Progress in Energy and Environment

Journal homepage: https://karyailham.com.my/index.php/progee/index
Link to this article:

Vol. 31 Issue 05 (2025) 36–45

Case Studies

Comparative Analysis of PM_{10} and $PM_{2.5}$ Before, During, and After the COVID-19 Pandemic in Shah Alam, Malaysia

OPEN ACCESS

Fairus Muhammad Darus[1], Nurul Latiffah Abd Rani[*,1], Nurul Nisa' Khairol Azmi[2]

[1] School of Chemistry & Environment, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam 40450, Selangor, Malaysia

[2] Centre of Mathematical Sciences, Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Seremban Campus, 70300 Seremban, Negeri Sembilan, Malaysia

[*] **Correspondence email:** nurullatiffah@uitm.edu.my

Abstract

Particulate matter (PM_{10} and $PM_{2.5}$) is a major environmental and public health concern due to its ability to penetrate the human respiratory system and elevate risks of respiratory and cardiovascular diseases. This study examines the impact of COVID-19 restrictions on PM_{10} and $PM_{2.5}$ concentrations in Shah Alam, Malaysia, from 2018 to 2023, covering three phases: pre-COVID (2018–2019), COVID (2020–2021), and post-COVID (2022–2023). Daily 24-hour mean data from the Department of Environment were analysed using the Kruskal–Wallis test with Dunn's post hoc comparisons. Results revealed significant differences across the three phases ($p < 0.001$). PM_{10} and $PM_{2.5}$ concentrations declined sharply during the COVID period by approximately 29% and 32.5%, respectively, compared to pre-COVID levels, with large effect sizes confirming substantial reductions. Post-COVID years showed modest rebounds but remained 23% (PM_{10}) and 25.5% ($PM_{2.5}$) lower than pre-pandemic baselines. These findings align with national and international evidence, underscoring the strong influence of anthropogenic activity on particulate matter levels. The results highlight the importance of integrating emission control policies with regional haze management to sustain long-term improvements in urban air quality.

Article Info

Received: 7 July 2025

Received in revised form: 28 August 2025

Accepted: 27 September 2025

Available online 23 October 2025

Keywords

Air Pollution Trends
PM10
PM2.5
Shah Alam
COVID-19

1. Introduction

Air pollution is a longstanding environmental and public health concern, particularly in rapidly urbanising regions, where particulate matter (PM_{10} and $PM_{2.5}$) is of greatest concern due to its ability to penetrate deep into the respiratory system and elevate risks of respiratory and cardiovascular diseases [1]. Exposure to these particles has been consistently linked to respiratory diseases, cardiovascular complications, and elevated mortality risks [2]. Globally, fine particulate matter is estimated to contribute to millions of premature deaths annually, underscoring the severity of the issue [3].

Urban and industrialised areas such as Shah Alam in Malaysia are especially vulnerable. High traffic volumes, intensive industrial activities, and recurring transboundary haze episodes frequently push pollution levels above the World Health Organisation's recommended limits [4]. These challenges highlight the importance of continuous monitoring and systematic air quality evaluation as integral components of environmental management.

The COVID-19 pandemic, beginning in 2020, provided a unique natural experiment to assess the influence of anthropogenic activity on air quality. Strict Movement Control Orders (MCOs) sharply declined economic activity, traffic, and industrial emissions. This allowed observing how urban air quality responded when human pressures were abruptly curtailed [5]. Evidence from multiple regions worldwide consistently shows that pandemic lockdowns brought about short-term improvements in air quality. For example, PM_{10} concentrations declined by nearly 30% in major cities in China, while $PM_{2.5}$ levels exhibited comparable reductions during the strictest lockdown phases [6,7]. Global comparative studies echoed these findings, reporting reductions in fine particulate matter of more than one-third in many urban centres during 2020 [3].

Abdullah et al. [5] reported that $PM_{2.5}$ concentrations declined by more than 60% at several locations during the initial MCO, with PM_{10} showing comparable reductions. These findings emphasise the dominant role of transport and industrial emissions in shaping the nation's air quality. However, most studies have concentrated on the early months of the pandemic, leaving relatively limited evidence on longer-term air quality trends once restrictions were relaxed and economic activities resumed. Comparative research from other countries further suggests that while improvements during lockdowns were substantial, they were not always sustained. In China, particulate matter concentrations rebounded as restrictions were lifted, and industrial activities resumed [6]. Global evidence similarly indicates that post-pandemic air quality trends varied across regions depending on local emission sources, meteorological conditions, and the stringency of lockdown measures [3].

While short-term reductions in particulate matter concentrations during COVID-19 lockdowns are well-documented, empirical evidence remains on how these improvements evolved in the longer term, particularly in the Malaysian context. Existing studies have largely focused on the immediate effects of the initial lockdown phases, providing limited insight into whether air quality gains were sustained as restrictions were lifted and economic activities normalised. This knowledge gap constrains the ability of policymakers to design evidence-based interventions for long-term air quality management.

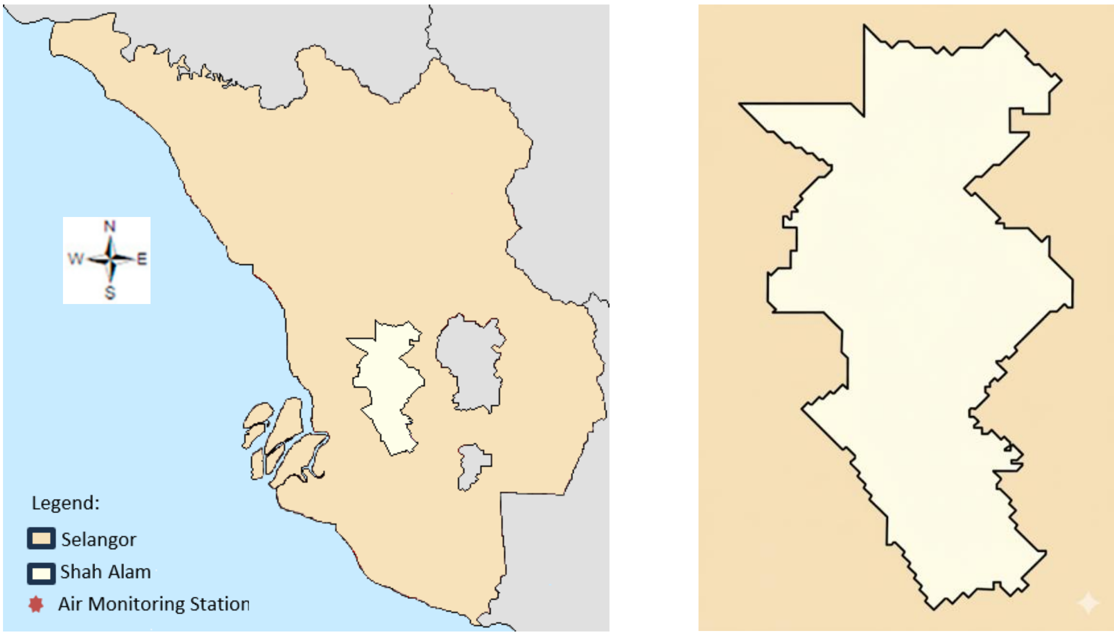
This study aims to compare PM_{10} and $PM_{2.5}$ concentrations in Shah Alam, Malaysia, before, during, and after the COVID-19 pandemic (2018–2023). By examining differences across these three phases, the study aims to quantify how anthropogenic activity influenced particulate matter levels and provide insights into the sustainability of air quality improvements beyond the pandemic period.

2. Methodology

2.1. PM_{10} and $PM_{2.5}$ Data

PM_{10} and $PM_{2.5}$ concentration data were obtained from the Department of Environment (DOE), Ministry of Natural Resources and Environmental Sustainability, Malaysia. The data were sourced from the Shah Alam continuous air quality monitoring station in Selangor (coordinates: 3°06.287′ N, 101°33.368′ E). This station was selected due to its strategic location within a highly industrialised and densely populated urban zone, representing anthropogenic emission influences in the Klang Valley region [8]. The geographical position of the monitoring station is illustrated in Figure 1.

The dataset spanned 1 January 2018 to 31 December 2023, with concentrations averaged over 24-hour intervals. PM_{10} and $PM_{2.5}$ concentrations were recorded at 10-minute intervals and aggregated into hourly means to minimise short-term variability and enhance data robustness. The monitoring was conducted at the Continuous Air Quality Monitoring Station (CAQMS) in Shah Alam using a Thermo Scientific TEOM 1450-DF (Tapered Element Oscillating Microbalance) analyser, a U.S. EPA-designated Federal Equivalent Method (FEM) for particulate matter measurement. The instrument underwent routine monthly calibration and preventive maintenance to ensure accuracy, precision, and compliance with international quality assurance/quality control (QA/QC) protocols [9,10]. The monitoring system automatically validated all raw datasets, followed by secondary review and certification by trained personnel before submission to the Department of Environment (DOE) [11].



(a) (b)

Figure 1. (a) Selangor map and (b) Shah Alam map.

2.2. Statistical analysis

A nonparametric statistical approach was employed to assess potential differences in particulate matter (PM_{10} and $PM_{2.5}$) concentrations across distinct phases of the COVID-19 pandemic. Specifically, the Kruskal–Wallis H test was selected because it does not require the stringent assumptions of normality and homogeneity of variance typically associated with parametric tests such as ANOVA [12]. This approach is particularly suitable for environmental datasets, where pollutant concentrations frequently display skewed distributions, seasonal fluctuations, and outliers that violate parametric assumptions [13].

The analysis was stratified into three temporal phases reflecting the progression of the pandemic: the pre-pandemic phase (2018–2019), the pandemic phase (2020–2021), and the post-pandemic phase (2022–2023). This temporal categorisation enabled the evaluation of how abrupt reductions in anthropogenic activities, such as those imposed by the Movement Control Order (MCO), influenced ambient air quality in Shah Alam over time.

Following the overall significance test, multiple pairwise comparisons were performed to determine which specific phases differed significantly. Dunn's post hoc test with Bonferroni correction was applied to control for Type I error inflation caused by multiple comparisons [14]. The Bonferroni-adjusted Dunn procedure provided a conservative adjustment to the significance level, strengthening statistical inference's reliability. The combined use of the Kruskal–Wallis H test and Dunn's adjusted pairwise analysis ensured a rigorous examination of temporal differences in PM concentrations across the three phases of the COVID-19 period, allowing conclusions to be both statistically robust and environmentally meaningful.

2.3. Limitation

This study has several limitations. First, the analysis was limited to Shah Alam, which, although representative of a rapidly urbanising Malaysian city, does not capture the variability of air pollution dynamics across other urban, suburban, and rural regions in Malaysia, thereby restricting the generalizability of the findings. Second, the scope was confined to particulate matter (PM_{10} and $PM_{2.5}$), excluding other key pollutants such as NO_2, SO_2, CO, and O_3 that could provide a more comprehensive understanding of air quality. Third, reliance on secondary data from a single DOE monitoring station may also introduce calibration, missing values, or spatial representativeness uncertainties. Fourth, meteorological factors strongly influencing pollutant dispersion were not fully integrated into the analysis. Fifth, the pandemic context is a limitation, as the reductions observed during the Movement Control Order (MCO) reflected extraordinary conditions not directly replicable under normal policy settings. Finally, the post-pandemic assessment spanned only two years (2022–2023), limiting insights into the sustainability of observed improvements.

3. Results

3.1. Concentrations of PM_{10} and $PM_{2.5}$

Table 1 summarises the descriptive and inferential statistics of PM_{10} and $PM_{2.5}$ concentrations in Shah Alam across pre-COVID (2018–2019), COVID (2020–2021), and post-COVID (2022–2023) phases. The results reveal marked temporal variation, influenced by transboundary haze events and local anthropogenic activities.

For PM_{10}, the highest mean concentration was observed in 2019 (41.99 µg/m³), with extreme maxima exceeding 150 µg/m³ and high variability (SD = 21.61 µg/m³; IQR = 18.26 µg/m³). This aligns with the severe regional haze episodes reported that year [15]. In contrast, concentrations declined sharply during COVID, with the lowest mean recorded in 2020 (25.77 µg/m³). Inferential tests confirmed significant reductions between pre-COVID and COVID phases ($t = –6.44$, $p < 0.001$, $d = 0.74$), indicating a large and environmentally meaningful effect. Post-COVID years showed modest increases (26.67–32.26 µg/m³), yet remained below pre-pandemic peaks, with only a small effect size observed between COVID and post-COVID phases ($d = 0.25$).

A similar pattern was evident for $PM_{2.5}$. The pre-COVID phase again recorded the highest concentrations, particularly in 2019 (mean = 32.14 µg/m³; max = 144.92 µg/m³). $PM_{2.5}$ levels declined substantially during COVID, reaching a mean of 18.06 µg/m³ in 2020. Statistical comparisons confirmed significant reductions from pre-COVID to COVID ($t = –5.63$, $p < 0.001$, $d = 0.65$), with effect sizes indicating meaningful improvements. Post-COVID years showed slightly higher concentrations (20.66–22.07 µg/m³) but remained lower than pre-pandemic levels, with only a small rebound effect ($d = 0.28$).

Figure 2 illustrates the percentage change in PM_{10} and $PM_{2.5}$ concentrations during COVID-19 (2020–2021) and post-COVID (2022–2023) compared with pre-COVID levels (2018–2019). Both pollutants showed significant reductions during the COVID-19 period. PM_{10} decreased by 29.1%, while $PM_{2.5}$ declined even more sharply by 32.5% relative to pre-COVID concentrations. These reductions reflect the direct effect of the Movement Control Order (MCO), which curtailed vehicular traffic, industrial activities, and other anthropogenic emissions. The sharper decline in $PM_{2.5}$ compared with PM_{10} underscores the dominant role of combustion-related sources, such as transportation and industrial fuel use, which were most affected during lockdowns.

Table 1. Descriptive and inferential statistics of PM_{10} and $PM_{2.5}$ (µgm-3) concentrations in Shah Alam across pre-COVID, COVID, and post-COVID episodes.

Variable	Episode	Year	Min	Max	Mean	SD	Median	IQR	t or Z	p	Effect size (d or r)
PM_{10}	Pre-COVID	2018	11.76	78.38	34.51	10.37	32.90	13.40			
		2019	15.02	156.55	41.99	21.61	37.13	18.26			
	COVID	2020	8.43	46.81	25.77	7.34	25.53	9.63	-6.44	<0.001*	0.74
		2021	8.22	53.67	28.45	8.13	27.27	9.62			
	Post-COVID	2022	6.98	59.84	32.26	9.70	32.00	13.44	-2.10	0.04*	0.25
		2023	7.35	66.02	26.67	10.88	24.25	13.39			
$PM_{2.5}$	Pre-COVID	2018	8.60	62.64	25.20	8.15	23.77	11.67			
		2019	10.11	144.92	32.14	19.71	27.27	15.40			
	COVID	2020	5.97	35.60	18.06	5.53	17.60	7.41	-5.63	<0.001*	0.65
		2021	5.61	43.01	20.64	6.32	20.20	8.16			
	Post-COVID	2022	5.47	39.35	20.66	6.15	19.67	7.88	-2.20	0.03*	0.28
		2023	5.12	58.60	22.07	9.93	19.94	11.98			

Note: Independent samples t-tests were conducted to compare mean concentrations between episodes. Cohen's d was calculated as the measure of effect size. * denote statistical significance at $p < 0.05$.*

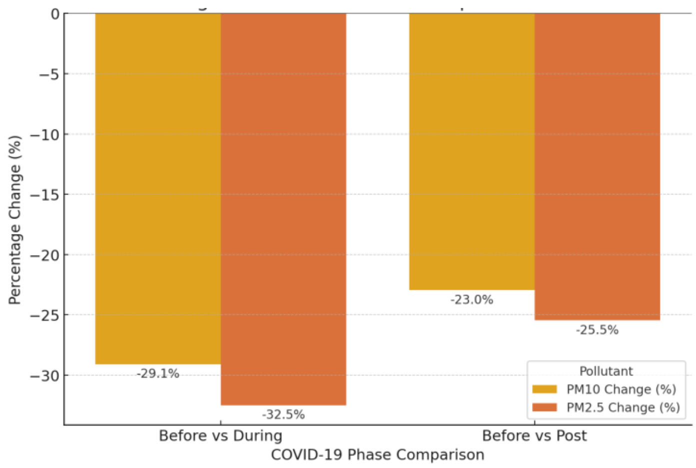
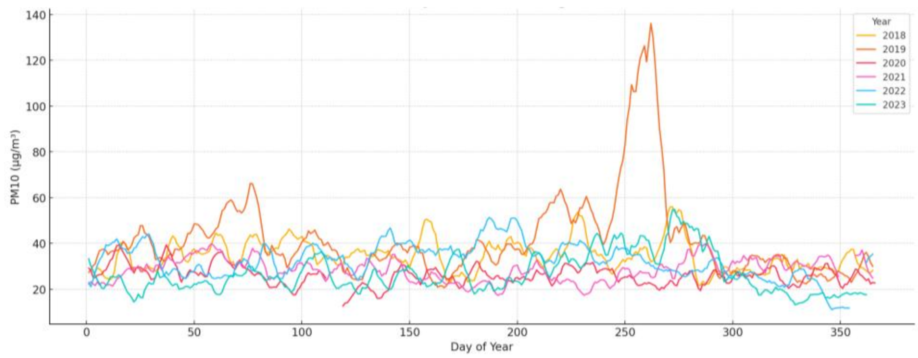


Figure 2. The bar chart shows the percentage change in PM10 and PM2.5 concentrations before, during, and after COVID-19.

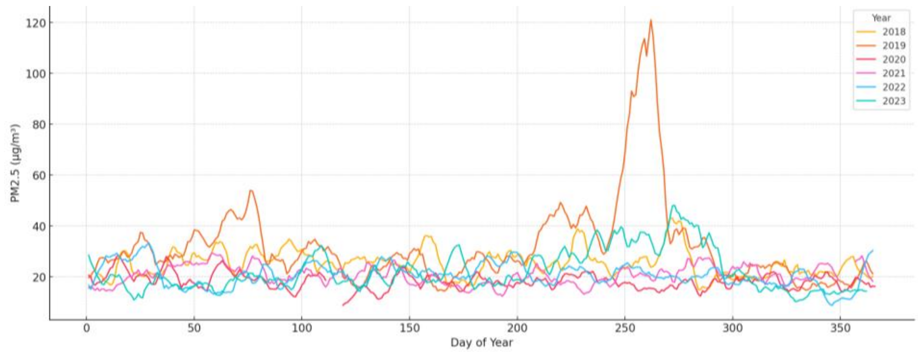
In the post-COVID period, PM_{10} and $PM_{2.5}$ remained lower than pre-COVID baselines, with declines of 23.0% and 25.5%, respectively. Although slightly higher than during the lockdown years, these values indicate that concentrations did not return to pre-pandemic peaks, suggesting a partial rebound. This pattern may be attributed to the resumption of economic and social activities, tempered by regulatory measures, cleaner fuel adoption, and the absence of severe haze events.

3.2. Annual Trends of PM_{10} and $PM_{2.5}$ Concentrations

Figure 3 illustrates the annual variations of PM_{10} and $PM_{2.5}$ concentrations in Shah Alam between 2018 and 2023, using a 7-day smoothed average. The graphs highlight seasonal fluctuations and episodic pollution events, demonstrating the interplay of regional haze, meteorological conditions, and local anthropogenic sources in shaping urban air quality. Meanwhile, Figure 4 presents the monthly distribution of PM_{10} and $PM_{2.5}$ concentrations in Shah Alam across three phases: pre-COVID (2018–2019), COVID (2020–2021), and post-COVID (2022–2023). The boxplots highlight seasonal fluctuations and episodic anomalies, while also illustrating the broader shifts in pollutant levels attributable to pandemic-related activity changes.



(a) PM_{10}

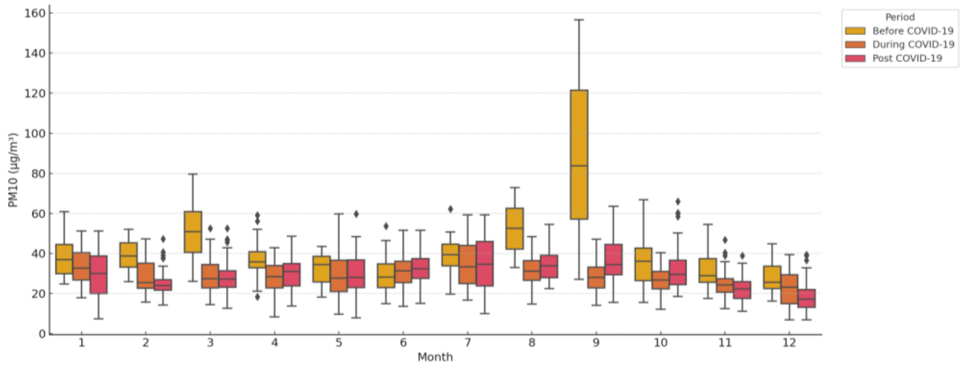


(b) $PM_{2.5}$

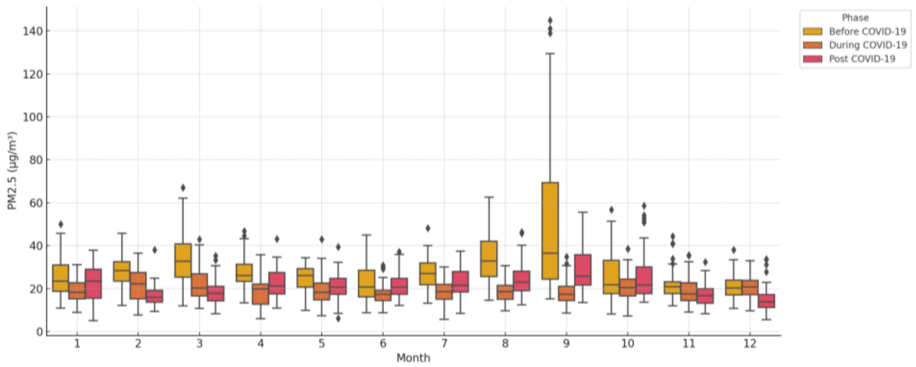
Figure 3. Annual trend distribution of (a) PM_{10} and (b) $PM_{2.5}$ concentrations.

For PM_{10}, concentrations in 2019 were consistently elevated compared to other years, with a pronounced peak around mid-year (Day 240–260), where values exceeded 120 µg/m³. This sharp rise corresponds with documented regional haze episodes linked to biomass burning in neighbouring countries, significantly impacting Malaysia's air quality. In contrast, concentrations during 2020 and 2021 were markedly lower and more stable, rarely exceeding 50 µg/m³. This period coincides with the COVID-19 lockdowns, when reduced vehicular traffic, industrial activity, and cross-border haze contributions collectively improved air quality. Post-COVID years (2022–2023) show moderate increases in PM_{10}, with episodic spikes but without reaching the extreme levels observed in 2019, suggesting a partial rebound of emissions alongside seasonal influences.

For $PM_{2.5}$, the temporal trend mirrors that of PM_{10}, with the highest concentrations in 2019 and a peak exceeding 100 µg/m³ during the haze event around Day 250. This highlights the role of fine particulate matter as a critical component of haze pollution, with stronger health implications given its ability to penetrate deep into the respiratory system. Like PM_{10}, the COVID years exhibited substantially lower $PM_{2.5}$ levels, averaging around 20 µg/m³, reflecting the reduced anthropogenic contributions. Post-COVID years (2022–2023) show a gradual increase in $PM_{2.5}$, with mean concentrations ranging between 20–30 µg/m³, but again not approaching the severe peaks of 2019.



(a) PM_{10}



(b) $PM_{2.5}$

Figure 4. Monthly distribution of (a) PM_{10} and (b) $PM_{2.5}$ concentrations in Shah Alam.

3.3. Particulate Matter Trends Across Pre-COVID, COVID, and Post-COVID Phases

This study comprehensively assesses PM_{10} and $PM_{2.5}$ concentrations in Shah Alam over six years (2018–2023), capturing conditions before, during, and after the COVID-19 pandemic. The results reveal substantial temporal variability shaped by both local anthropogenic activities and episodic transboundary haze, with three key phases: elevated levels in 2019, sharp declines during the Movement Control Order (MCO) in 2020–2021, and modest rebounds in 2022–2023.

The pre-COVID period, particularly 2019, emerged as the most polluted year, with annual mean PM_{10} and $PM_{2.5}$ concentrations reaching 41.99 µg/m³ and 32.14 µg/m³, respectively. Episodic spikes exceeded 150 µg/m³ for PM_{10} and 100 µg/m³ for $PM_{2.5}$, corresponding with severe transboundary haze episodes. These findings are consistent with long-term evidence from Shah Alam, where Azmi et al. [16] reported average PM_{10} concentrations of 54.84 µg/m³ between 1997 and 2006, attributing extreme values to vehicular emissions, industrial activity, and haze. Similarly, Zainal et al. [15] documented dramatic increases in PM_{10} and $PM_{2.5}$ in Kuala Lumpur and Putrajaya during the 2019 haze, with concentrations more than doubling compared to pre-haze periods. More recently, Rahim et al. [17]

confirmed through predictive modelling that PM_{10} frequently exceeded 150 µg/m³ during 2019 haze events across several Malaysian cities, underscoring the dominance of biomass burning in Sumatra as the principal driver. These studies reinforce that 2019 was a benchmark year for extreme particulate matter episodes in Malaysia.

The COVID-19 pandemic created an unprecedented "natural experiment" for assessing the influence of anthropogenic activity on urban air quality. In Shah Alam, PM_{10} and $PM_{2.5}$ concentrations declined sharply in 2020 to 25.77 µg/m³ and 18.06 µg/m³, respectively, with large effect sizes confirming substantial improvements. This aligns with nationwide observations: Abdullah et al. [5] reported reductions of up to 61.5% for PM_{10} and 63.2% for PM_{10} and $PM_{2.5}$ during strict MCO phases across Malaysia. Othman and Latif [18] similarly noted reductions across nine major Malaysian cities, while Rama Naidu and Chelliapan [19] highlighted consistent declines in particulate matter during the lockdown, alongside broader environmental benefits. Beyond Malaysia, global studies echo this trend. Benchrif et al. [20] observed significant reductions in PM_{10} and $PM_{2.5}$ across Moroccan cities, while Liang et al. [3] documented one-third reductions in fine particulate matter in urban centres worldwide. These findings affirm that reduced traffic and industrial activity were the dominant factors shaping improved air quality during the pandemic.

In the post-COVID years, PM_{10} and $PM_{2.5}$ concentrations increased moderately, with means ranging between 26.67–32.26 µg/m³ (PM_{10}) and 20.66–22.07 µg/m³ ($PM_{2.5}$). While higher than during the lockdown, these values remained lower than the extreme peaks of 2019, suggesting partial rebounds rather than full reversions. This pattern mirrors national and international evidence. Abdullah et al. [9] reported gradual increases during the conditional and recovery MCO phases, while studies in China similarly noted rebounds once restrictions were lifted [6,7]. The persistence of lower post-COVID baselines may reflect structural shifts in emissions due to regulatory measures, cleaner fuels, altered commuting patterns, and the absence of severe haze events during this period.

The declines in particulate matter during COVID-19 have direct implications for public health. Yeo et al. [21] demonstrated that PM_{10} and $PM_{2.5}$ were dominant predictors of COVID-19 case dynamics in Hulu Langat, surpassing meteorological factors. This supports the dual environmental and health benefits observed in the present study, where reduced particulate levels coincided with lower transmission risks. The cumulative evidence across studies underscores the urgency of sustaining air quality improvements through structural interventions rather than temporary restrictions.

4. Conclusions

This study provides evidence of temporal variability in PM_{10} and $PM_{2.5}$ concentrations in Shah Alam between 2018 and 2023, shaped by anthropogenic activity and transboundary haze. Concentrations peaked in 2019 during severe haze events, declined significantly during the COVID-19 Movement Control Order, and showed modest rebounds in 2022–2023. Statistical analysis confirmed large effect sizes between pre-COVID and COVID phases, underscoring the dominant role of traffic and industrial emissions in driving particulate matter levels.

The results complement long-term studies and recent nationwide evidence, reinforcing that meaningful improvements in air quality can be achieved when anthropogenic pressures are reduced. Importantly, post-COVID levels have not returned to pre-pandemic maxima, suggesting potential structural shifts in emission baselines. For policymakers, these findings highlight the dual need to control local emissions and strengthen regional cooperation on transboundary haze management. Future research should incorporate source apportionment and health risk assessments to support evidence-based air quality strategies in Malaysia.

Declaration of Conflict of Interest

The authors declared no conflict of interest with any other party in the publication of the current work.

Acknowledgement

The authors thank Mashitah Darus from the Air Division, Department of Environment, Ministry of Natural Resources and Environmental Sustainability, Malaysia, for providing us with our study's raw data of Shah Alam monitoring stations. This research was not funded by any grant.

References

[1] J. Guo, G. Chai, X. Song, X. Hui, Z. Li, X. Feng, and K. Yang, Long-Term Exposure to Particulate Matter on Cardiovascular and Respiratory Diseases in Low- and Middle-Income Countries: A Systematic Review and Meta-Analysis. Frontiers in Public Health 11 (2023) 1134341. https://doi.org/10.3389/fpubh.2023.1134341.

[2] World Health Organization, WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide, 2021.

[3] S. Muhammad, X. Long, and M. Salman, COVID-19 Pandemic and Environmental Pollution: A Blessing in Disguise? The Science of the Total Environment 728 (2020) 138820. https://doi.org/10.1016/j.scitotenv.2020.138820.

[4] R. Afroz, M.N. Hassan, and N.A. Ibrahim, Review of Air Pollution and Health Impacts in Malaysia. Environmental Research 92 (2003) 71–77. https://doi.org/10.1016/s0013-9351(02)00059-2.

[5] S. Abdullah, A.A. Mansor, N.N.L.M. Napi, W.N.W. Mansor, A.N. Ahmed, M. Ismail, and Z.T.A. Ramly, Air Quality Status during 2020 Malaysia Movement Control Order (MCO) Due to 2019 Novel Coronavirus (2019-nCoV) Pandemic. The Science of the Total Environment 729 (2020) 139022. https://doi.org/10.1016/j.scitotenv.2020.139022.

[6] L. Li, Q. Li, L. Huang, Q. Wang, A. Zhu, J. Xu, Z. Liu, H. Li, L. Shi, R. Li, M. Azari, Y. Wang, X. Zhang, Z. Liu, Y. Zhu, K. Zhang, S. Xue, M.C.G. Ooi, D. Zhang, and A. Chan, Air Quality Changes during the COVID-19 Lockdown over the Yangtze River Delta Region: An Insight into the Impact of Human Activity Pattern Changes on Air Pollution Variation. The Science of the Total Environment 732 (2020) 139282. https://doi.org/10.1016/j.scitotenv.2020.139282.

[7] Y. Wang, Y. Yuan, Q. Wang, C. Liu, Q. Zhi, and J. Cao, Changes in Air Quality Related to the Control of Coronavirus in China: Implications for Traffic and Industrial Emissions. The Science of the Total Environment 731 (2020) 139133. https://doi.org/10.1016/j.scitotenv.2020.139133.

[8] S.R.A. Tahman, S.N.S. Ismail, M.F. Ramli, M.T. Latif, E.Z. Abidin, and S.M. Praveena, The Assessment of Ambient Air Pollution Trend in Klang Valley, Malaysia. World Environment 5 (2015) 1–11.

[9] S. Abdullah, M. Ismail, and S.Y. Fong, Multiple Linear Regression (MLR) Models for Long Term Pm10 Concentration Forecasting during Different Monsoon Seasons. Journal of Sustainability Science and Management 12 (2017) 60–69.

[10] M. Othman, and M.T. Latif, Air Pollution Impacts from COVID-19 Pandemic Control Strategies in Malaysia. Journal of Cleaner Production 291 (2021) 125992. https://doi.org/10.1016/j.jclepro.2021.125992.

[11] N. Banan, M.T. Latif, L. Juneng, and F. Ahamad, Characteristics of Surface Ozone Concentrations at Stations with Different Backgrounds in the Malaysian Peninsula. Aerosol and Air Quality Research 13 (2013) 1090–1106. https://doi.org/10.4209/aaqr.2012.09.0259.

[12] J.D. Gibbons, and S. Chakraborti, Nonparametric statistical inference, fifth edition, 5th edn, Chapman & Hall/CRC, Philadelphia, PA, 2010. https://doi.org/10.1201/9781439896129.

[13] D.R. Helsel, R.M. Hirsch, K.R. Ryberg, S.A. Archfield, and E.J. Gilroy, Statistical Methods in Water Resources. Techniques and Methods (2020). https://doi.org/10.3133/tm4a3.

[14] A. Dinno, Nonparametric Pairwise Multiple Comparisons in Independent Groups Using Dunn's Test. The Stata Journal 15 (2015) 292–300. https://doi.org/10.1177/1536867X1501500117.
[15] S. Zainal, N.M. Zamre, and M.F. Khan, Emission Level of Air Pollutants during 2019 Pre-Haze, Haze, and Post-Haze Episodes in Kuala Lumpur and Putrajaya. Malaysian Journal of Chemical Engineering and Technology (MJCET) 4 (2021) 137. https://doi.org/10.24191/mjcet.v4i2.14299.
[16] S.Z. Azmi, M.T. Latif, A.S. Ismail, L. Juneng, and A.A. Jemain, Trend and Status of Air Quality at Three Different Monitoring Stations in the Klang Valley, Malaysia. Air Quality, Atmosphere, & Health 3 (2010) 53–64. https://doi.org/10.1007/s11869-009-0051-1.
[17] N.A.A.A. Rahim, N.M. Noor, I.A.M. Jafri, A.Z. Ul-Saufie, M.A. Kamaruddin, M.R.R.M.A. Zainol, A.V. Sandu, P. Vizureanu, and G. Deak, Modelling Particulate Matter (PM10) Variations during Transboundary Haze Events Using a Modified Quantile Regression Approach. Analytical Science Advances 6 (2025) e70027. https://doi.org/10.1002/ansa.70027.
[18] M. Othman, and M.T. Latif, Air Pollution Impacts from COVID-19 Pandemic Control Strategies in Malaysia. Journal of Cleaner Production 291 (2021) 125992. https://doi.org/10.1016/j.jclepro.2021.125992.
[19] S.N. Rama Naidu, and S. Chelliapan, The Impact of Movement Control Order (MCO) during COVID-19 Pandemic on Air and Water Quality in Malaysia: A Mini Review. 89 (2021) 601–606.
[20] A. Benchrif, A. Wheida, M. Tahri, R.M. Shubbar, and B. Biswas, Air Quality during Three Covid-19 Lockdown Phases: AQI, PM2.5 and NO2 Assessment in Cities with More than 1 Million Inhabitants. Sustainable Cities and Society 74 (2021) 103170. https://doi.org/10.1016/j.scs.2021.103170.
[21] P. Yeo, A. Abu Bakar, Z. Othman, M. Sahani, S. Zainudin, and Z. Suli, The Effect of Meteorology and Air Quality to the Covid-19 Cases in Malaysia: A Multivariate Deep Learning Approach. Sains Malaysiana 53 (2024) 3831–3843. https://doi.org/10.17576/jsm-2024-5311-24.