BILINGUAL PUBLISHING GROUP

Journal of Atmospheric Science Research
https://journals.bilpubgroup.com/index.php/jasr

ARTICLE

Spatial and Temporal Variation of Particulate Matter (PM10 and PM2.5) and Its Health Effects during the Haze Event in Malaysia

Afiqah Ma'amor[1], *Norazian Mohamed Noor*[1,2*], *Izzati Amani Mohd Jafri*[1,2], *Nur Alis Addiena*[1,2], *Ahmad Zia Ul Saufie*[3], *Nor Azrita Amin*[4], *Madalina Boboc*[5], *Gyorgy Deak*[5]

[1] *Faculty of Civil Engineering & Technology, Universiti Malaysia Perlis, Jejawi, Arau, Perlis, 02600, Malaysia*

[2] *Sustainable Environment Research Group (SERG), Centre of Excellence Geopolymer and Technology (CEGeoGTech), Jejawi, Arau, Perlis, 02600, Malaysia*

[3] *Faculty of Computer and Mathematical Sciences, Universiti Teknologi Mara (UiTM), Shah Alam, 40450, Malaysia*

[4] *Institute of Engineering Mathematics, Universiti Malaysia Perlis, Pauh Putra Campus, Arau, Perlis, 02600, Malaysia*

[5] *National Institute for Research and Development in Environmental Protection INCDPM, Splaiul Independentei 294, Bucharest, 060031, Romania*

ABSTRACT

This study aims to assess and compare levels of particulate matter (PM10 and PM2.5) in urban and industrial areas in Malaysia during haze episodes, which typically occur in the south west monsoon season. The high concentrations of atmospheric particles are mainly due to pollution from neighbouring countries. Daily PM concentrations were analysed for urban and industrial areas including Alor Setar, Tasek, Shah Alam, Klang, Bandaraya Melaka, Larkin, Balok Baru, and Kuala Terengganu in 2018 and 2019. The analysis employed spatiotemporal to examine how PM levels were distributed. The data summary revealed that PM levels in all study areas were right-skewed, indicating the occurrence of high particulate events. Significant peaks in PM concentrations during haze events were consistently observed between June and October, encompassing the south west monsoon and inter-monsoon periods. The study on acute respiratory illnesses primarily focused on Selangor. Analysis revealed that Klang had the highest mean number of inpatient cases for acute exacerbation of bronchial asthma (AEBA) and acute exacerbation of chronic obstructive pulmonary disease (AECOPD) with values of 260.500 and 185.170, respectively. Similarly, for outpatient cases of AEBA and AECOPD, Klang had the highest average values of 41.67 and 14.00, respectively. Shah Alam and Sungai Buloh did not show a significant increase in cases during periods of biomass burning. The statistical analysis concluded that higher concentrations of PM were associated with increased hospital admissions, particularly from June to September, as shown in the bar diagram. Haze episodes were associated with more healthcare utilization due to haze-related respiratory illnesses, seen in higher inpatient and outpatient visits ($p < 0.05$). However, seasonal variability had minimal impact on healthcare utilization. These findings offer a comprehensive assessment of PM levels during historic haze episodes, providing valuable insights for authorities to develop policies and guidelines for effective monitoring and mitigation of the negative impacts of haze events.

Keywords: Haze; Particulate matter (PM10 and PM2.5); AEBA and AECOPD; Spatial variability

*CORRESPONDING AUTHOR:
Norazian Mohamed Noor, Faculty of Civil Engineering & Technology, Universiti Malaysia Perlis, Jejawi, Arau, Perlis, 02600, Malaysia; Sustainable Environment Research Group (SERG), Centre of Excellence Geopolymer and Technology (CEGeoGTech), Jejawi, Arau, Perlis, 02600, Malaysia; Email: norazian@unimap.edu.my

ARTICLE INFO
Received: 2 August 2023 | Revised: 3 October 2023 | Accepted: 8 October 2023 | Published Online: 16 October 2023
DOI: https://doi.org/10.30564/jasr.v6i4.5873

CITATION
Ma'amor, A., Noor, N.M., Jafri, I.A.M., et al., 2023. Spatial and Temporal Variation of Particulate Matter (PM10 and PM2.5) and Its Health Effects during the Haze Event in Malaysia. Journal of Atmospheric Science Research. 6(4): 26-47. DOI: https://doi.org/10.30564/jasr.v6i4.5873

1. Introduction

The haze event is defined as the presence of fine particles (0.1-1.0 µm in diameter) dispersed at a high concentration through a portion of the atmosphere that diminishes the horizontal visibility, giving the atmosphere a characteristic opalescent appearance [1]. In the meantime, China Meteorological Administration defined haze as a pollution phenomenon that cuts atmospheric visibility to 10 km due to complex materials that are suspended in the atmosphere, such as solid or liquid particulates, dust, smoke, and vapour [2]. Due to a toxic mixture of air pollutants, including particulate matter and toxic gases, that are impacted by weather patterns including ambient temperature, relative humidity, and wind speed, these circumstances enhance the severity of the air quality [3]. Since the 1980s until recently, Malaysia has endured this terrible phenomenon for a decade. Whenever the relative humidity is less than 80% and vision is less than 10 km, haze is observed if the surrounding air has a high concentration of particulate matter remaining in the air, which could or could not been seen with the naked eye [4].

Transboundary smoke haze from open biomass burning in Indonesia can affect Malaysia's air quality. This environmental issue is a seasonal occurrence [5]. Haze pollution, caused by the burning of forests, has been identified as a global environmental issue affecting South East Asian countries such as Malaysia, Singapore, Indonesia, Brunei Darussalam, and Southern Thailand [6]. Haze occurs in Indonesia because of recurring biomass burning, including wildfires, wetlands, and agricultural burning. The effect of uncertain monsoon rain as well as the El-Nino event are worsening the transboundary haze given the long and dry meteorological conditions, particularly throughout the south west monsoon condition [7].

Indonesia, being the largest global producer, relies heavily on palm oil production as its primary economic driver. The country supplies approximately half of the world's palm oil. This industry has witnessed a remarkable surge, escalating from 157,000 tonnes in 1964 to an astounding 43.5 million tonnes in 2020 [8]. The islands of Borneo and Sumatra are the primary contributors to Indonesia's palm oil output. Unfortunately, a prevalent practice among many landholders involves the deliberate burning of forests and peatlands to facilitate clearance, drainage, and subsequent replanting for industrial plantation purposes [9].

Regrettably, this method leads to the occurrence of haze, an atmospheric phenomenon, which can disperse to neighboring nations such as Malaysia, Singapore, and other countries in South-east Asia [10]. This dispersion is influenced by key meteorological factors including temperature (T), relative humidity (RH), wind speed (WS), and wind direction (WD). During haze episodes, there is a significant increase in the concentration of particulate matter, particularly those with an aerodynamic diameter equal to or less than 10 µm (PM10), in the surrounding air. These concentrations often exceeded the Malaysian Ambient Air Quality Standard (MAAQS) for PM10, which is set at 100 $\mu g/m^3$ for a 24-hour average [11].

Typically, the seasonal transboundary haze occurs due to the release of smoke from combustion, resulting in high concentrations of airborne particulate matter. Most of these particles have a size of less than 2.5 microns (PM2.5), allowing them to remain suspended in wind currents for extended durations. Furthermore, their small size enables them to penetrate deep into the respiratory tract of humans [12]. During seasonal haze episodes, there is a noticeable exacerbation of asthma and other respiratory-related symptoms in the short term. However, the long-term health implications of intermittent extreme episodes of seasonal haze exposure are still not well understood. While some studies have indicated a potentially elevated risk of chronic diseases like lung cancer, these findings have primarily been observed in the context of chronic exposure [13,14].

Consequently, lack of conclusive evidence regarding the potential health impacts of haze-induced morbidity in developing countries within ASEAN especially Malaysia. Therefore, further research particularly in Malaysia is necessary to facilitate more effective public health planning in the future. Taking this into account, the objective of this study is to identify the spatiotemporal patterns of particulate matter (PM10 and PM2.5 level) and assess the potential health impacts of seasonal haze exposure resulting from biomass burning in Malaysia using statistical methods.

2. Materials and methods

2.1 Study area and dataset

In this research, the daily measurement data (2018-2019) for PM10 and PM2.5 of air monitoring stations in Peninsular Malaysia were collected from the Department of Environmental (DOE) Malaysia. This study focused on peninsular Malaysia with certain locations including Shah Alam and Klang (Selangor), Bandaraya Melaka (Melaka), Balok Baru (Kuantan), Larkin (Johor Bahru), Alor Setar (Kedah), Kuala Terengganu (Terengganu) and Tasek (Ipoh) since peninsular Malaysia are closer to Sumatera and are more densely populated [11] as well as have experienced significant haze events in the past, making them relevant study sites for understanding the historical and ongoing impacts of transboundary haze. Besides, these areas have established research infrastructure, including monitoring stations and data collection systems [15]. This infrastructure can provide a valuable foundation for conducting comprehensive studies on the effects of transboundary haze. The air quality dataset that was acquired from the Department of Environment, Malaysia was commonly subjected to standard quality control processes and quality assurance procedures [16]. The procedures that were used in the monitoring stations followed the standards outlined States Environmental Protection Agency (USEPA) [17].

Figure 1 shows the location of the study area in Peninsular Malaysia. **Table 1** provides a detailed description of the selected monitoring areas and the climatic conditions such as the average wind speed (m/s), relative humidity (%) and temperature (°C). The lowest wind speed was observed in Shah Alam and Larkin (0.89 m/s) whereas the highest temperature was recorded in Klang (28.4 °C) and Melaka (28.2 °C).

There was no exact article that mentioned the starting and end date of haze episode in 2019 but there was one newspaper article written by Sinar Harian dated 21st September 2019 mentioned that the hazy weather that hit the region of the country was expected to improve within the week due to the monsoon transition phase [18]. In addition, it was reported by the Department of Environment [19] that air quality in Malaysia is considered rather degraded, as the annual mean PM2.5 concentration was about 20 μg m^{-3} in 2019, thus exceeding the limit set by WHO.

In addition, the health data for two consecutive years (2018-2019) of monthly in-patients and out-patients diagnosed with Acute Exacerbation of Bronchial Asthma (AEBA) and Acute Exacerbation of Chronic Obstructive Pulmonary Disease (AE-COPD) due to the association with particulate matter during haze events were collected from the Ministry of Health (MOH). Respiratory health data from eight hospitals in Peninsular Malaysia were used for the analysis. However, due to limited cooperation from some hospitals, the respiratory health data were only obtained from hospitals in Selangor.

2.2 Contour plot (ArcGIS and Kriging Method)

GIS is a significant tool for monitoring and analysing air quality. GIS has been used in certain significant studies for geographical and temporal characterization of emitted air pollutants [20]. A spatial interpolation method is one of the common techniques for mapping air pollution [21]. Furthermore, incorporating spatial analysis in GIS can assist researchers in expanding their understanding of the distribution of pollutants in specific locations or areas, as well as understanding the factors that influence trends and significance. The spatial map may give an initial overview of the potential health risks faced by people living in areas with high levels of air pollution [22].

Interpolation involves utilizing sample data from neighboring locations and considering spatial autocorrelation-variogram to predict the pollutant values in areas where direct measurements are not available. By leveraging GIS and interpolation techniques,

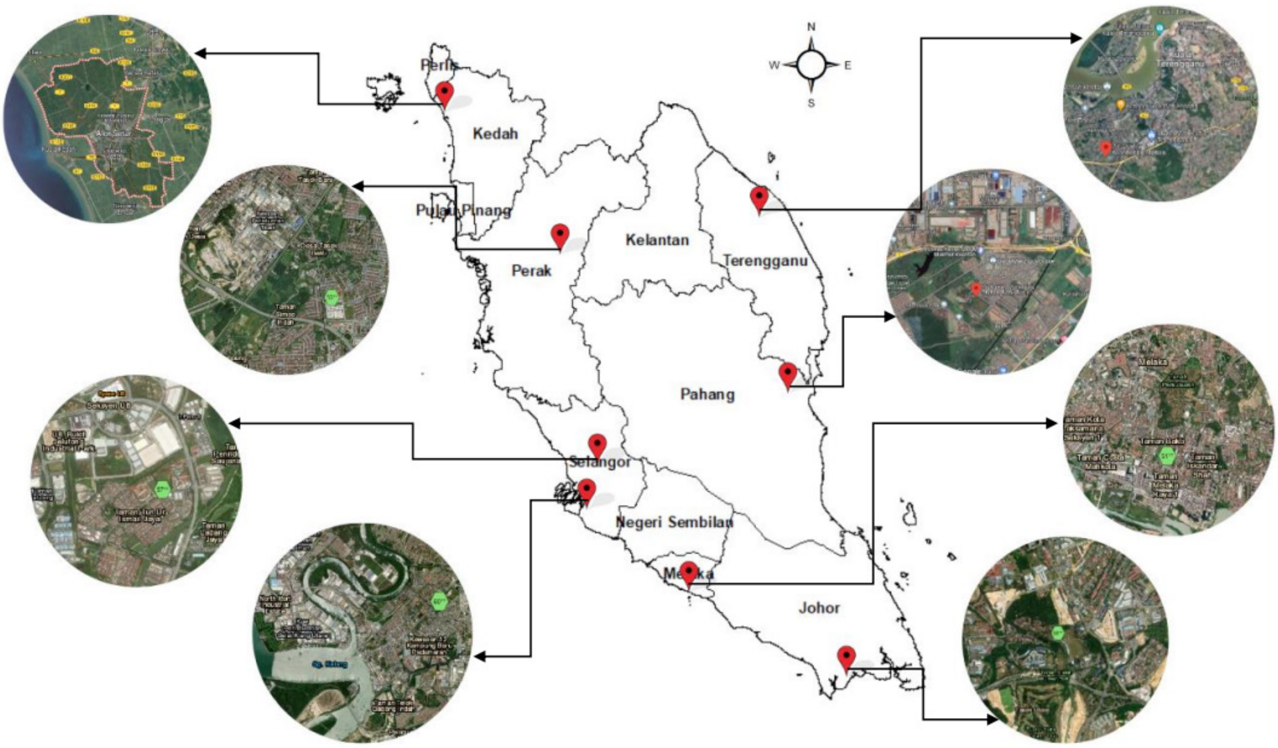


Figure 1. Air quality monitoring station in Peninsular Malaysia.

Table 1. Air quality monitoring station.

Monitoring location	Area	Coordinates	Background	Average wind speed (m/s)	Average relative humidity (%)	Average temperature (°C)
Secondary Islamic School of Kedah	Alor Setar	N 6.213148 E 100.329915	Urban	1.33	79.10	27.92
Jalan Tasek National Secondary School	Tasek	N 4.630805 E 101.117826	Industrial	1.28	74.71	27.69
TTDI Jaya Primary School	Shah Alam	N 3.104710 E 101.556179	Urban	0.86	78.24	27.49
Raja Zarina Secondary Girls School	Klang	N 3.009994 E 101.408374	Urban	1.38	78.55	28.40
Melaka Secondary High School	Bandaraya Melaka	N 2.191726 E 102.254588	Urban	1.41	78.02	28.24
IPG, Campus Temenggong Ibrahim	Larkin	N 1.492353 E 103.738014	Industrial	0.89	83.47	27.59
Balok Baru Primary School	Balok Baru	N 3.96175 E 103.38212	Industrial	1.94	82.28	26.79
Pusat Chabang Tiga Primary School	Kuala Terengganu	N 5.306791 E 103.122190	Urban	1.26	82.44	26.88

it becomes possible to gain additional insights into the distribution of PM10 and PM2.5 beyond the coverage of monitoring stations. In this study, spatial analysis was performed using Ordinary Kringing Interpolation Method (OKM) using ArcGIS software version 10.5 to analyze the continuous distribution of PM10 and PM2.5 concentration for all the stations [23]. Compared with the Inverse Distance Weighted (IDW) interpolation method, the output of the OKM has better continuity. In addition, OKM is widely applied to study the spatiotemporal distribution of air quality, and the corresponding model has the best superiority in cross validation [24].

3. Results and discussion

3.1 Temporal analysis of particulate matter concentration

Table 2 presented data on the concentration of particulate matter (PM) in the eight different locations over a two-year period. According to the Malaysian Ambient Air Quality Standard (MAAQS) interim target 2 (IT-2), the recommended limit for the 1-year average of PM10 is 45 μg/m^3. The mean PM10 values in the selected study areas for all stations were below this threshold, however, the mean values of PM10 and PM2.5 level for all stations in 2018 and 2019 exceeded their median values, suggesting that the distribution of the data were skewed or extreme concentrations of PM10 were present during those years.

Overall, the mean values observed in all stations during the two years were higher than the median values, indicating a positively skewed distribution of PM10 concentrations. This suggests a higher likelihood of PM10 measurements exceeding the permissible value of MAAQS (IT-2), which was 120 μg/m^3 for the 24-hour average. The skewness values, mostly greater than +1 in most areas, further indicate that the data was highly skewed to the right.

In 2019, the maximum PM10 concentration was recorded as the highest value compared to all study areas during the two-year period. Bandaraya Melaka and Klang had the highest concentrations, with measurements of 173.897 μg/m^3 and 163.536 μg/m^3 respectively. Alor Setar, Tasek, Shah Alam, Larkin, Balok Baru, and Kuala Terengganu recorded their highest PM10 concentrations ranging from 80.015 μg/m^3 to 156.553 μg/m^3. In general, most of the maximum values in each year of the study exceeded the MAAQS.

For PM2.5, the MAAQS sets a guideline of 25 μg/m^3 for the 1-year average. The mean PM2.5 values in the study area, which is primarily categorized as an urban industrial area, exceeded this standard. Similar to PM10, the mean values of PM2.5 concentration for all stations in 2018 and 2019 exceeded their median values, indicating the concentration was right skewed hence signifying the extreme concentrations of PM2.5 during those years. This suggests a positively skewed distribution of PM2.5 concentrations, with a higher possibility of exceeding the permissible value of MAAQS, which is 50 μg/m^3 for the 24-hour average.

The highest PM2.5 concentration in 2019 was recorded in Bandaraya Melaka and Shah Alam, with measurements of 151.105 μg/m^3 and 144.917 μg/m^3, respectively, compared to the other study areas. The standard deviation indicates that the PM2.5 measurements showed more variability, with a higher range of PM2.5 levels observed in Shah Alam. In general, the concentrations of PM10 and PM2.5 in 2019 were significantly higher compared to 2018, indicating the occurrence of an intense haze event during 2019. Despite the lower particulate matter concentration in 2018, it still exceeded the standard value set by the MAAQS.

Daily variations of particulate matter PM10 and PM2.5 were shown in **Figures 2 and 3** respectively. The black solid line indicates the Malaysian Ambient Air Quality Standard (MAAQS) for 24-hour average time which was 120 μg/m^3 for PM10 and 50 μg/m^3 for PM2.5. Seasonal patterns were clearly observed in **Figure 3** in which higher PM10 concentration values can be seen during the South west monsoon (June to September). During this period, almost all air quality monitoring stations in the Malaysian Peninsular area were affected by the transboundary

Table 2. Data summary of PM10 and PM2.5 concentration.

Stations	Statistics	2018		2019	
		PM10 (μg/m³)	PM2.5 (μg/m³)	PM10 (μg/m³)	PM2.5 (μg/m³)
Alor Setar	N (Valid)	365	365	365	365
	Mean	21.514	14.659	22.278	16.103
	Median	19.116	12.336	19.026	12.804
	Std Dev	10.756	9.264	12.710	10.989
	Variance	115.683	85.828	161.554	120.762
	Skewness	2.392	2.919	1.730	2.198
	Minimum	6.072	3.335	5.516	3.288
	Maximum	95.089	84.178	80.015	71.074
Tasek	N (Valid)	365	365	365	365
	Mean	28.757	18.752	31.142	22.843
	Median	28.627	17.862	27.199	18.889
	Std Dev	9.969	6.949	17.653	16.032
	Variance	99.377	48.293	311.639	257.040
	Skewness	0.858	1.568	3.470	3.471
	Minimum	11.266	6.702	11.113	6.606
	Maximum	78.185	60.630	149.742	133.332
Shah Alam	N (Valid)	365	365	365	365
	Mean	34.508	25.202	41.989	32.138
	Median	32.898	23.773	37.129	27.273
	Std Dev	10.367	8.148	21.607	19.708
	Variance	107.485	66.384	466.842	388.392
	Skewness	0.721	0.832	2.643	2.961
	Minimum	11.757	8.155	15.023	10.111
	Maximum	78.380	62.641	156.553	144.917
Klang	N (Valid)	365	365	365	365
	Mean	40.898	27.787	41.419	33.037
	Median	39.889	25.976	36.104	28.909
	Std Dev	15.730	11.234	22.582	18.517
	Variance	247.440	126.197	509.967	342.864
	Skewness	1.319	2.387	2.597	2.930
	Minimum	13.588	9.210	11.688	9.764
	Maximum	135.369	117.015	163.536	140.321
Bandaraya Melaka	N (Valid)	365	365	365	365
	Mean	25.595	18.692	30.624	23.491
	Median	23.542	16.847	24.797	18.782
	Std Dev	10.780	8.890	21.125	18.348
	Variance	116.200	79.027	446.273	336.656
	Skewness	1.660	2.400	2.947	3.092
	Minimum	7.571	3.200	9.147	5.223
	Maximum	98.075	94.033	173.897	151.105

Table 2 continued

Stations	Statistics	2018		2019	
		PM10 (μg/m³)	PM2.5 (μg/m³)	PM10 (μg/m³)	PM2.5 (μg/m³)
Larkin	N (Valid)	365	365	365	365
	Mean	29.248	20.479	35.604	24.660
	Median	27.554	19.629	31.812	21.492
	Std Dev	8.625	6.783	16.139	14.180
	Variance	74.386	46.011	260.472	201.063
	Skewness	0.633	0.592	2.584	2.658
	Minimum	8.184	5.285	10.339	6.750
	Maximum	56.704	42.954	135.588	112.243
Balok Baru	N (Valid)	365	365	365	365
	Mean	28.555	17.846	33.818	23.184
	Median	27.025	16.431	28.755	18.177
	Std Dev	9.934	7.754	18.587	17.400
	Variance	98.694	60.129	345.492	302.743
	Skewness	0.534	0.887	2.704	2.765
	Minimum	7.316	3.533	9.965	4.563
	Maximum	58.324	47.538	141.645	129.584
Kuala Terengganu	N (Valid)	365	365	365	365
	Mean	25.344	17.343	28.862	19.738
	Median	24.334	16.324	26.175	17.291
	Std Dev	10.169	8.138	14.072	12.840
	Variance	103.417	66.224	198.032	164.860
	Skewness	0.997	0.851	2.735	2.766
	Minimum	6.057	3.011	8.325	3.566
	Maximum	76.347	53.167	118.189	103.259

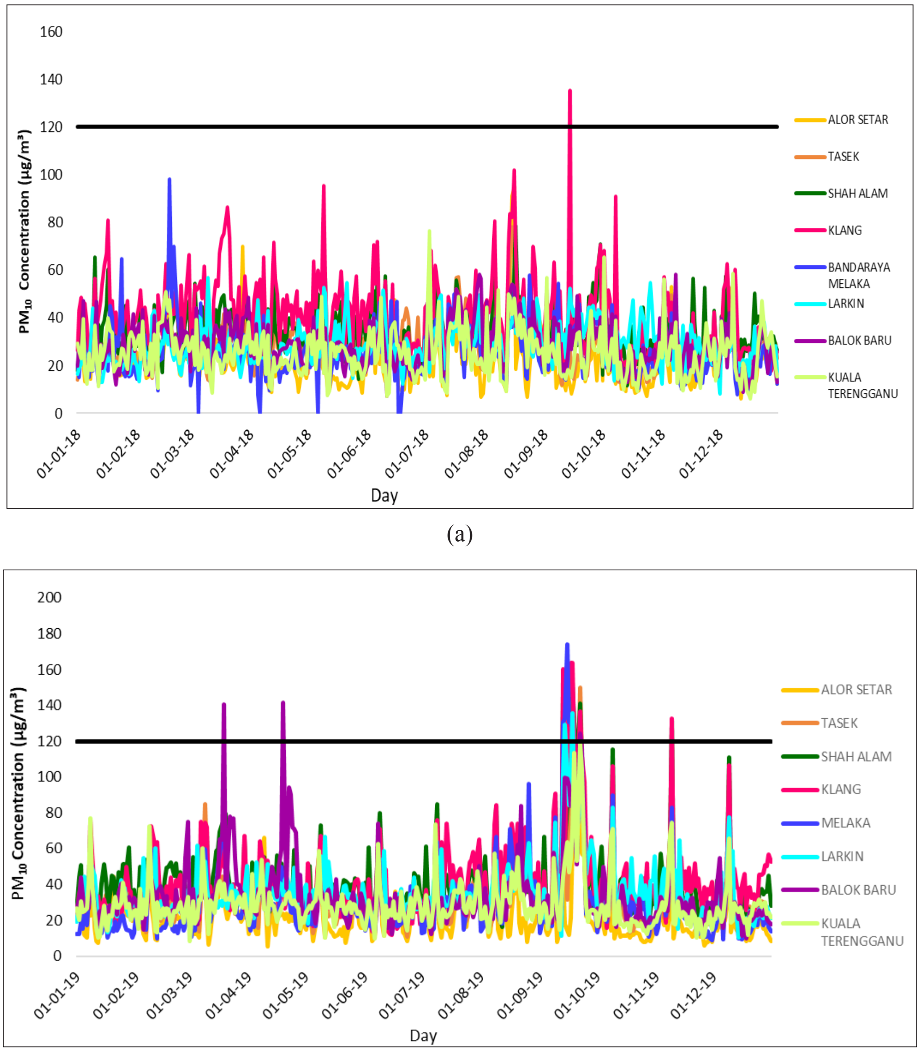
sources of biomass burning from Sumatra, Indonesia [21]. In 2018, the level of PM10 began to increase in early May and reached its peak by the end of September and October. This peak can be clearly observed before weakening in November when the arrival of delayed monsoonal rain helped extinguish fires and improve air quality in the region [22]. During the peak period, all study areas were found to have similar intensities of PM10 levels.

However, Klang recorded the highest concentration, with levels reaching almost 135.659 μg/m^3, exceeding the 120 μg/m^3 threshold set for a 24-hour duration. Conversely, the lowest concentration of PM10 during the peak was observed in Larkin, with a concentration of 56.704 μg/m^3. In early March, Melaka exhibited a higher PM10 concentration, although it did not exceed the MAAQS value. Overall, a significant peak in PM10 concentration was observed from June during the south west monsoon until the inter-monsoon period in October. Although Melaka experienced higher PM10 concentrations in early March, it remained within the acceptable MAAQS limits. In general, all monitoring stations recorded PM10 concentrations below the standard value, except for Klang.

Meanwhile, in 2019, the concentration of PM10 was significantly higher compared to 2018. It was evident that haze events occurred more frequently, starting around June and lasting until October, with the peak period observed in September and October. However, for certain locations like Shah Alam, Klang, and Melaka, the peak extended until the end of December. Among these areas, Melaka recorded the highest PM10 concentration at 173.897 μg/m^3, followed by Klang and Shah Alam with 163.536 μg/m^3 and 156.553 μg/m^3 respectively. The distribution of pollutants during this period was likely influenced by monsoons.

The transboundary air pollution resulting from the burning of fires on Indonesia's Sumatra Island was a major contributor to the haze event. Strong winds carried the smoke across the Melaka Strait during the south west monsoon season. The peak concentration levels of PM10 were mostly detected from June to September, coinciding with the south west monsoon when low-level winds facilitated the long-range transport of pollutants [22]. These fine particles were able to be transported across borders from Sumatra and Kalimantan, moving northward to peninsular Malaysia due to the prevailing regional wind direction [25].

The daily concentrations of PM2.5 in all study areas mostly exceed the standard value of the Malaysian Ambient Air Quality Standard (MAAQS) for 24-hour which is 50 μg/m^3 (**Figure 3**). The concentration of PM2.5 was higher during the haze episode than before it. The highest PM2.5 value was 117.015 μg/m^3 in Klang in 2018 and 151.105 μg/m^3 in Melaka in 2019. Each highest result was in June to September which may be related to the South west Monsoon. During the haze episode, the smoke from Sumatra will travel to Peninsular Malaysia. In most cases, all the stations located on the west coast of Peninsular Malaysia have similar patterns of PM2.5



(a)

(b)

Figure 2. Daily time-series plot of PM10 concentration (a) 2018 and (b) 2019.

concentration during the haze episode based on the intensity of the smoke and wind direction.

On top of that, Balok Baru, Kuantan recorded the highest peak in late March until late May. During this period, the eastern coast of peninsular Malaysia was influenced by the northeast monsoon, which brought dry and stagnant weather conditions. These conditions can lead to the accumulation of pollutants in the air, resulting in higher PM2.5 concentrations [26]. Besides, Balok Baru, being an urban area with industrial activities and transportation, has local pollution sources that contribute to the higher PM10 levels. Industrial emissions, vehicle exhaust, and construction activities can all release particulate matter into the air, increasing the concentration of PM10.

South west monsoon largely influenced phases of the El Nino phenomenon [27]. These dry conditions coupled with the warm temperatures associated with El Nino create an extremely favorable and conducive environment for large-scale outbreaks in Sumatra and Kalimantan. PM2.5 concentrations were strongly affected by meteorological parameters such as wind direction, wind speed, temperature, and relative humidity [4]. At low wind speeds, the atmosphere tends to stabilize and spread slowly, and discharged contaminants easily accumulate, resulting in a higher concentration of particulate matter [22]. Lower wind speeds might inhibit the dispersion of pollutants in

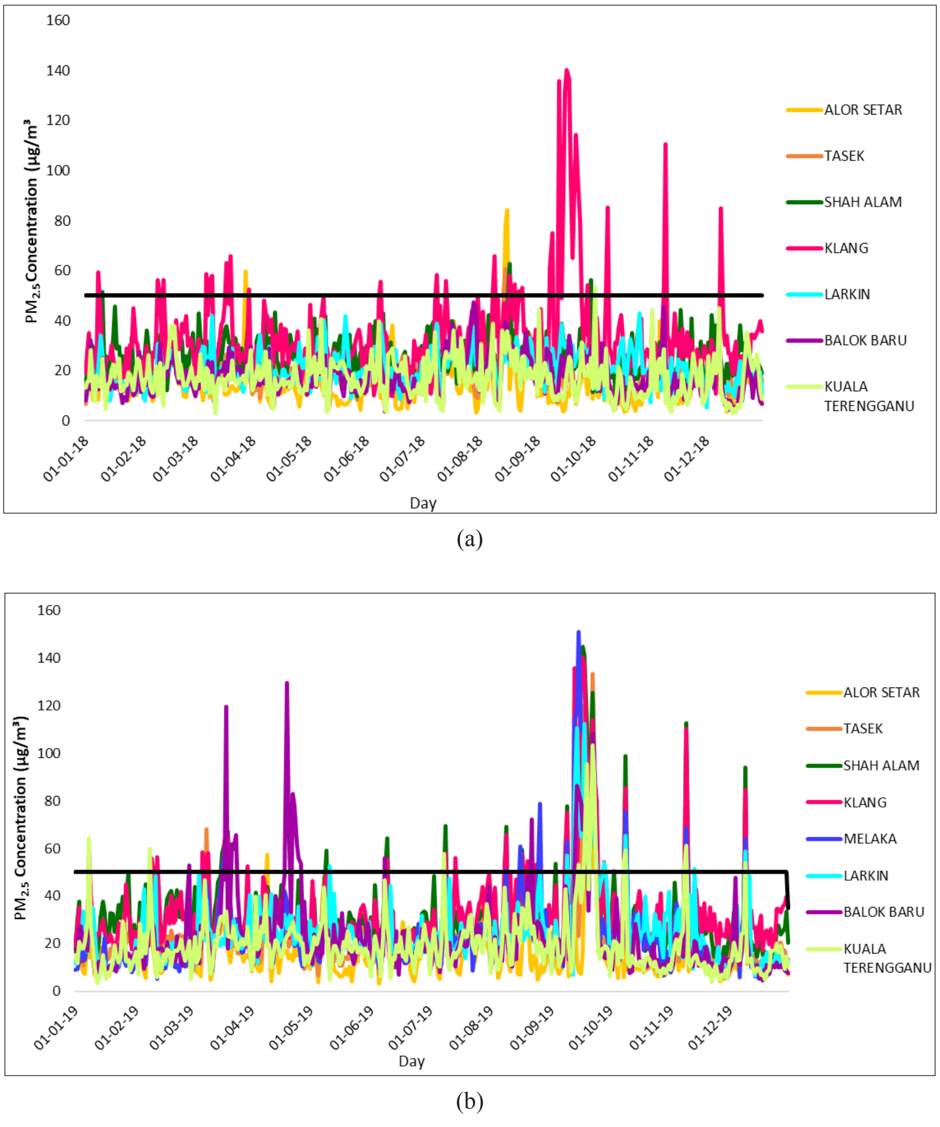


Figure 3. Daily time-series plot of PM2.5 concentration (a) 2018 and (b) 2019.

vertical and horizontal directions, while higher temperatures and humidity promote gas-to-particle conversion and generate secondary aerosols [28].

3.2 Spatial variation of particulate matter concentration

Monthly variations of PM10 and PM2.5 concentration for all study areas were analyzed by using contour plots as depicted in **Figures 4 and 5**. The spatial variation of PM10 and PM2.5 for selected study areas showed spatial variability from January to December. In general, the levels of PM10 concentration were in the range of 19 to 74 μg/m^3 while PM2.5 concentration was in the range of 13 to 61 μg/m^3 from January to December. From January to March, Klang and Shah Alam stations recorded elevated PM10 and PM2.5 concentrations of between 38 to 46 and 29 to 35 respectively and the other stations also displayed a similar but smaller distribution range while Melaka showed the highest PM10 and PM2.5 concentration in April.

However, monthly PM10 and PM2.5 concentration was observed higher from May until September which was during the south west monsoon. From previous analysis, it can be determined that seasonal variation of PM10 and PM2.5 levels seem much related to south-westerly winds which coincides with the regional biomass burning period which starts around May and lasts until September. The seasonal variations, El Nino modulation enhance the effects of haze and the pollutants concentration in the region during the south west monsoon dry season [29]. Overall, the highest monthly concentration was observed during the end of the south west monsoon especially in August and September whereas the concentration dropped in November when the north east monsoon started.

A study by Elhadi et al. [30] revealed that the south west monsoon wind from Sumatra reaches the central area of peninsular Malaysia within 48-h during south west monsoon season prevailing every year. Overall, the higher PM10 and PM2.5 observed during the south west monsoon season were influenced by local sources of emissions. In addition, low wind speeds, low temperature, low humidity, and low rainfall promote higher concentrations of PM2.5 and PM10, especially during this season [31]. On top of that, spatial variation in particulate matter levels has been observed during the wet season which is north east monsoon. A Low level of particulate matter can be seen from November until March with the range of 38 to 46 μg/m^3 for PM10 and 27 to 35 μg/m^3 for PM2.5. During the wet season, the humidity level is high and there is a higher chance of rainfall. The water vapors wash away all the suspended particles from the atmosphere, thereby reducing the particulate matter level [32,22].

3.3 Descriptive analysis of acute respiratory disease

Data summary for respiratory disease hospitalizations in three study areas, namely Hospital Shah Alam, Hospital Sungai Buloh, and Hospital Tengku Ampuan Rahimah in Klang, are presented in **Table 3** for 2018 and 2019. The statistics include mean, median, standard deviation, skewness, minimum, and maximum values. Overall, Klang had the highest number of patients admitted to the hospital for ACOPD and AEBA.

For inpatient AECOPD and AEBA cases, Hospital Tengku Ampuan Rahimah in Klang recorded the highest mean values of 185.17 and 260.50, respectively, in 2018, with standard deviations of 40.296 and 54.959. The mean values observed in all study areas and years were higher than the corresponding medians, indicating a positively skewed distribution for inpatient AECOPD and AEBA cases. Similarly, for outpatient AECOPD and AEBA cases, Hospital Tengku Ampuan Rahimah in Klang had the highest mean values of 14.00 and 41.67, with standard deviations of 12.799 and 17.385, respectively.

Furthermore, the highest maximum values for hospital admissions were 400 in 2018 and 297 in 2019, both for AEBA inpatient cases at Hospital Tengku Ampuan Rahimah in Klang. However, the specific data on hospital admissions for AECOPD and AEBA at Hospital Shah Alam and Hospital Sungai Buloh may not indicate a significant increase during periods of biomass burning from forest and

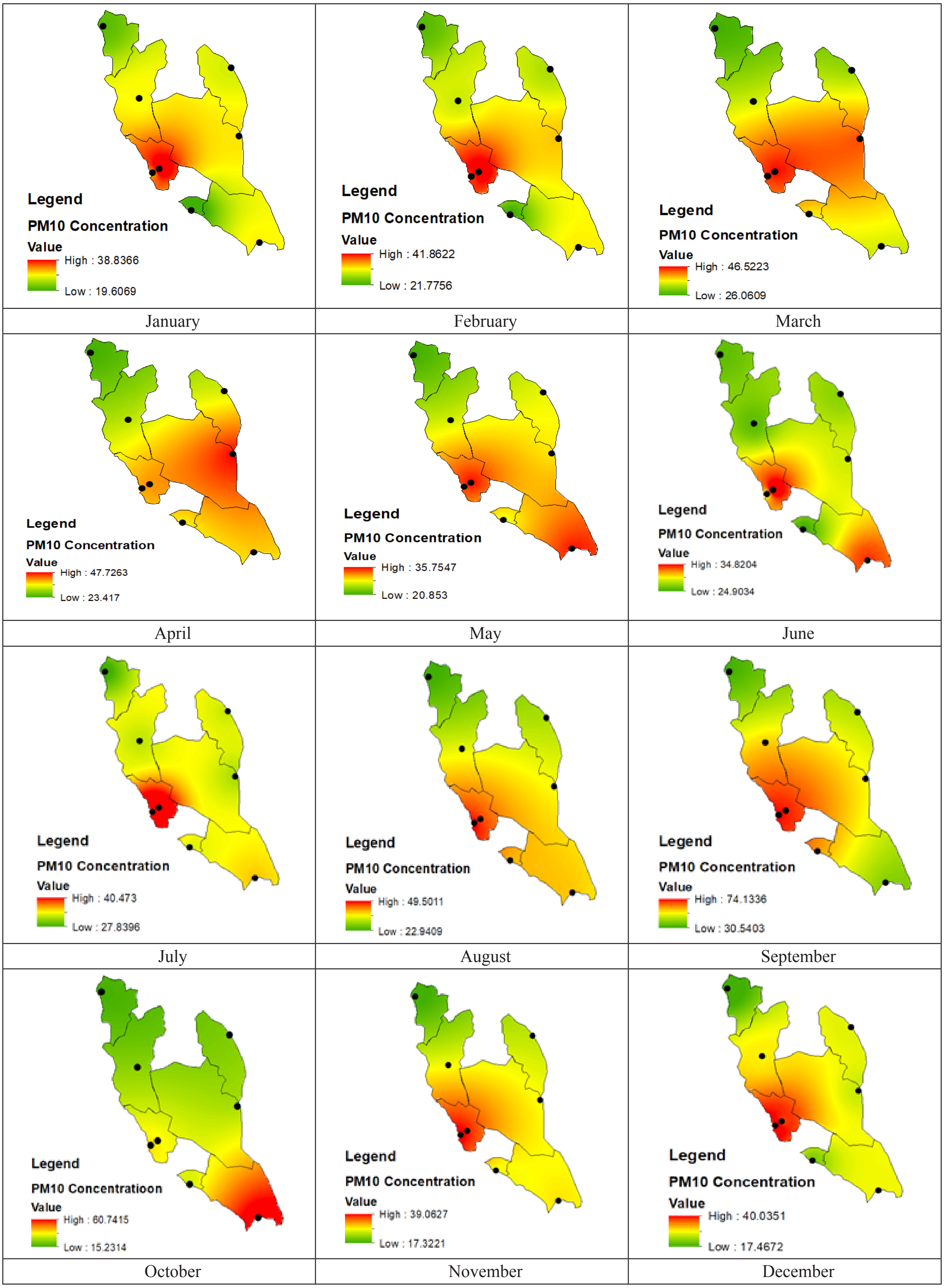


Figure 4. Mapping of PM10 concentration distribution at study area (January-December).

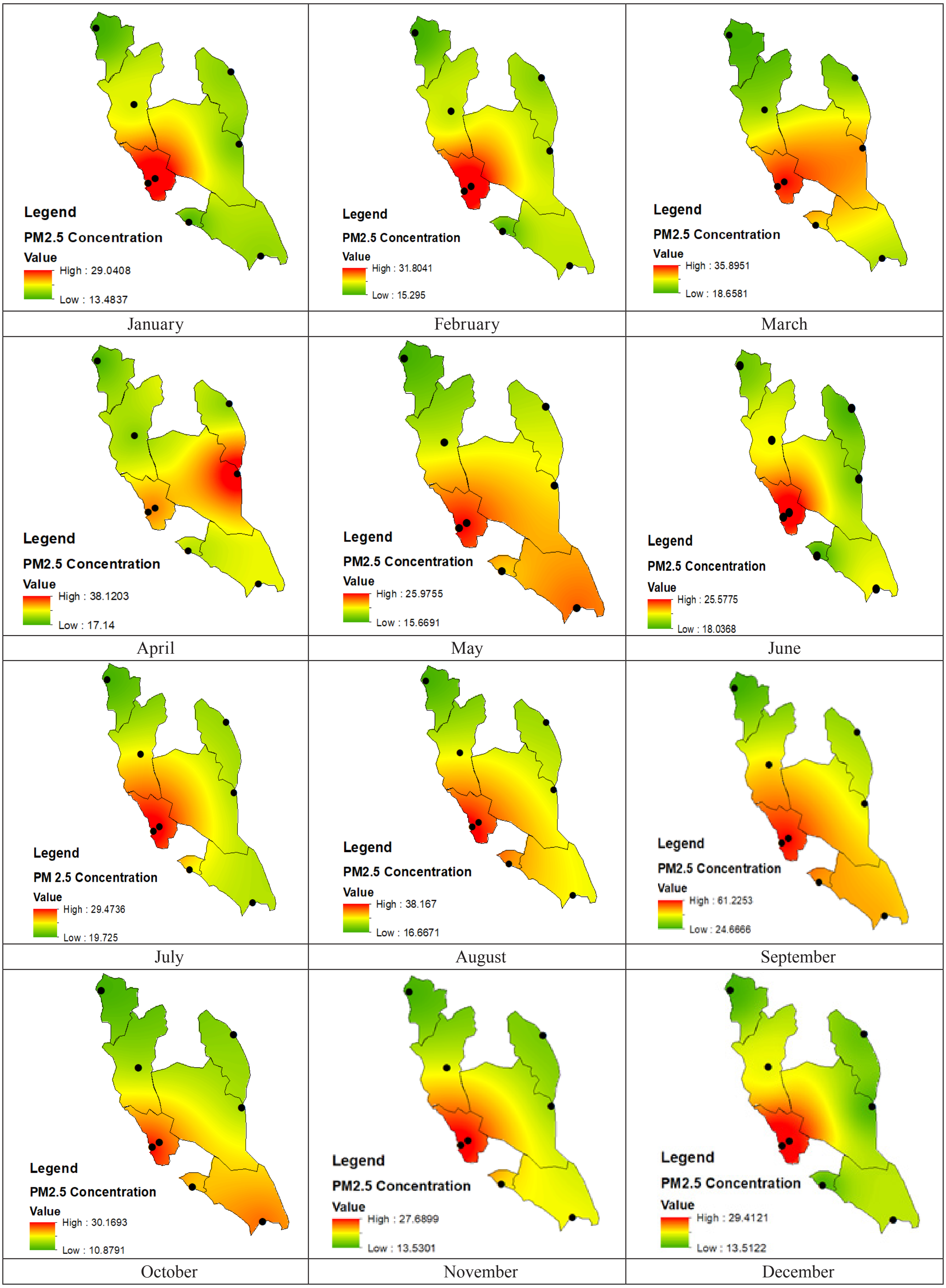


Figure 5. Mapping of PM2.5 concentration distribution at study area (January-December).

Table 3. Data summary of acute respiratory ill diseases.

Year	Healthcare utilization (Respiratory disease)		Statistics	Hospital Shah Alam	Hospital Sungai Buloh	Hospital Tengku Ampuan Rahimah, Klang
2018	Inpatient	AECOPD	N (Valid)	12	12	12
			Mean	30.750	15.420	185.170
			Median	27.000	15.000	173.500
			Std Dev	14.040	5.125	40.296
			Variance	197.114	26.265	1623.788
			Skewness	0.612	0.727	0.990
			Minimum	9	9	144
			Maximum	56	26	260
		AEBA	N (Valid)	12	12	12
			Mean	88.420	46.500	260.500
			Median	88.500	49.500	244.500
			Std Dev	26.559	11.844	54.959
			Variance	705.356	140.273	3020.455
			Skewness	0.775	–0.084	1.642
			Minimum	44	30	203
			Maximum	150	64	400
	Outpatient	AECOPD	N (Valid)	12	12	12
			Mean	0.670	0.580	14.000
			Median	0.000	0.000	8.500
			Std Dev	1.155	1.730	12.799
			Variance	1.333	2.992	163.818
			Skewness	1.638	3.309	1.763
			Minimum	0	0	2
			Maximum	3	6	47
		AEBA	N (Valid)	12	12	12
			Mean	16.420	19.580	41.670
			Median	17.000	14.500	38.500
			Std Dev	7.192	13.521	17.385
			Variance	51.720	182.811	302.242
			Skewness	–0.079	2.393	1.173
			Minimum	5	9	21
			Maximum	29	58	82

Table 3 continued

Year	Healthcare utilization (respiratory disease)		Statistics	Hospital Shah Alam	Hospital Sungai Buloh	Hospital Tengku Ampuan Rahimah, Klang
2019	Inpatient	AECOPD	N (Valid)	12	12	12
			Mean	20.580	14.330	157.080
			Median	18.000	15.000	145.500
			Std Dev	9.199	5.805	33.530
			Variance	84.629	33.697	1124.265
			Skewness	0.465	–0.081	0.789
			Minimum	9	3	107
			Maximum	36	24	229
		AEBA	N (Valid)	12	12	12
			Mean	88.500	43.250	203.670
			Median	82.000	42.500	194.500
			Std Dev	30.527	7.300	45.777
			Variance	931.909	53.295	2095.515
			Skewness	1.008	–0.151	0.752
			Minimum	54	32	152
			Maximum	154	54	297
	Outpatient	AECOPD	N (Valid)	12	12	12
			Mean	5.830	1.420	9.830
			Median	1.500	0.000	10.500
			Std Dev	7.756	2.275	7.802
			Variance	60.152	5.174	60.879
			Skewness	1.429	1.603	0.052
			Minimum	0	0	0
			Maximum	22	6	23
		AEBA	N (Valid)	12	12	12
			Mean	14.250	14.670	39.330
			Median	8.500	11.000	38.500
			Std Dev	14.372	8.195	11.523
			Variance	206.568	67.152	132.788
			Skewness	1.779	0.750	0.652
			Minimum	4	6	23
			Maximum	50	29	63

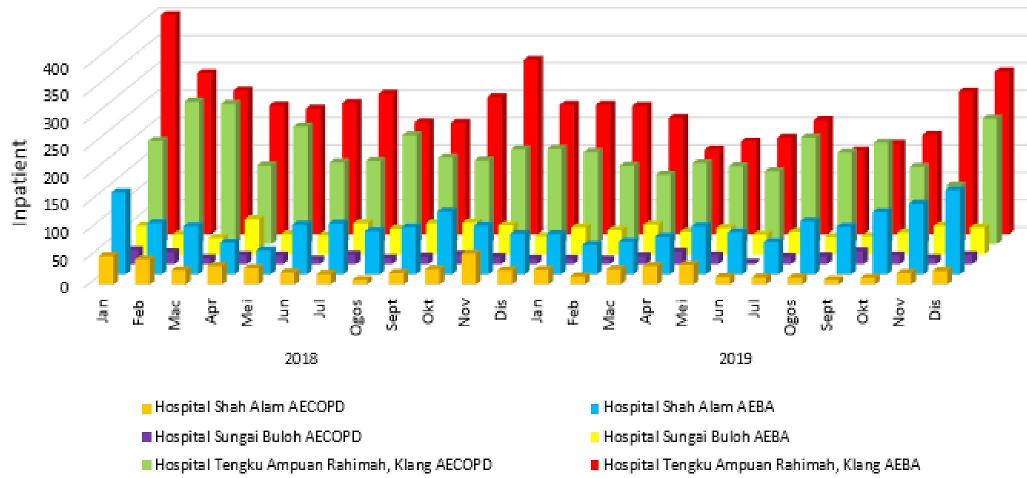
peat fires caused by agricultural land clearing in Indonesia. It is important to consider that certain health conditions, such as respiratory infections or seasonal allergies, may exhibit seasonal patterns. Factors like haze, increased pollen levels, or climate changes during specific times of the year can worsen respiratory conditions and lead to higher hospital admissions during those periods.

3.4 Trends of healthcare utilization

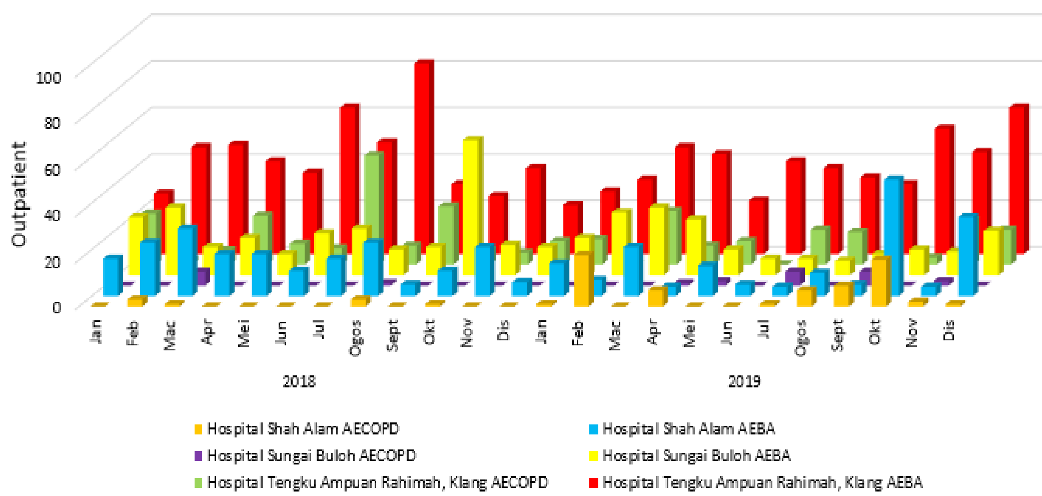
Figure 6 illustrates the bar diagram for the monthly average of healthcare utilization for 2018 and 2019. The trend in healthcare utilization can be seen in those hospitals. The findings of this study indicate that there was a higher utilization of healthcare services for respiratory illnesses from June until September which coincided with the south-westerly monsoon season. The analysis considered both acute exacerbation of bronchial asthma (AEBA) and acute exacerbation of chronic obstructive pulmonary disease (AECOPD), examining the total and average number of hospital admissions and outpatient visits.

Hospital Tengku Ampuan Rahimah, Klang showed the highest number in healthcare utilization among all study areas. Klang located in the western area experienced higher PM10 and PM2.5 concentration distribution as compared to the eastern and northern parts of Klang Valley. It can be evident from previous analysis in the time series plot (**Figures 2 and 3**), that Klang depicts the highest PM concentration among all study areas.

During these periods, the highest recorded levels of haze were observed due to biomass burning resulting from agricultural land clearing in Indonesia. This situation was exacerbated by the south-west monsoon season, which typically occurs from May



(a)



(b)

Figure 6. Monthly histogram plot healthcare utilization (a) inpatient and (b) outpatient.

to September. The prevailing winds from Sumatra, which followed the south west monsoon pattern, took approximately 48 hours to reach all Continuous Air Quality Monitoring (CAQM) stations in Selangor, Malaysia. As the wind carried the particulate matter and gaseous pollutants from the affected region, particularly Selangor's western part, it contributed to the elevated levels of haze in the area [33].

3.5 Association between healthcare utilization and particulate matter concentrations

The Mann-Whitney U test was used to compare the healthcare utilization (AEBA inpatient and outpatient) between two independent groups mainly particulate matter PM10 and PM2.5. Based on **Table 4**, the overall mean AEBA inpatient with particulate matter (PM10 and PM2.5) was higher than the mean AEBA outpatient with particulate matter (PM10 and PM2.5) which indicates that hospital admission in Selangor was higher compared to outpatient. Overall, the p-values for both healthcare utilization variables are less than 0.001 (except for AEBA outpatient in Klang), indicating a strongly statistically significant relationship between healthcare utilization and particulate matter levels in this area. Hence, there was sufficient evidence to reject that there was no difference between the mean of PM10 and PM2.5 with acute respiratory diseases.

In order to observe seasonal association, **Table 5** shows the mean values and p-values for healthcare utilization (AEBA inpatient and outpatient) during the South West Monsoon (SWM) and North East Monsoon (NEM) seasons, along with the particulate matter concentrations (PM10 and PM2.5). Overall, both particulate matter concentrations (PM10 and PM2.5) were statistically significant with healthcare utilization, as indicated by the p-values of < 0.001 (except for AEBA outpatient during the North east monsoon season). The results indicate that higher concentrations of PM10 and PM2.5 are associated with increased healthcare utilization for both AEBA inpatient and outpatient cases during both the SWM and NEM seasons. However, it is important to note that the association with PM2.5 becomes non-significant for AEBA outpatient cases during the NEM season. During haze episodes, particulate matter was the most dominant air pollutant. Previous studies showed that particulate matter triggered inflammatory reactions, mainly affecting the respiratory system, and resulted in AEBA [34]. As a result of exposure to higher concentrations levels of particulate matter during haze episodes, the number of AEBA cases was also expected to rise and subsequently lead to an increase in healthcare utilization during haze episodes, as seen in this study.

Table 4. Association between healthcare utilization and particulate matter concentrations.

Location	Healthcare utilization		PM10	PM2.5
Shah Alam	AEBA inpatient	Mean	63.360	58.573
		P-value	< 0.001	< 0.001
	AEBA outpatient	Mean	26.798	22.011
		P-value	< 0.001	< 0.001
Sungai Buloh	AEBA inpatient	Mean	41.569	36.781
		P-value	0.013	< 0.001
	AEBA outpatient	Mean	27.694	22.906
		P-value	< 0.001	< 0.001
Klang	AEBA inpatient	Mean	136.620	131.251
		P-value	< 0.001	< 0.001
	AEBA outpatient	Mean	40.828	35.460
		P-value	0.536	0.006

Table 5. Association between healthcare utilization and particulate matter concentrations during monsoon season.

Healthcare utilization	Monsoon seasons		PM10	PM2.5
AEBA inpatient	SWM	Mean	74.994	69.785
		P-value	< 0.001	< 0.001
	NEM	Mean	88.162	83.235
		P-value	< 0.001	< 0.001
AEBA outpatient	SWM	Mean	31.944	26.735
		P-value	< 0.001	< 0.001
	NEM	Mean	31.312	26.385
		P-value	< 0.001	0.128

3.6 Association between healthcare utilization and meteorological parameter

Table 6 shows the coefficients, p-values, and VIF (Variance Inflation Factor) values for healthcare utilization (AEBA inpatient and outpatient) meteorological parameters, wind speed (WS), relative humidity (RH), and temperature (T) in different locations (Shah Alam, Sungai Buloh, and Klang). Overall, VIF values recorded were less than 10 which indicates that no multicollinearity issues were involved. In Shah Alam, the p-values for WS, RH, and T were 0.860, 0.431, and 0.019, indicating that only the temperature (T) variable has a statistically significant relationship with AEBA inpatient healthcare utilization.

For AEBA outpatient cases in Shah Alam, none of the coefficients for WS, RH, and T were statistically significant based on their p-values. In Sungai Buloh, none of the coefficients for WS, RH, and T were statistically significant for both AEBA inpatient and outpatient cases. In Klang, for AEBA inpatient cases, the p-values for WS, RH, and T were 0.034, 0.006, and 0.001, indicating that wind speed (WS), relative humidity (RH), and temperature (T) have statistically significant relationships with AEBA inpatient healthcare utilization.

For AEBA outpatient cases in Klang, none of the coefficients for WS, RH, and T were statistically significant based on their p-values. Overall, the results suggest that the weather parameters have varying levels of association with healthcare utilization for AEBA in different locations. Specifically, in Shah Alam, only temperature (T) is significantly associated with AEBA inpatient cases. In Klang, wind speed

Table 6. Association between healthcare utilization and meteorological parameters.

Location	Healthcare utilization		WS	RH	T
Shah Alam	AEBA inpatient	Coefficient	9.560	–2.902	–47.620
		P-value	0.860	0.431	0.019
		VIF	1.077	3.060	3.154
	AEBA outpatient	Coefficient	–37.627	0.446	–3.398
		P-value	0.142	0.790	0.695
		VIF	1.077	3.060	3.154
Sungai Buloh	AEBA inpatient	Coefficient	–13.978	–0.152	–0.317
		P-value	0.558	0.924	0.969
		VIF	1.077	3.060	3.154
	AEBA outpatient	Coefficient	17.508	–2.266	–13.031
		P-value	0.505	0.207	0.161
		VIF	1.077	3.060	3.154
Klang	AEBA inpatient	Coefficient	–187.103	–15.230	–92.417
		P-value	0.034	0.006	0.001
		VIF	1.828	1.974	2.149
	AEBA outpatient	Coefficient	–13.242	–2.015	0.206
		P-value	0.687	0.314	0.983
		VIF	1.828	1.974	2.149

(WS), relative humidity (RH), and temperature (T) show significant associations with AEBA inpatient cases. However, for AEBA outpatient cases, there are no significant associations observed with the weather parameters.

In addition, to provide a clearer understanding, **Table 7** shows the coefficients, p-values, and VIF (Variance Inflation Factor) values for healthcare utilization (AEBA inpatient and outpatient) during the South West Monsoon (SWM) and North East Monsoon (NEM) seasons, along with the weather parameters wind speed (WS), relative humidity (RH), and temperature (T). Overall, VIF values recorded were less than 10 which indicates that no multicollinearity issues were involved. For AEBA inpatient cases during the SWM season, the p-value of WS and AEBA inpatient is 0.002 suggesting that this relationship was statistically significant. However, RH and T do not show significant associations.

During the NEM season for AEBA inpatient cases, the p-value for WS was 0.035, which was also statistically significant. For AEBA outpatient cases during the SWM season, the coefficient for WS was 49.040, indicating a positive relationship with healthcare utilization and it was statistically significant with a p-value of 0.006. However, RH and T do not show significant associations.

During the NEM season for AEBA outpatient cases, none of the coefficients for WS, RH, and T were statistically significant. In summary, the results suggest that wind speed (WS) has a significant positive association with healthcare utilization for AEBA inpatient cases during both SWM and NEM seasons. However, the associations with relative humidity (RH) and temperature (T) are generally not significant. For AEBA outpatient cases, the associations with the meteorological parameters were not statistically significant during both seasons.

In summary, the findings indicate that during the south west monsoon season, there is a significant impact of wind speed on both AEBA inpatient and outpatient cases, with p-values of 0.002 and 0.006, respectively. However, during the north east monsoon season, only AEBA inpatient cases show a significant impact on wind speed, with a p-value of 0.035. Additionally, AEBA inpatient cases during the north east monsoon season also exhibit a significant impact on temperature, with a p-value of 0.051.

Table 7. Association between healthcare utilization and meteorological parameters during monsoon season.

Healthcare utilization	Monsoon seasons		WS	RH	T
AEBA inpatient	SWM	Coefficient	182.850	–0.210	5.337
		P-value	0.002	0.966	0.872
		VIF	4.855	2.158	5.934
	NEM	Coefficient	157.343	9.607	89.800
		P-value	0.035	0.155	0.051
		VIF	4.855	2.158	5.934
AEBA outpatient	SWM	Coefficient	49.040	–2.140	–4.357
		P-value	0.006	0.169	0.670
		VIF	4.855	2.158	5.934
	NEM	Coefficient	12.391	0.690	12.118
		P-value	0.365	0.586	0.159
		VIF	4.855	2.158	5.934

The causal relationship between AEBA inpatient and outpatient with meteorological parameters is given in **Table 8**. The table reveals both positive and negative correlations between AEBA inpatient and outpatient with meteorological parameters. A strong negative correlation was found between AEBA inpatient and temperature in Shah Alam with an r-value of –0.60 while a moderate positive correlation between inpatient and relative humidity with an r-value of 0.40. This result denoted that temperature contributes much influence on inpatients compared to relative humidity. A study by Anderson et al. [35] stated that a larger increase in daily temperature would result in more excess hospitalizations and a lower increase in fewer hospitalizations.

Furthermore, a strong negative correlation was found between meteorological parameters such as relative humidity and temperature ranging from –0.81 to –0.67 which indicated that an increase in temperature causes a decrease in relative humidity and vice versa. Besides, in Klang a strong negative correlation was observed between wind speed and relative humidity with an r-value of –0.59. Meanwhile, a strong positive correlation between wind speed and temperature with an r-value of 0.63. Overall, in Sungai Buloh, the correlation recorded between AEBA inpatients and meteorological parameters were negatively correlated which indicated that meteorological parameters did not influence the number of AEBA Inpatients during the haze event.

Table 8. Correlation coefficient matrix of AEBA inpatient and outpatient with meteorological parameters.

Shah Alam					
	Inpatient	Outpatient	WS	RH	T
Inpatient	1				
Outpatient	0.32	1.00			
WS	–0.10	–0.35	1.00		
RH	0.40	0.22	–0.02	1.00	
T	–0.60	–0.28	0.17	–0.81	1.00
Sungai Buloh					
	Inpatient	Outpatient	WS	RH	T
Inpatient	1				
Outpatient	0.39	1.00			
WS	–0.14	0.06	1.00		
RH	–0.02	–0.04	–0.02	1.00	
T	–0.01	–0.13	0.17	–0.81	1.00
Klang					
	Inpatient	Outpatient	WS	RH	T
Inpatient	1.00				
Outpatient	1.00	1.00			
WS	0.07	0.07	1.00		
RH	–0.25	–0.25	–0.59	1.00	
T	0.14	0.14	0.63	–0.67	1.00

4. Conclusions

The objective of this project was to analyze the spatial and temporal variations of particulate matter (PM10 and PM2.5) in urban and industrial areas of Malaysia, specifically in Alor Setar, Tasek, Shah Alam, Klang, Melaka, Larkin, Balok Baru, and Kuala Terengganu. Additionally, the study aimed to investigate the relationship between particulate matter and acute respiratory illnesses in the Selangor region, focusing on Klang, Shah Alam, and Sungai Buloh. During the haze events in 2019, the levels of PM10 and PM2.5 exceeded the permissible limits set by the Malaysian Ambient Air Quality Standard (MAAQS). Bandaraya Melaka and Klang had the highest concentrations of PM10, while Bandaraya Melaka and Shah Alam had the highest concentrations of PM2.5 during the same year. The time series analysis revealed that Bandaraya Melaka had the highest peak in haze event in 2019 which happened in September, during the south west monsoon season.

Data analysis of respiratory illnesses diseases revealed that Klang had the highest mean number of inpatient and outpatient cases for AEBA and AECOPD. Besides, the highest healthcare utilization for both AEBA and AECOPD cases occurs mainly from June to September or during the south west monsoon season. The Mann-Whitney U test revealed a statistically significant association between particulate matter and hospital utilization, with p-values below 0.05, indicating sufficient evidence to reject that there was no difference between the mean of PM10 and PM2.5 with acute respiratory ill diseases. Multiple linear regression analysis identified significant associations between healthcare utilization and meteorological parameters. Specifically, for AEBA inpatients in Klang, wind speed, relative humidity, and temperature showed significant associations. Moreover, seasonal variability analysis indicated significant associations between wind speed, temperature, and healthcare utilization during the South West Monsoon (SWM) and North East Monsoon (NEM).

More research is required to determine consistent associations between wildfire smoke exposure and cardiovascular effects, specific causes of mortality, birth outcomes, and mental health outcomes. The current estimations are largely based on common statistical methods, making it difficult to establish a direct causal relationship between haze and certain health conditions due to the complex nature of air pollutants and the lack of accurate epidemiological records. By addressing these research areas, future studies can contribute to a better understanding of the association between particulate matter and respiratory diseases during haze events. This knowledge can inform public health policies, air pollution management strategies, and targeted interventions to protect vulnerable populations and mitigate the health impacts of haze-related particulate matter exposure.

Author Contributions

Conceptualization, Norazian Mohamed Noor; Methodology, Norazian Mohamed Noor; Software, Afiqah Ma'amor and Izzati Amani Mohd Jafri; Validation, Ahmad Zia Ul Saufie, and Nor Azrita Amin; Formal analysis, Afiqah Ma'amor; Investigation, Afiqah Ma'amor and Nur Alis Addiena; Writing—original draft preparation, Afiqah Ma'amor; Writing—review and editing, Norazian Mohamed Noor; Supervision, Norazian Mohamed Noor; Project administration, Gyorgy Deak and Madalina Boboc.

Conflict of Interest

The authors declare no conflict of interest.

Funding

This research received no external funding.

Acknowledgement

The author would like to thank to Department of Environment Malaysia for the air pollutant dataset and the Ministry of Health (MOH) Malaysia for the health dataset.

References

[1] Wu, S., Deng, F., Wang, X., et al., 2013. Association of lung function in a panel of young healthy adults with various chemical components of ambient fine particulate air pollution in Beijing, China. Atmospheric Environment. 77, 873-884.
DOI: https://doi.org/10.1016/j.atmosenv.2013.06.018

[2] Wang, S., Hao, J., 2012. Air quality management in China: Issues, challenges, and options. Journal of Environmental Sciences. 24(1), 2-13.
DOI: https://doi.org/10.1016/S1001-0742(11)60724-9

[3] Li, Y., Zheng, C., Ma, Z., et al., 2019. Acute and cumulative effects of haze fine particles on mortality and the seasonal characteristics in Beijing, China, 2005-2013: A time-stratified case-crossover study. International Journal of Environmental Research and Public Health. 16(13), 2383.
DOI: https://doi.org/10.3390/ijerph16132383

[4] Latif, M.T., Othman, M., Idris, N., et al., 2018. Impact of regional haze towards air quality in Malaysia: A review. Atmospheric Environment. 177, 28-44.
DOI: https://doi.org/10.1016/j.atmosenv.2018.01.002

[5] Mahmud, M., 2013. Assessment of atmospheric impacts of biomass open burning in Kalimantan, Borneo during 2004. Atmospheric Environment. 78, 242-249.
DOI: https://doi.org/10.1016/j.atmosenv.2012.03.019

[6] Dotse, S.Q., Dagar, L., Petra, M.I., et al., 2016. Influence of Southeast Asian Haze episodes on high PM10 concentrations across Brunei Darussalam. Environmental Pollution. 219, 337-352.
DOI: https://doi.org/10.1016/j.envpol.2016.10.059

[7] Wen, Y.S., bin Mohd Nor, A.F., 2016. Transboundary air pollution in Malaysia: Impact and perspective on haze. Nova Journal of Engineering and Applied Sciences. 5(1).
DOI: https://doi.org/10.20286/nova-jeas-050103

[8] Indonesia Palm Oil Production by Year (1000 MT) [Internet]. Available from: https://www.indexmundi.com/agriculture/?country=id&commodity=palm-oil&graph=production

[9] Zainal, Z., 2016. Root problem of forest fire and solutions in completion (Study in the Riauprovince). Proceedings International Conference on Social Politics. 1.

[10] Forsyth, T., 2014. Public concerns about transboundary haze: A comparison of Indonesia, Singapore, and Malaysia. Global Environmental Change. 25, 76-86.
DOI: https://doi.org/10.1016/j.gloenvcha.2014.01.013

[11] Jafri, I.A.M., Noor, N.M., Rahim, N.A.A.A., et al., 2023. Spatial and temporal analysis of particulate matter (PM10) in urban-industrial environment during episodic haze events in Malaysia. Environment Asia. 16(1), 111-125.
DOI: https://doi.org/10.14456/ea.2023.10

[12] Pavagadhi, S., Betha, R., Venkatesan, S., et al., 2013. Physicochemical and toxicological characteristics of urban aerosols during a recent Indonesian biomass burning episode. Environmental Science and Pollution Research. 20, 2569-2578.
DOI: https://doi.org/10.1007/s11356-012-1157-9

[13] Khan, M.F., Latif, M.T., Saw, W.H., et al., 2016. Fine particulate matter in the tropical environment: monsoonal effects, source apportionment, and health risk assessment. Atmospheric Chemistry and Physics. 16(2), 597-617.
DOI: https://doi.org/10.5194/acp-16-597-2016

[14] Abba, E.J., Unnikrishnan, S., Kumar, R., et al., 2012. Fine aerosol and PAH carcinogenicity estimation in outdoor environment of Mumbai City, India. International Journal of Environmental Health Research. 22(2), 134-149.
DOI: https://doi.org/10.1080/09603123.2011.613112

[15] Department of Environment., 2010. Air quality: Continuous Air Quality Monitoring (CAQM) [Internet]. Available from: https://www.doe.gov.my/wp-content/uploads/2021/10/Air-Qulaity.pdf

[16] Mohammed, S.A., Yusof, M.M., 2013. Towards an evaluation framework for information quality management (IQM) practices for health information systems—evaluation criteria for effective IQM practices. Journal of Evaluation in Clinical Practice. 19(2), 379-387.
DOI: https://doi.org/10.1111/j.1365-2753.2012.01839.x

[17] Latif, M.T., Dominick, D., Ahamad, F., et al., 2014. Long term assessment of air quality from a background station on the Malaysian Peninsula. Science of the Total Environment. 482, 336-348.
DOI: https://doi.org/10.1016/j.scitotenv.2014.02.132

[18] Hussain, H., 2019. Jerebu bakal pulih, ribut petir pula menyusul [Haze will recover, thunderstorms will follow] [Internet]. Available from: https://www.sinarharian.com.my/article/48783/BERITA /Nasional/Jerebu-bakal-pulih-ribut-petir-pula-menyusul

[19] Official Portal of Department of Environment. Environmental Quality Report 2019 [Internet]; DOE: Putrajaya, Malaysia, 2019. Available from: https://enviro2.doe.gov.my/ekmc/wp-content/uploads/2020/09/EQR-20191.pdf

[20] Kumar, A., Gupta, I., Brandt, J., et al., 2016. Air quality mapping using GIS and economic evaluation of health impact for Mumbai City, India. Journal of the Air & Waste Management Association. 66(5), 470-481.
DOI: https://doi.org/10.1080/10962247.2016.1143887

[21] Jumaah, H.J., Ameen, M.H., Kalantar, B., et al., 2019. Air quality index prediction using IDW geostatistical technique and OLS-based GIS technique in Kuala Lumpur, Malaysia. Geomatics, Natural Hazards and Risk. 10(1), 2185-2199.
DOI: https://doi.org/10.1080/19475705.2019.1683084

[22] Rahman, S.R.A., Ismail, S.N.S., Raml, M.F., et al., 2015. The assessment of ambient air pollution trend in Klang Valley, Malaysia. World Environment. 5(1), 1-11.

[23] De Iaco, S., Palma, M., Posa, D., 2005. Modeling and prediction of multivariate space-time random fields. Computational Statistics & Data Analysis. 48(3), 525-547.
DOI: https://doi.org/10.1016/j.csda.2004.02.011

[24] Fan, H., Zhao, C., Yang, Y., 2020. A comprehensive analysis of the spatio-temporal variation of urban air pollution in China during 2014-2018. Atmospheric Environment. 220, 117066.
DOI: https://doi.org/10.1016/j.atmosenv.2019.117066

[25] Amil, N., Latif, M.T., Khan, M.F., et al., 2016. Seasonal variability of PM 2.5 composition and sources in the Klang Valley urban-industrial environment. Atmospheric Chemistry and Physics. 16(8), 5357-5381.
DOI: https://doi.org/10.5194/acp-16-5357-2016

[26] Jaafar, H., Azzeri, A., Isahak, M., et al., 2021. The impact of haze on healthcare utilizations for acute respiratory diseases: Evidence from Malaysia. Frontiers in Ecology and Evolution. 9, 764300.

DOI: https://doi.org/10.3389/fevo.2021.764300

[27] Khan, M.F., Hamid, A.H., Ab Rahim, H., et al., 2020. El Niño driven haze over the southern Malaysian peninsula and Borneo. Science of the Total Environment. 730, 139091.
DOI: https://doi.org/10.1016/j.scitotenv.2020.139091

[28] Tella, A., Balogun, A.L., 2021. Prediction of ambient PM10 concentration in Malaysian cities using geostatistical analyses. Journal of Advanced Geospatial Science & Technology. 1(1), 115-127.

[29] Wang, W., Ying, Y., Wu, Q., et al., 2015. A GIS-based spatial correlation analysis for ambient air pollution and AECOPD hospitalizations in Jinan, China. Respiratory Medicine. 109(3), 372-378.
DOI: https://doi.org/10.1016/j.rmed.2015.01.006

[30] Marmaya, E.A., Mahbub, R., 2018. A comparative study on the environmental impact assessment of industrial projects in Malaysia. IOP Conference Series: Earth and Environmental Science. 117(1), 012020.
DOI: https://doi.org/10.1088/1755-1315/117/1/012020

[31] Daoud, J.I., 2017. Multicollinearity and regression analysis. Journal of Physics: Conference Series. 949(1), 012009.
DOI: https://doi.org/10.1088/1742-6596/949/1/012009

[32] Azmi, S.Z., Latif, M.T., Ismail, A.S., et al., 2010. Trend and status of air quality at three different monitoring stations in the Klang Valley, Malaysia. Air Quality, Atmosphere & Health. 3, 53-64.
DOI: https://doi.org/10.1007/s11869-009-0051-1

[33] Wang, Y., Wild, O., Chen, H., et al., 2020. Acute and chronic health impacts of PM2.5 in China and the influence of interannual meteorological variability. Atmospheric Environment. 229, 117397.
DOI: https://doi.org/10.1016/j.atmosenv.2020.117397

[34] Sansuddin, N., Ramli, N.A., Yahaya, A.S., et al., 2011. Statistical analysis of PM 10 concentrations at different locations in Malaysia. Environmental Monitoring and Assessment. 180, 573-588.
DOI: https://doi.org/10.1007/s10661-010-1806-8

[35] Anderson, G.B., Dominici, F., Wang, Y., et al., 2013. Heat-related emergency hospitalizations for respiratory diseases in the Medicare population. American Journal of Respiratory and Critical Care Medicine. 187(10), 1098-1103.
DOI: https://doi.org/10.1164/rccm.201211-1969OC