 4256 all cause U5Y mortality was recorded over the 12 districts in Malaysia during the study period. Kota Bharu had the lowest U5Y mortality rate of 7.3, while the highest was recorded in Kuala Lumpur (KL), 8.9 mortality per 1000 live births per year (**Figure 1**). Our bootstrap with 10 000 simulations showed an empirical U5Y mortality rate of 8.2 (95% CI: 7.9, 8.5) per 1000 live births per year.

Table 1 summarizes the information for air pollutants and weather variables. Kuching recorded the lowest daily mean concentration of PM10 with 40.2µg/m^3, while Klang recorded the highest (68.9µg/m^3). Daily mean temperatures were similar among the districts (range between 26.8ºC (Kuantan) to 28.4ºC (Petaling, Klang, Melaka Tengah), while RH ranged 70.3% (Timur Laut) to 85.2% (Kuantan). Time trends of PM10 concentration in each district are shown in **Supplementary Material**. Several peaks of PM10 concentration were observed during February-March in 2014 and 2015, and June-October in 2014, 2015 (highest peaks throughout the study period) and 2016. **Table 2** shows the total number of haze days under each definition. There were fewer number of haze days when longer duration and higher intensity were considered, except for Intensity-4 whereby the number of haze days were same for Duration-1 and Duration-2.

Figure 2 shows single lag patterns over each duration and intensity. Generally, our study showed null association between haze and U5Y mortality at Intensity-1 and 2. At Intensity-3, peak was observed at lag 4 for Duration-1 and Duration-2. Lag pattern at Intensity-1 was different from those at Intensity-2 and 3; there was no obvious peak except for Duration-2, whereby there was a peak at lag 2. Such pattern was more obvious at Intensity-4. On the other hand, moving average lag patterns (**Figure 3)** showed minimal variation. At Intensity-1, higher OR at lag 0-2, 0-3 and 0-4; while at Intensity-2, the ORs were almost plateau, except a lower OR at lag 0-1. Intensity-3 showed that OR of U5Y mortality was highest at lag 0-1.

In the sensitivity analyses (**Figure 4**), adjustment for each pollutant and influenza epidemic into the main model showed no difference in the ORs. However, the ORs showed different pattern for “low” and “high” categories over different duration and intensity. “Low” category showed higher OR at lower intensities (Intensity-1 and Intensity-2), while “high” category showed higher OR at higher intensities (Intensity-3 and Intensity-4). In “low” category, higher ORs were observed at Intensity-2, whereby Duration-3 recorded marginal positive OR (OR: 1.210 (95% CI: 1.000, 1.464)) of U5Y mortality on haze day. Interestingly, Intensity-4 showed the lowest ORs among all intensities for the “low” category. In “high” category, higher ORs were observed at Intensity-3 and Intensity-4, whereby the ORs were almost similar. The ORs were around null at Intensity-1 and 2.

Discussion

Our findings showed null association between smoke haze and U5Y mortality. Significant positive association was only observed at Duration-3 Intensity-2 of “low” category (OR: 1.210 (95% CI: 1.000, 1.464)). Lag patterns revealed that at longer duration, higher OR of U5Y mortality occurred at shorter lags, though variation was minimal. The lag patterns at Intensity-2 and Intensity-3 were similar. Districts with "low" exposure (95th percentile of PM10 concentration $\leq$100µg/m^3) were sensitive towards haze days defined at Intensity-2, while those with "high" exposure showed higher ORs at Intensity-3 and Intensity-4.

The ORs of U5Y mortality were increased at shorter lags in two conditions: (1) over increasing duration, and (2) over increasing intensity (except for Intensity-4). OR increment over increasing duration was very small, while it is more observable over increasing intensity. However, we observed lower OR of U5Y mortality at the highest intensity (Intensity-4). This is probably due to that the reference category (haze=0, binary), contained days with PM10 concentration exceeding 100µg/m^3, which is a concentration "unhealthy" to the U5Ys. Meanwhile, in countries with relatively lower PM10 trends, health risks were reported even at lower PM10 concentration. For example, concentration at the 99th percentile of PM10 (42µg/m^3, and 47µg/m^3) was used to define a haze event in studies in Australia[31,32]. Besides, the effect estimates and lag patterns at Intensity-2 and 3 were similar, but different from Intensity-1 and 4. This may suggest that haze days with PM10 concentration exceeding 75µg/m^3 and below 150µg/m^3, especially between 100µg/m^3 and 150µg/m^3, is probably the crucial level of exposure among U5Y children in Malaysia during the study period. Furthermore, after adjusting for PM10 in the model as a sensitivity analysis, we observed a small decrease in OR of U5Y mortality at Intensity-4. Such effect became less observable over increased duration. There may be potentially higher PM-attributed risk at days with PM10 concentration exceeding 150µg/m^3, but other hazardous pollutants in the smoke plumes may be of more importance at Intensity-1 to Intensity-3.

In terms of duration, there was an apparent trend of elevated risk, and increased acuteness over prolonged duration. Some studies have taken the approach of examining a "window of high exposure", comparing the health effects during this period and those outside of this period[24]. Such methods may be useful when focusing on an isolated extreme event which occurs at a specific time point. On the other hand, Liu et al. (2017)[23] had examined haze effects on hospital admissions by timing of the occurrence of haze, stratified as 1st to 2nd day, 3rd to 7th day, and 8th or later days, of haze. There were increasing trend of respiratory admission, but decreasing trend of cardiovascular admission, at later timing of haze. In contrast, we defined Duration in a continuous context; every single day of haze (Duration-1), two continuous days (Duration-2), and three or more continuous days (Duration-3). While Liu et al.'s study[23] was able to demonstrate whether which strata of haze days were of higher importance to each type of disease, our approach allows us to observe the health effects over prolonged haze period. In addition, we defined duration based on consecutive days with PM10 concentration exceeding 50µg/m^3. By doing this, each increasing Intensity would perform as a proxy of increasing intensity levels of haze, without sacrificing the information from haze occurrence at the lowest PM10 concentration being considered as "good" air quality (75µg/m^3).

We demonstrated the use of duration in addition to lag. Lag pattern is commonly used in air pollution and health studies[42], to examine existence of harvesting effects, and the delayed time between exposure and onset of disease. By including the duration aspect, we were able to account for both length and continuity of haze occurrence, which could not be clarified merely based on lag. Examining lag up to 7 days is possible regardless of whether PM concentration reaches a specific level of intensity for a few days continuously, but duration depends on the continuity of occurrence. Lag pattern could not explain possible difference in health effect estimates between a "one-day's haze" and "three-days' haze". Acknowledging this aspect is important, as occurrence over prolonged duration of haze may shorten the lag effects, in other words, the health effects might be more acute. Furthermore, there might be some behavioral change towards taking preventive measures when haze occurred continuously for a longer time period, if compared to "one-day's haze" events. Although our study could not prove that prolonged haze increases awareness level, it is plausible due to increased reporting through mass media as the situation persists.

Children is characterized as a susceptible population due to their physico-developmental conditions. Incomplete metabolic systems and immature host defense during growth stages increase their vulnerability to air pollutants. The inflammatory responses in children are different than those in adults[46], and even in different ages among children[37]. Inflammation is one of the pathological pathways due to PM exposure[47,48], and it showed an age dependent trend[37]. In addition, the oxidative potentials of complex mixtures of components from vegetative fires[11,49] cause oxidative stress responses, especially in the respiratory system[49]. Previous studies revealed increased U5Y mortality[40,41] of respiratory outcomes[39,40] due to exposure to PM[39,50,51], and household biomass PM[41]. Only a few studies emphasized the health effects of haze[16] and haze-related PM[22,32], while increase in children (ages 0-14) mortality on lag 2 haze day has been reported[16]. However, null association was observed in current study. This may be due to behavioral change of the public (e.g. reducing outdoor activities)[52], especially the parents or caretakers to whom the U5Ys are dependent on. In Malaysia, warnings and information of haze are usually disseminated to the public through media. In addition, the reduced visibility in the environment due to haze may alert the public about the deteriorated air quality. One study revealed that people with higher level of awareness about haze are more prone to take preventive measures[52]. It is necessary to include more studies on haze-related health effects among U5Y children to elucidate the association.

There was no difference in the association when we added influenza into the main model. Although there are other major infectious diseases in Malaysia, such as dengue fever and malaria, these are less prevalent in children (i.e. only 10% were children dengue fatality[53], and 0.030/1 000 000 mortality rate from malaria[54]). Instead, a study in Malaysia suggested high risks of influenza mortality among children[55], especially the U5Ys[56]. In Malaysia, major causes of death among the children (ages 0-14) include septicemia, pneumonia, meningitis, and chronic lower respiratory diseases, besides another two main factors (i.e. certain conditions originating in the perinatal period and congenital anomalies[57,58]). However, due to limitation of available data, we only managed to adjust for using influenza data but none from other infectious diseases. Future studies may consider different infectious diseases to improve the sensitivity tests.

To the best of our knowledge, this is the first study which examined association of haze and U5Y mortality accounting for duration, intensity, and time lags concurrently. Although there is one study which examined this as sensitivity analysis[23], there are some differences in approaches for definition of haze, in terms of duration and intensity. Our approach emphasized the continuity of haze occurrence, and at different intensities of haze. This demonstrates a clear and concise delivery of information, i.e. lag pattern could be observed for each duration and intensity concurrently. Moreover, we address the important implication of characterizing “haze” by accounting for the three aspects. Information about “haze” with warning and alert over Southeast Asian region is available for the public (http://asmc.asean.org/asmc-alerts/). Whereas in Malaysia, air pollution index (API) is commonly reported to communicate “haze” risks to the public (http://apims.doe.gov.my/public_v2/api_table.html). Several studies in Singapore attempted to examine health risks based on pollutant standard index (PSI)[18,59]. One shortcoming of using these indexes is that, the main pollutant attributing for the health outcomes is unknown (i.e. only the max index of monitored pollutants is reported as representative index value). In such case, the underlying pathophysiological mechanisms of the air pollution could not be elucidated via cross-discipline approaches. Besides, they do not account for the continuity of haze occurrence (i.e. duration). Understanding the duration in addition to the intensity could facilitate decisions on preventive measure. For example, the Malaysian Meteorological Department issues warnings of heatwaves, which are characterized by extreme temperatures and the duration (https://www.met.gov.my/iklim/kemarau/statusgelombanghaba?lang=en). Our approach adds merit for understanding the severity and condition of "haze" compared to the use of API, as API only accounts for information over shorter time (within 24 hours).

Nonetheless, there are a few limitations which we would like to address. First, we used absolute measures of PM10 concentrations to define "haze day". Although this had allowed us to view in the perspective of future policy decision on air quality, the number of haze days may be small for certain concentrations in some districts. As such, we excluded one district due to unavailable days with PM10>100µg/m^3. Had we used percentile, number of haze days and level of concentration in each district would not be much of a concern, but then it would be difficult to interpret for future policy on air quality. Second, we used the ground measured data for PM10 concentration. There might be exposure misclassification as we could not verify the personal exposure. We attempted to minimize such possibility by restricting the study area to each district matched to the monitoring station. Third, we imputed the PM10 concentrations for days with missing values. We used this method as it is among the simplest and probably suitable under the assumption that the difference of concentration is least within closest days. Finally, we could not verify neither the emission type, nor whether is it local or transboundary sourced. A study in upper northern Thailand has demonstrated the use of PM10 concentration coupled with number of hotspots to characterize a haze event due to vegetation fires (i.e.

burning activity)[20]. The approach would be useful if the study area consists local burning issues, but haze in Malaysia is mainly characterized by transboundary sources[10].

In conclusion, we observed null association between haze and U5Y mortality. Despite so, it is worth highlighting the importance of considering duration and intensity in defining “haze day”. Future studies should also consider comparable the three aspects (i.e. time lag, duration and intensity) in haze definition and exposure assessment to facilitate quantification of the haze-related health effects over Southeast Asia.

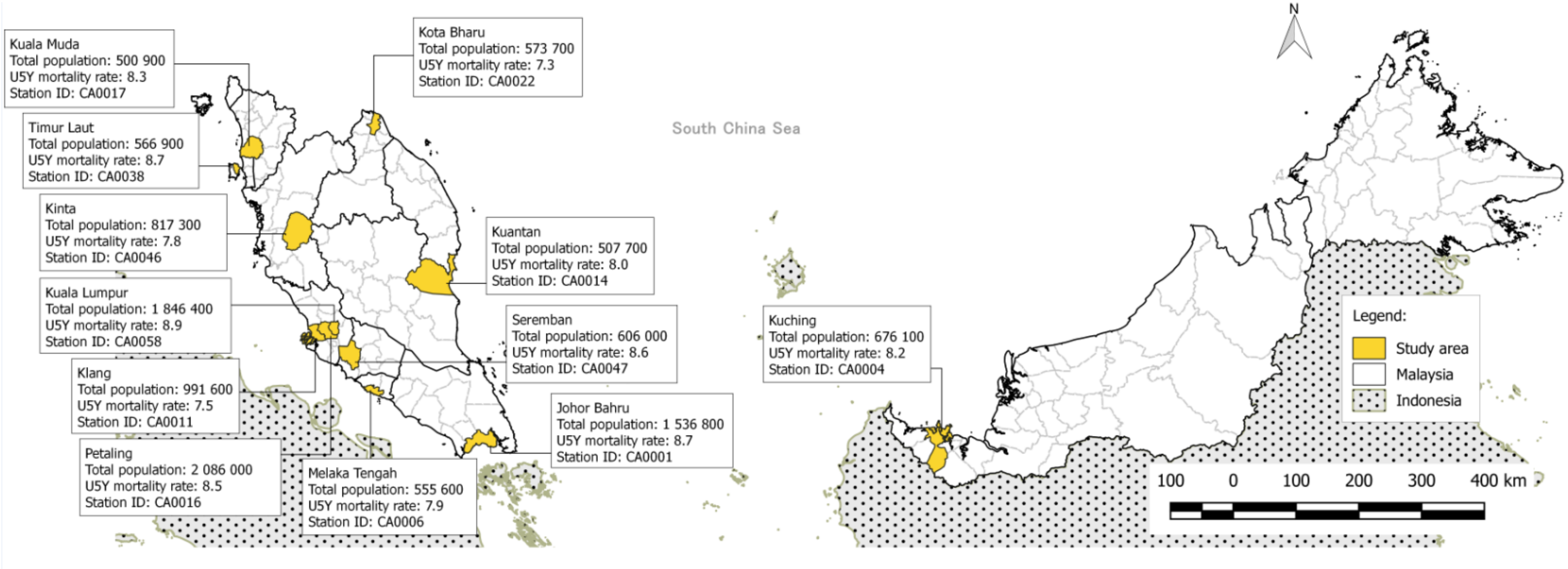


Figure 1. Map of Malaysia and location of the 12 districts included in this study.

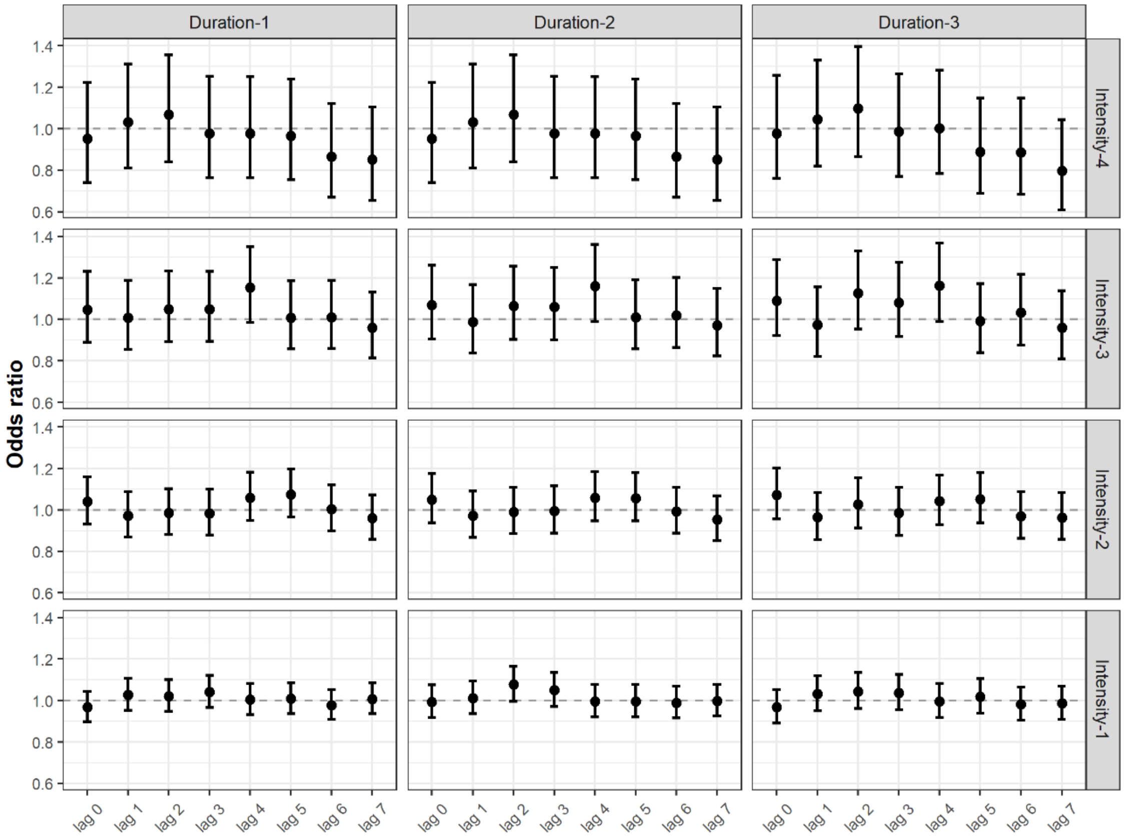


Figure 2. Single lag pattern over different duration and intensity.

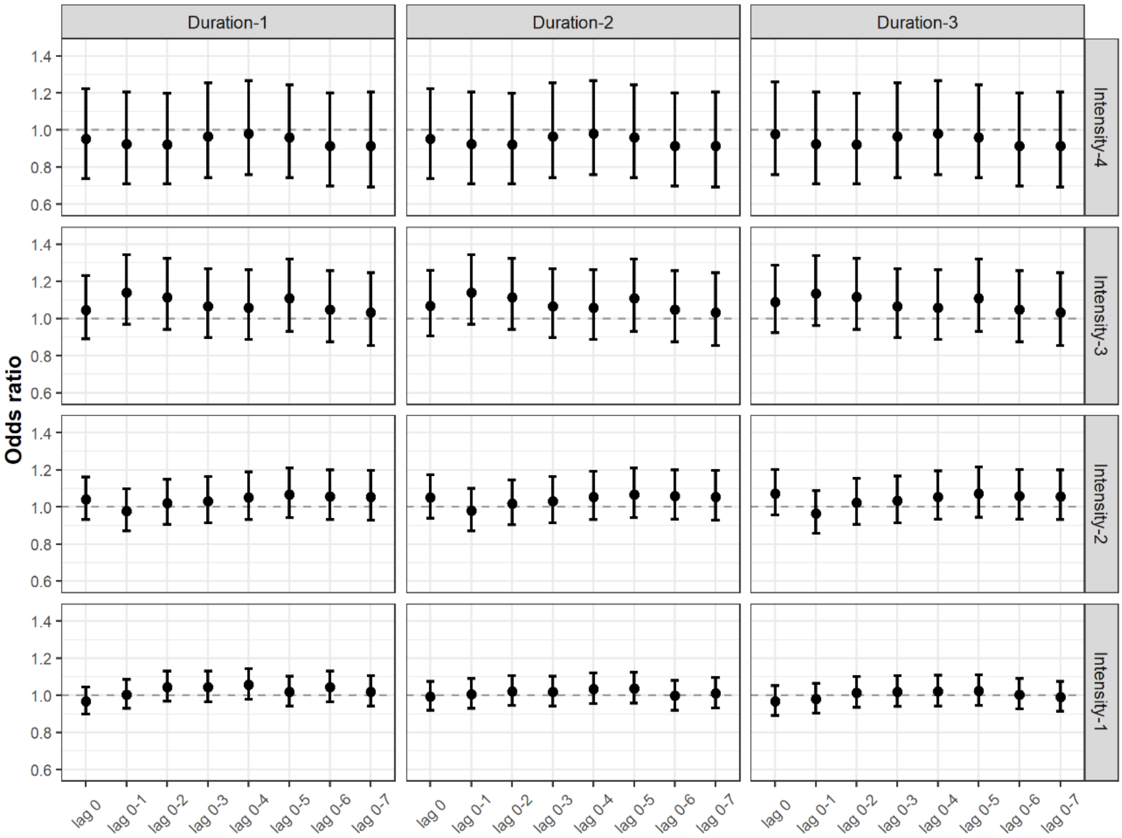


Figure 3. Moving average lag pattern over different duration and intensity. Note: Lag 0 from single lag is displayed.

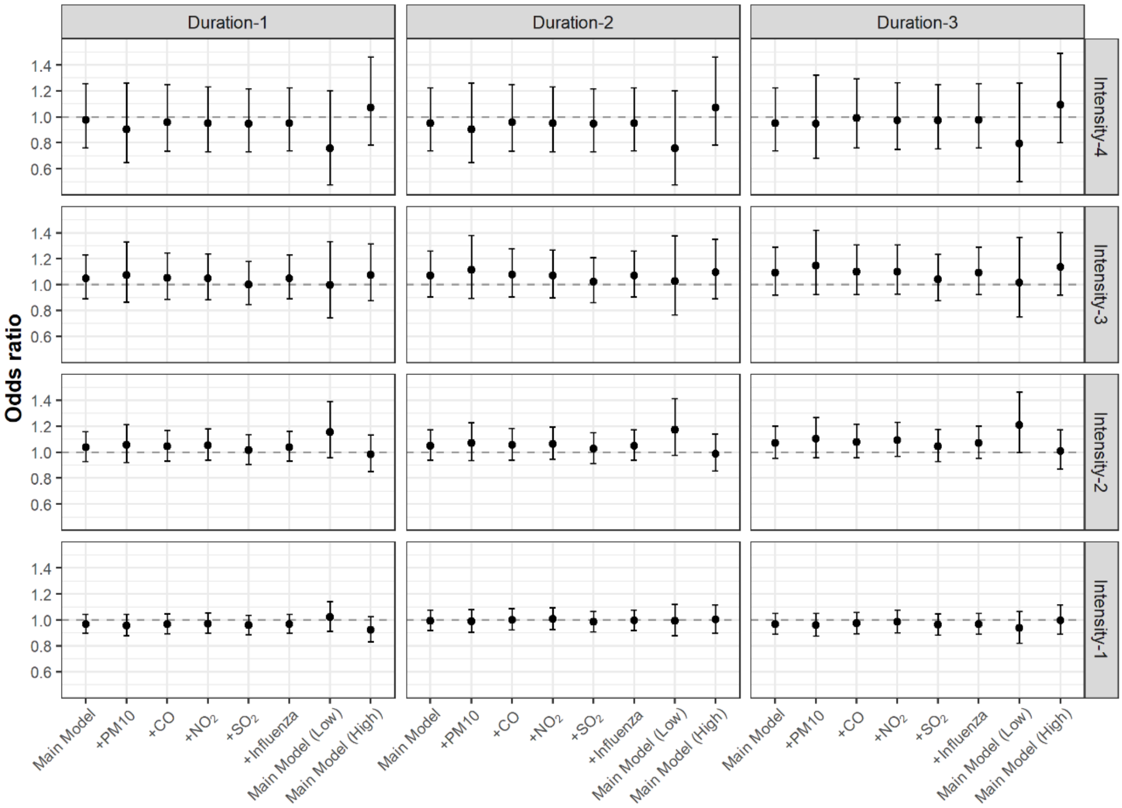


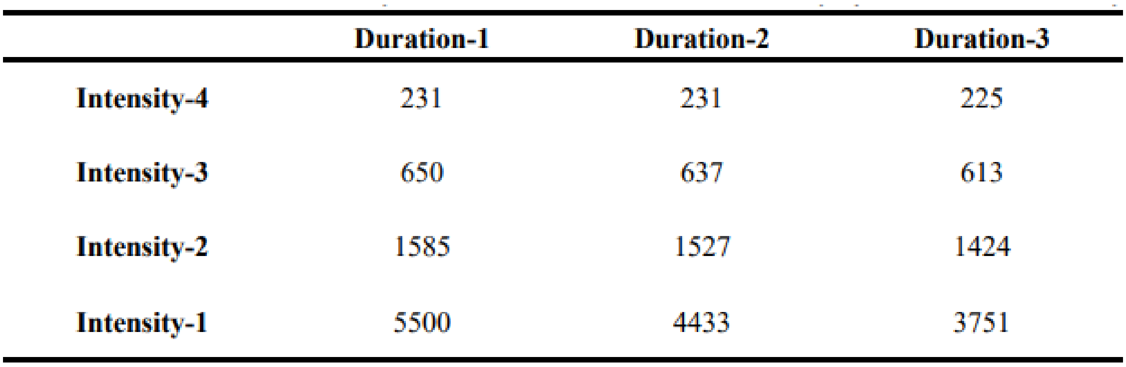
Figure 4. Sensitivity analyses. Note: +PM10, +CO, +NO_2, and +SO_2 indicate adjusting for each pollutant in the main model one at a time; +Influenza indicates adjusting for influenza epidemic in the main model; Main model (Low) and Main model (High) indicate main model with districts of which the 95th percentile of PM10 distribution was below and above 100µg/m^3, respectively.

Table 1. Characteristics of each district in Malaysia from 2014 to 2016.

District	Total population ('000)[a]	Total live births (2016)[a]	Mortality rate (per 1000 live births per year)[b]	Station ID	PM10[c] (μg/m^3)	SO_2[c] (ppb)	NO_2[c] (ppb)	CO[c] (ppm)	Temperature[c] (°C)	Relative humidity[c] (%)
Kuala Muda	500.9	7746	8.3±1.2	CA0017	66.9 (24.0)	1.4 (0.9)	9.1 (3.0)	0.884 (0.259)	28.1 (1.2)	77.0 (8.6)
Timur Laut	566.9	5008	8.7±1.5	CA0038	50.2 (25.3)	1.4 (1.0)	11.0 (2.7)	0.717 (0.330)	27.4 (1.2)	70.3 (9.2)
Kinta	817.3	10 692	7.8±1.0	CA0046	50.7 (25.5)	1.4 (0.8)	10.0 (3.7)	0.679 (0.268)	28.3 (1.1)	75.3 (6.7)
Kota Bharu	573.7	12 147	7.3±0.9	CA0022	51.2 (21.6)	0.8 (0.9)	4.6 (1.6)	0.705 (0.269)	27.3 (1.4)	79.0 (5.3)
Kuantan	507.7	9128	8.0±1.1	CA0014	40.4 (20.3)	1.3 (0.8)	7.3 (2.1)	0.518 (0.252)	26.8 (1.3)	85.2 (5.3)
Kuala Lumpur	1846.4	17 662	8.9±0.7	CA0058	52.8 (33.6)	2.9 (1.2)	19.4 (5.6)	1.002 (0.328)	28.0 (1.3)	81.4 (8.8)
Petaling	2086.0	32 085	8.5±0.6	CA0016	52.6 (32.6)	4.4 (1.9)	26.8 (6.7)	1.532 (0.461)	28.4 (1.2)	72.6 (6.3)
Klang	991.6	16 220	7.5±0.8	CA0011	68.9 (40.8)	3.7 (1.7)	20.8 (6.4)	1.038 (0.392)	28.4 (1.2)	72.6 (6.3)
Seremban	606.0	9775	8.6±1.1	CA0047	48.6 (31.6)	2.6 (1.4)	8.9 (2.8)	0.916 (0.453)	27.6 (1.1)	76.6 (7.5)
Melaka Tengah	555.6	8776	7.9±1.1	CA0006	57.1 (30.7)	3.2 (1.5)	11.0 (3.0)	0.851 (0.298)	28.4 (1.0)	78.1 (7.4)
Johor Bahru	1536.8	25 750	8.7±0.7	CA0001	53.9 (25.0)	4.3 (2.8)	13.4 (6.5)	0.780 (0.366)	28.0 (1.0)	76.7 (5.6)
Kuching	676.1	8709	8.2±1.1	CA0004	40.2 (28.3)	1.4 (0.5)	7.0 (2.2)	0.485 (0.295)	27.3 (1.1)	82.0 (4.0)

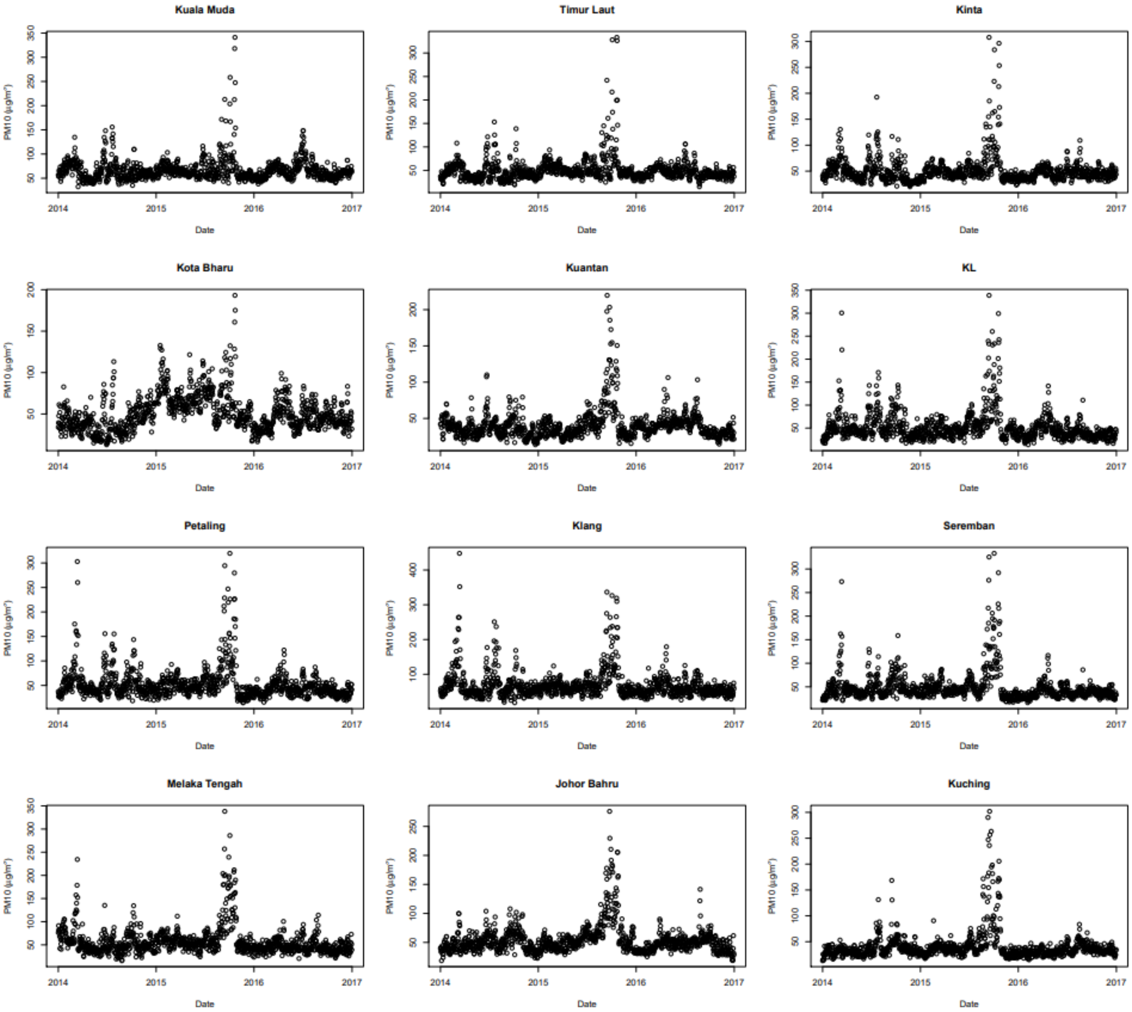
[a] Information based on Population Statistics 2016 (DOSM, 2020). [b] Mortality rate is number of under-five (U5Y) mortality per 1000 live births (Based on census 2016). Bootstrap by 10 000 simulations: Overall U5Y mortality rate = 8.2 (95% CI: 7.9, 8.5). [c] Values are shown as 'daily mean (standard deviation)'. SO_2, sulphur dioxide; NO_2, nitrogen dioxide; CO, carbon monoxide.

Table 2. Total number of haze days in the districts included in this study by duration and intensity.



	Duration-1	Duration-2	Duration-3
Intensity-4	231	231	225
Intensity-3	650	637	613
Intensity-2	1585	1527	1424
Intensity-1	5500	4433	3751

Supplementary material. PM10 concentration over time in each district in Malaysia (2014-2016).



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