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Trend and Interrelationship of $PM_{2.5}$, Gaseous Pollutants and Meteorological Factors in Kuala Terengganu, Malaysia

Nurul Ain Ismail[1], Samsuri Abdullah[1,2*], Amalina Abu Mansor[2], Aimi Nursyahirah Ahmad[2], Ali Najah Ahmed[3], Marzuki Ismail[2,4]

[1] Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu, Kuala Nerus 21030, Malaysia
[2] Institute of Tropical Biodiversity and Sustainable Development, Universiti Malaysia Terengganu, Kuala Nerus 21030, Malaysia
[3] Research Centre for Human-Machine Collaboration (HUMAC), School of Engineering and Technology, Sunway University, Bandar Sunway 47500, Malaysia
[4] Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, Kuala Nerus 21030, Malaysia

Corresponding Author Email: samsuri@umt.edu.my

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ABSTRACT

Air pollution has become a major environmental health issue in the world. Over the years, air pollution in Malaysia is contributed by growing numbers of air pollutant sources. This study identifies the trend of the particulate matters ($PM_{2.5}$, PM_{10}), gaseous pollutant (SO_2, NO_2, O_3, CO) and meteorological factors (wind speed, relative humidity, and ambient temperature) at Kuala Terengganu. The study was conducted through descriptive analysis by using the air quality data of the selected parameters and meteorological data from year 2018 until 2022. Result of the study found that similar trend recorded for concentration $PM_{2.5}$ and PM_{10}. The study also found uniform trend of concentration for SO_2, NO_2, O_3, CO, wind speed, relative humidity, and ambient temperature over the years. There are several times of unusual high concentration of the air pollutants and meteorological parameters which suspected due to external factors and events. Result of the correlation analysis shows that $PM_{2.5}$ is strongly affected by concentration PM_{10} ($r=0.900$, $p<0.01$) and CO ($r=0.500$, $p<0.05$) and weakly negative correlated with relative humidity ($r=-0.020$, $p<0.05$) and wind speed ($r=-0.035$, $p<0.05$). A strong correlation between $PM_{2.5}$ and CO indicated that human-caused emissions, such as those from vehicles and industries, were the main contributors of $PM_{2.5}$, which is stable in the atmosphere. Poor air quality can have an impact on visibility, agricultural productivity, public health, and cultural and aesthetic values, it is essential to manage it by determine the cause and interrelationship of $PM_{2.5}$ towards others gaseous pollutants and meteorological factors which can be use by local authority for decision making.

1. INTRODUCTION

Outdoor air pollution has become a leading environmental health issue in low, middle – and high-income countries where WHO estimated in the year 2019 that about 4.2 million premature deaths worldwide, which caused by exposure to fine particulate matter. The exposure eventually causes cardiovascular disease, respiratory disease, and cancer [1]. Particulate matter 2.5 microns ($PM_{2.5}$) is air particulates that possess has aerodynamic diameter equal to less than 2.5µm. Its tiny size made it easier to penetrate the human respiratory system and become one major cause of mortality and morbidity in humans [2]. Previous studies found that an increment in risk of arrhythmia, atherosclerosis, hypertension, myocardial infarction (MI), stroke, thrombosis, and heart failure in susceptible individuals within several hours to days of exposure to $PM_{2.5}$ [3-6]. According to the Environmental Quality Report 2020, growing numbers of air pollutants point of sources have resulted in air pollution in Malaysia. The main sources of the air pollutants emission were from operation of power plants, industrial activities, motor vehicles and other activities such as residential, commercial, and agricultural activities [4]. Industrial activities have caused $PM_{2.5}$ to be one of the main air pollutants which violate air quality in Southern Peninsular Malaysia [5].

Othman et al. [5] emphasized that air pollution might be affected by numerous factors and variability of air pollutants also can be affected by various sources of pollution. Nonetheless, Wu and Zhang [6] highlighted that the concentration of $PM_{2.5}$ is strongly affected by the concentration of air pollutants and conditions of the meteorological parameters in a non-linear pattern. Thus, this study was conducted to investigate the trend of the particulate matter, gaseous pollutants, and meteorological factors from the year 2018 until 2022 and to investigate the relationship of $PM_{2.5}$, gaseous pollutants, and meteorological factors at Kuala Terengganu. The outcome of this study shall be to help towards a better understanding of the variation of the air pollutants concentrations and meteorological factors over time and their function and external factors that affect the concentration of $PM_{2.5}$ concentrations which may be linked to the air pollution, and sources of the air pollutants at the area. Comprehending the relationship between $PM_{2.5}$ with meteorological factors and gaseous pollutants can help prevent and diagnose related conditions, as well as drive the development of better techniques and technologies to treat $PM_{2.5}$-induced illnesses [7-9].

2. METHODOLOGY

2.1 Area of study and data acquisition

Kuala Terengganu is the capital city of Terengganu Darul Iman. It is located on the east coast of Peninsular Malaysia. It is in lowland topography as it is near to the coastline area. The continuous air quality monitoring station (CAQM) that had been chosen in this study is located at Sekolah Kebangsaan Chabang Tiga (latitude 05°18'29.13" N; longitude: 103°07'13.41" E). The continuous air quality monitoring station is managed by the Department of Environment Malaysia (DOE). Data were acquired from the Department of Environment Malaysia (DOE). Parameters selected in this study are Particulate Matter 2.5 microns ($PM_{2.5}$), Particulate Matter 10 microns (PM_{10}), Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Ozone (O_3), Carbon Monoxide (CO), Wind Speed (WS), Relative Humidity (RH) and Ambient Temperature (T). The parameters were recorded at an average of every 1 hour from the year 2018 until the year 2022 through the Kuala Terengganu Air Quality Monitoring Station.

2.2 Data analysis

The acquired data were pre-processed, where missing values found in the data set were removed through the deletion technique. Ahmad et al. [7] emphasized that this is crucial to minimize the risk of bias. Descriptive analysis was applied to the data that had been pre-processed to determine the trend of the particulate matter, air pollutants and meteorological factors. The descriptive analysis can give insight into the behavior of the air pollutants and their trend over time and location [8]. Line plots were used to simulate the trend of the parameters [9, 10]. The analysis that establishes the level of agreement between two variables is called a correlation analysis. Spearman correlation analysis was conducted to study the relationship between $PM_{2.5}$ with PM_{10}, SO_2, NO_2, O_3, CO, WS, RH, and AT. The Spearman correlation is an appropriate statistical method to determine the correlation between ordinal variables [10-14]. The main goals of correlation analysis, commonly referred to as bivariate analysis, are to ascertain whether a relationship between variables exists and, if so, how big and how it operates [10].

3. RESULTS AND DISCUSSION

3.1 Trend of air pollutants and meteorological factors

Results of the descriptive analysis of $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, CO, WS, RH, and AT are tabulated in Table 1. The trend of the air pollutants and meteorological factors from the year 2018 until 2022 was also illustrated in Figure 1, Figure 2, and Figure 3. Based on Table 1, the highest average concentration of PM_{10} was 29.445 µg/m^3 in the year 2019 which is higher than the concentration of $PM_{2.5}$ (20.507 µg/m^3) in the same year. The maximum concentrations of $PM_{2.5}$ and PM_{10} are 206.285 µg/m^3 and 216.649 µg/m^3, respectively, while the minimum concentration values of $PM_{2.5}$ and PM_{10} are 0.08 (2022) and 265 µg/m^3 (2021). Maximum value of $PM_{2.5}$ and PM_{10} are 206.285 µg/m^3 (2021) and 216.649 µg/m^3 (2021). The yearly mean of $PM_{2.5}$ is exceeded from the New Malaysian Ambient Air Quality Standard (NMAAQS) which is 40 µg/m^3 (PM_{10}) and 15 µg/m^3 ($PM_{2.5}$). Table 1 shows only the year 2020 complied with the standard for $PM_{2.5}$ with a value of 14.726 µg/m^3, while all yearly mean for PM_{10} comply with the standards. In Table 1, results showed that the highest value of yearly mean for the concentration of the gaseous pollutant is CO (0.646 ppm) at the year 2018 followed by O_3 (0.018 ppm) (2018), NO_2 (0.006 ppm) (2018) and SO_2 (0.001 ppm) (2018-2022). The maximum concentration of SO_2 (0.007 ppm) (2019 and 2022), NO_2 (0.030 ppm) (2019), O_3 (0.690 ppm) (2018), and CO (2.658ppm) (2018) while the minimum concentration of SO_2, NO_2, and O_3 is zero and the minimum concentration of the CO is 0.073 ppm (2021).

In Table 1, the highest yearly mean for wind speed is 1.372 m/s (2021), relative humidity (84.292%) (2022) and ambient air temperature (27.595℃) (2021). Maximum wind speed is 11.805 m/s (2020), relative humidity (99.283%) (2020) and ambient temperature (38.945℃) (2021) and minimum wind speed recorded is zero, relative humidity (44.634%) (2019) and ambient temperature (17.996℃) (2018).

Table 1. Descriptive statistics of hourly air pollutants and meteorological parameters in Kuala Terengganu from 2018-2022

Parameter	Year	Mean± SD			Kurtosis	Skewness	Minimum	Maximum
$PM_{2.5}$ (µg/m^3)	2018	17.537	±	12.815	8.081	2.026	0.106	131.593
	2019	20.507	±	18.231	12.128	2.821	0.069	187.096
	2020	14.726	±	11.146	11.104	2.457	0.061	153.833
	2021	15.897	±	13.425	16.762	2.931	0.068	206.285
	2022	15.860	±	11.279	8.633	2.147	0.008	134.379
PM_{10} (µg/m^3)	2018	25.468	±	14.952	6.228	1.736	1.611	142.620
	2019	29.445	±	20.101	10.693	2.599	0.288	203.955
	2020	23.320	±	13.051	8.069	1.947	1.588	168.220
	2021	24.443	±	15.759	11.076	2.318	0.265	216.649
	2022	22.547	±	13.419	6.070	1.776	0.740	149.199
SO_2 (ppm)	2018	0.001	±	0.000	12.026	2.448	0.000	0.003
	2019	0.001	±	0.000	37.528	4.555	0.000	0.007
	2020	0.001	±	0.000	1.690	0.761	0.000	0.004
	2021	0.001	±	0.000	0.153	0.407	0.000	0.003
	2022	0.001	±	0.001	2.152	0.663	0.000	0.007

NO_2 (ppm)	2018	0.006	±	0.004	2.582	1.416	0.000	0.028
	2019	0.005	±	0.004	3.272	1.568	0.000	0.030
	2020	0.004	±	0.003	3.243	1.600	0.000	0.024
	2021	0.004	±	0.003	3.775	1.676	0.000	0.020
	2022	0.005	±	0.003	2.739	1.478	0.000	0.021
O_3 (ppm)	2018	0.018	±	0.012	-0.079	0.654	0.000	0.069
	2019	0.016	±	0.011	-0.430	0.454	0.000	0.058
	2020	0.015	±	0.010	-0.436	0.452	0.000	0.057
	2021	0.015	±	0.010	-0.507	0.453	0.000	0.045
	2022	0.014	±	0.010	-0.244	0.613	0.000	0.054
CO (ppm)	2018	0.646	±	0.230	7.022	1.881	0.082	2.658
	2019	0.563	±	0.237	4.283	1.587	0.100	2.292
	2020	0.500	±	0.183	6.847	1.773	0.044	2.180
	2021	0.549	±	0.201	3.632	1.313	0.073	1.829
	2022	0.611	±	0.187	3.204	1.153	0.046	1.774
WS (m/s)	2018	1.283	±	0.775	5.505	1.724	0.000	7.500
	2019	1.292	±	0.755	1.010	0.996	0.000	5.388
	2020	1.288	±	0.675	9.406	1.587	0.045	11.805
	2021	1.372	±	0.786	0.959	1.008	0.032	6.022
	2022	1.307	±	0.790	0.642	0.920	0.000	5.320
RH (%)	2018	82.372	±	10.683	-0.816	-0.480	51.100	98.133
	2019	80.703	±	11.204	-0.960	-0.330	44.634	99.000
	2020	83.814	±	10.400	-0.887	-0.428	48.234	99.283
	2021	82.901	±	10.455	-0.917	-0.308	48.784	99.000
	2022	84.292	±	10.532	-0.965	-0.447	50.834	99.000
AT (°C)	2018	26.676	±	2.649	-0.733	0.346	17.996	34.204
	2019	27.591	±	2.808	-0.901	0.250	20.592	34.703
	2020	26.960	±	2.559	-0.897	0.297	21.028	34.917
	2021	27.595	±	2.812	-0.233	0.434	20.630	38.945
	2022	27.550	±	2.614	-1.029	0.275	20.800	33.650

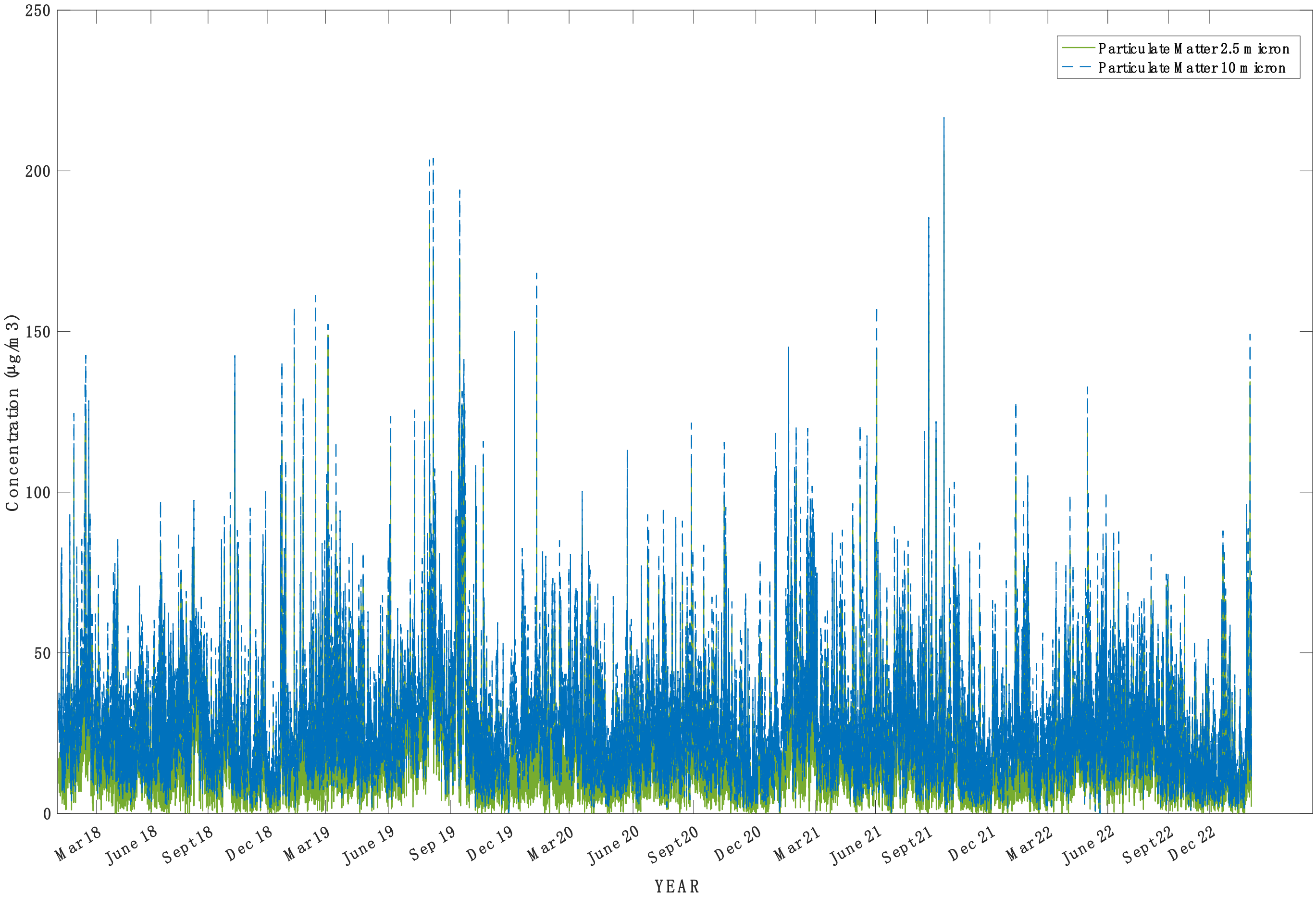
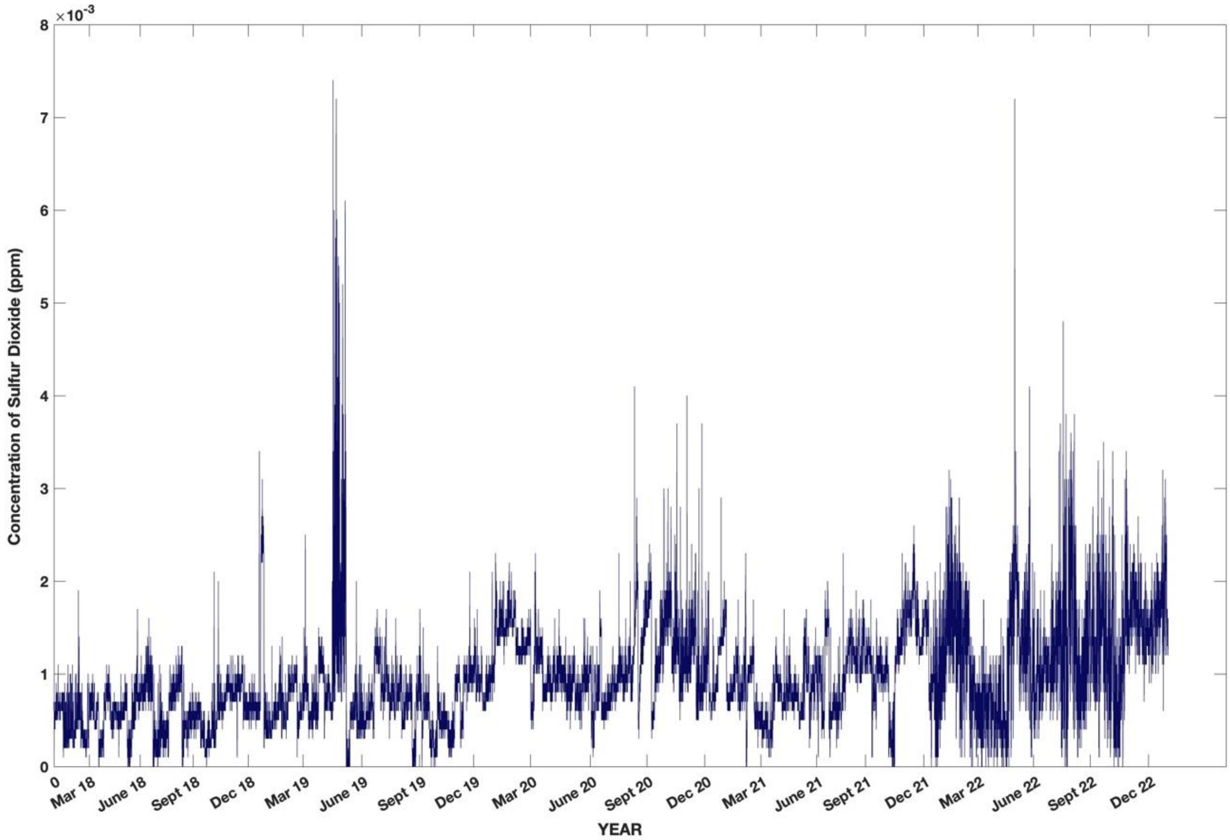
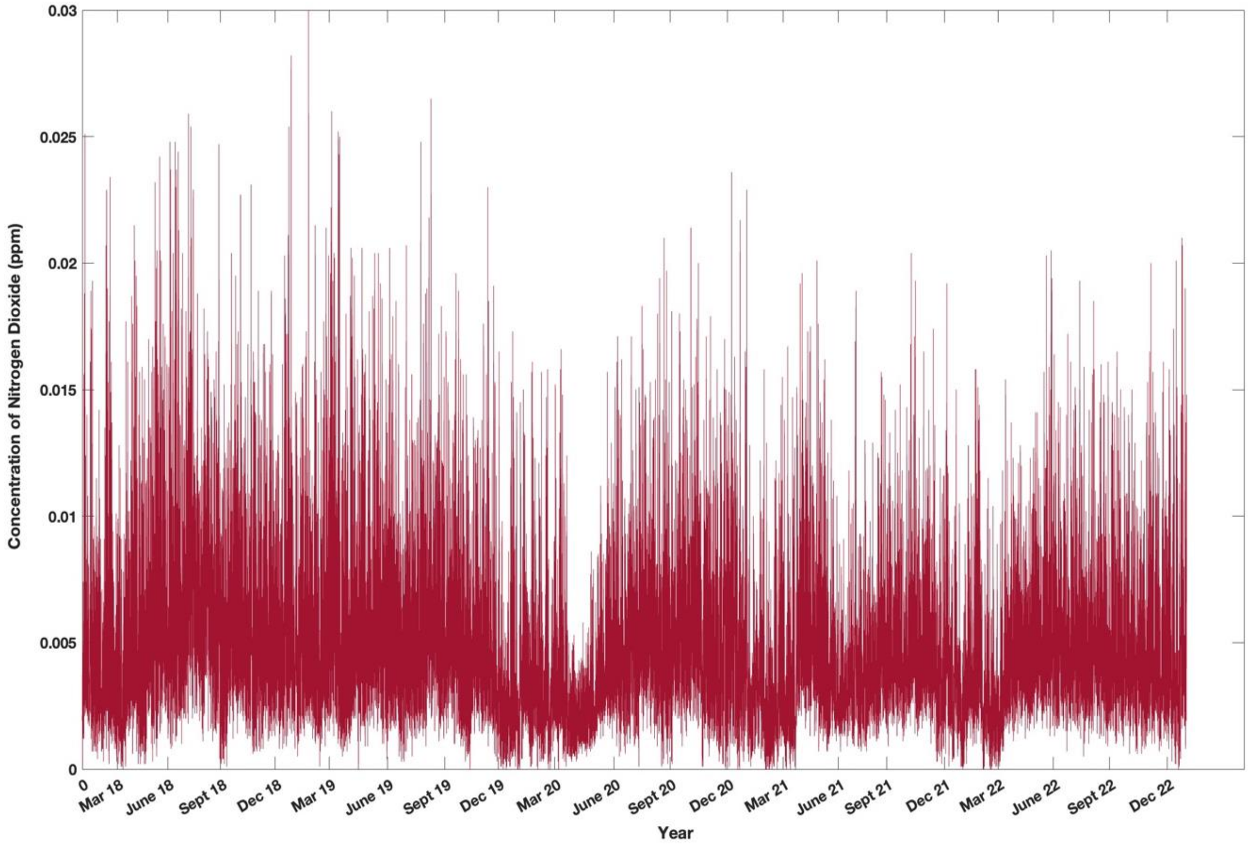


Figure 1. Trend of $PM_{2.5}$ and PM_{10} in Kuala Terengganu



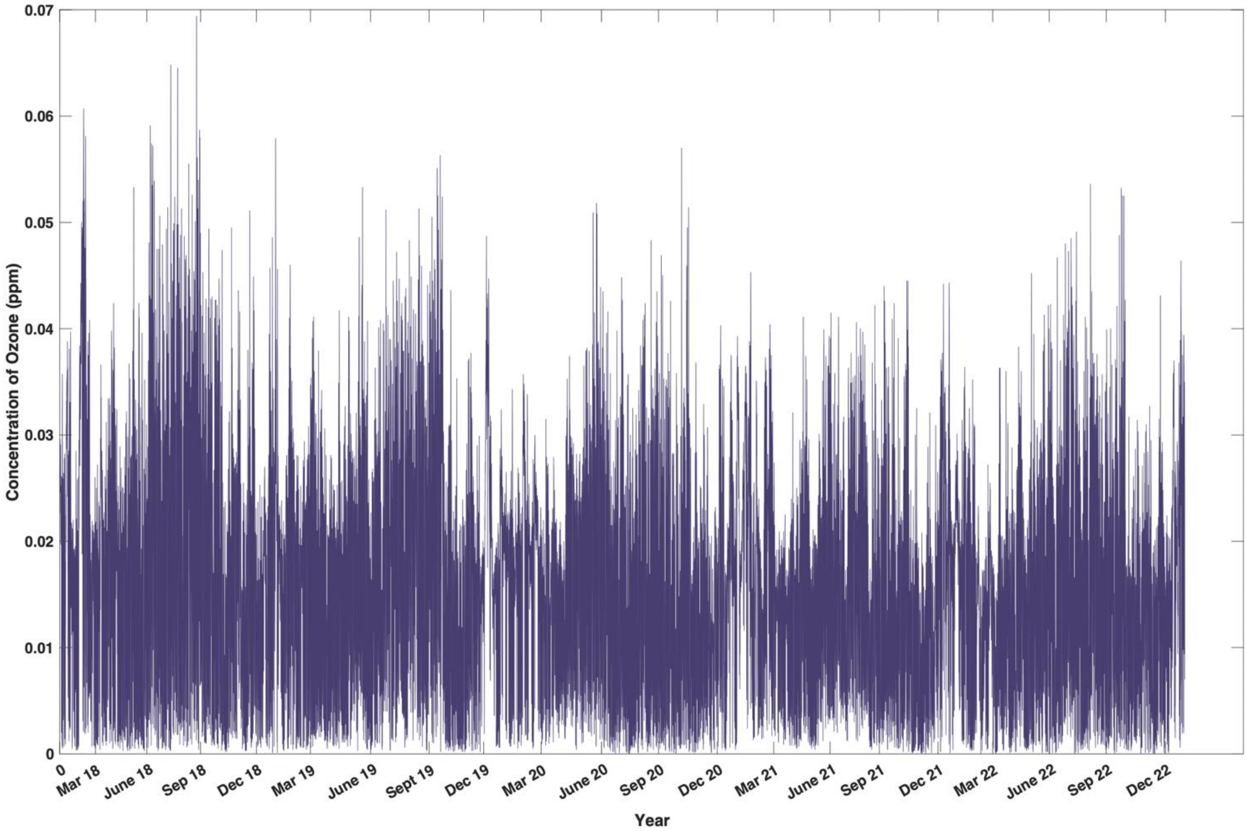
×10^-3
8
7
6
5
4
3
2
1
0
Concentration of Sulfur Dioxide (ppm)
0
Mar 18
June 18
Sept 18
Dec 18
Mar 19
June 19
Sept 19
Dec 19
Mar 20
June 20
Sept 20
Dec 20
Mar 21
June 21
Sept 21
Dec 21
Mar 22
June 22
Sept 22
Dec 22
YEAR

(a)

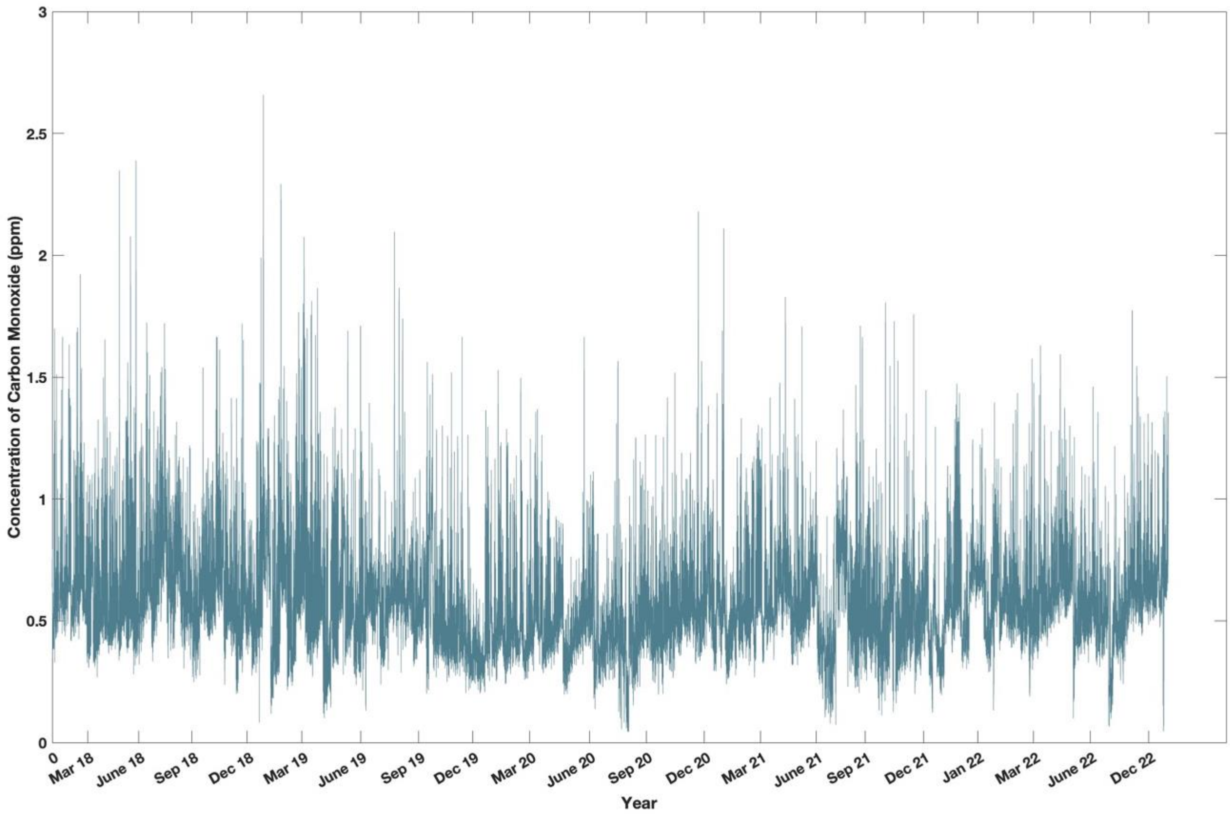


0.03
0.025
0.02
0.015
0.01
0.005
0
Concentration of Nitrogen Dioxide (ppm)
0
Mar 18
June 18
Sept 18
Dec 18
Mar 19
June 19
Sept 19
Dec 19
Mar 20
June 20
Sept 20
Dec 20
Mar 21
June 21
Sept 21
Dec 21
Mar 22
June 22
Sept 22
Dec 22
Year

(b)

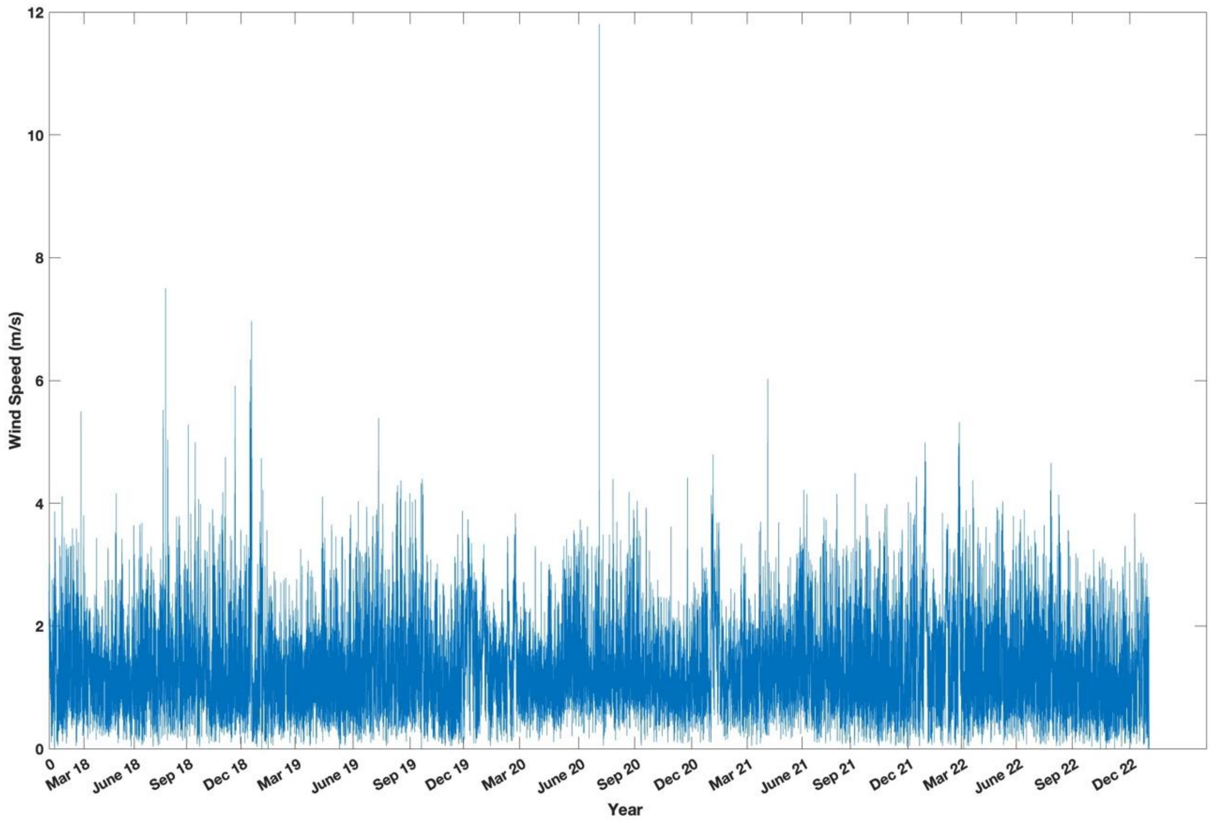


(c)

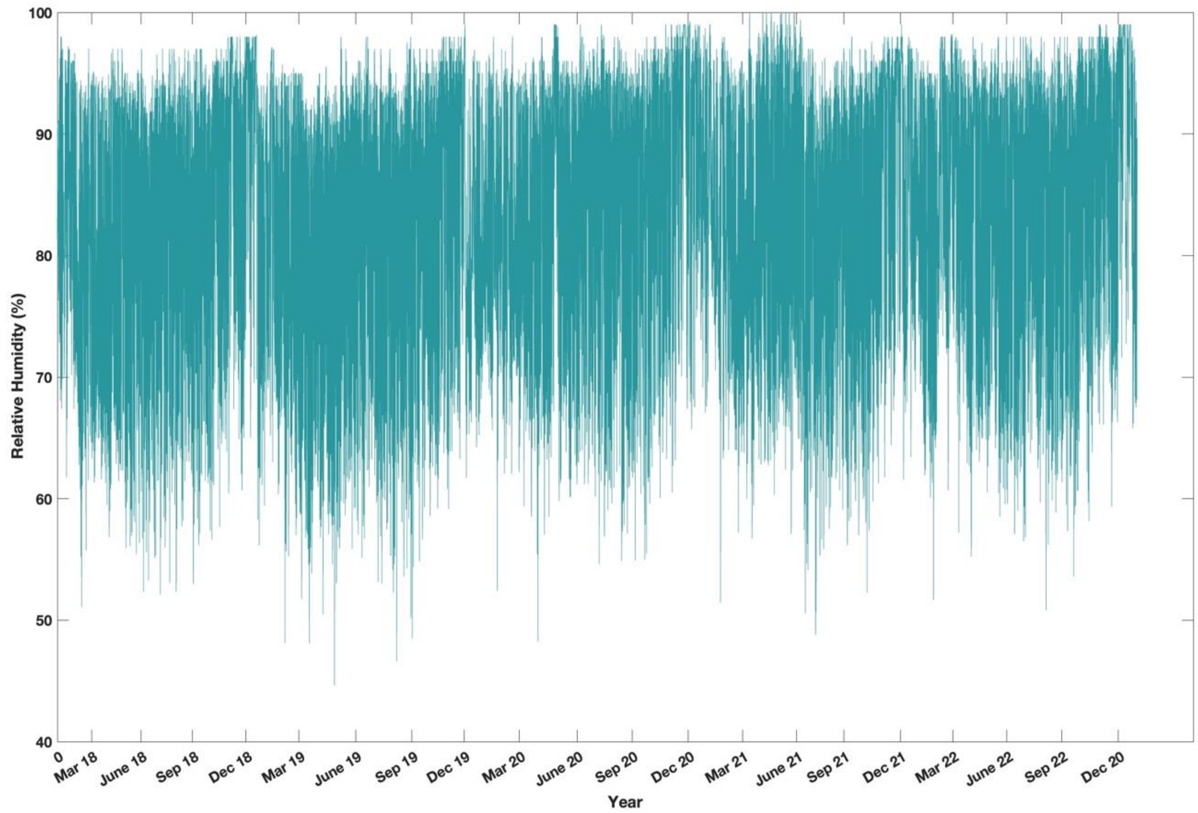


(d)

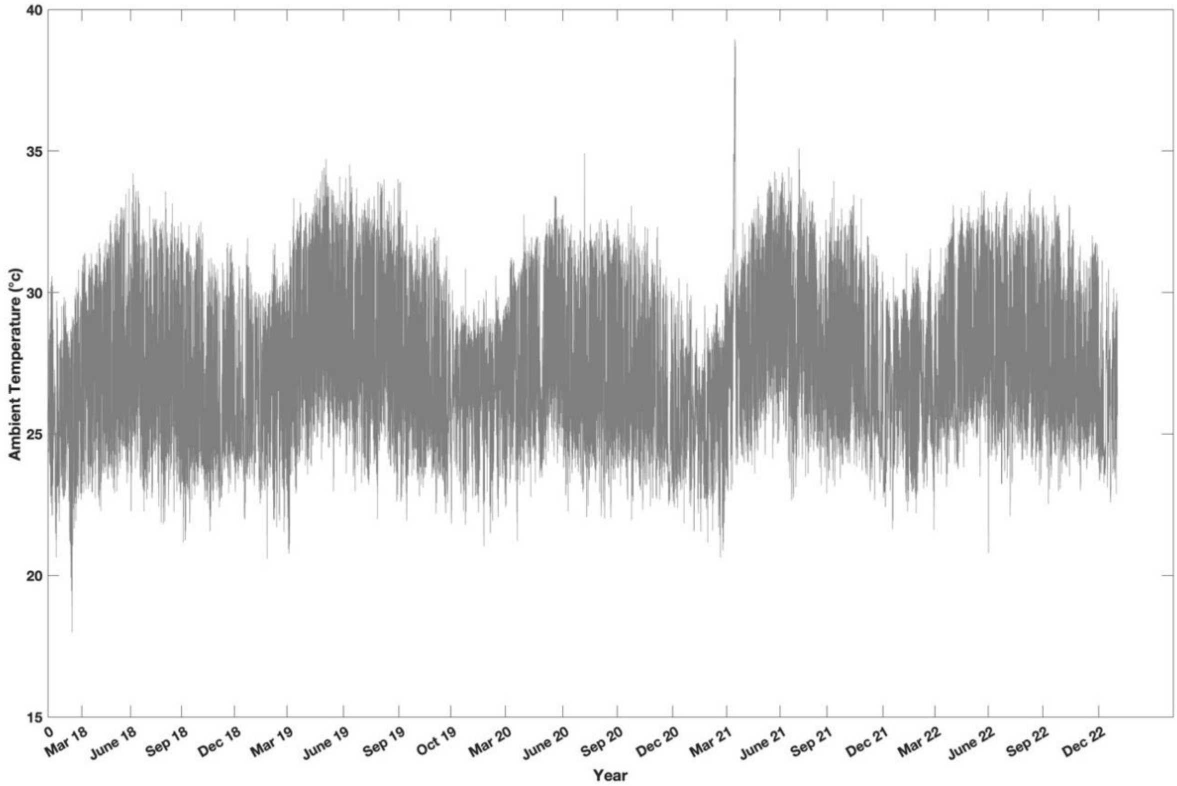
Figure 2. (a) Trend of sulfur dioxide (SO_2); (b) Trend of nitrogen dioxide (NO_2); (c) Trend of ozone (O_3); (d) Trend of carbon monoxide (CO)


Wind Speed (m/s)
0
2
4
6
8
10
12
0
Mar 18
June 18
Sep 18
Dec 18
Mar 19
June 19
Sep 19
Dec 19
Mar 20
June 20
Sep 20
Dec 20
Mar 21
June 21
Sep 21
Dec 21
Mar 22
June 22
Sep 22
Dec 22
Year

(a)


Relative Humidity (%)
40
50
60
70
80
90
100
0
Mar 18
June 18
Sep 18
Dec 18
Mar 19
June 19
Sep 19
Dec 19
Mar 20
June 20
Sep 20
Dec 20
Mar 21
June 21
Sep 21
Dec 21
Mar 22
June 22
Sep 22
Dec 20
Year

(b)



(c)

Figure 3. (a) Trend of wind speed; (b) Trend of relative humidity; (c) Trend of ambient temperature

Figure 1 shows that there is a similar trend of change in the concentration of $PM_{2.5}$ and PM_{10} over the period of five years. This is in line with the result of the study done by Mura et al. [8] that had identified that there is a strong positive correlation between $PM_{2.5}$ and PM_{10}. The trend of high concentrations of particulate matter between August and September 2019 and 2022 is most likely due to dry weather conditions in Malaysia as concluded by Othman et al. [5]. The overall concentration of particulate matter in 2020 was slightly lower compared to the previous years. Particulate matter (PM) emissions in Malaysia decreased from the previous year to approximately 22.6 thousand metric tons in 2020 [15]. That year saw the lowest level of PM pollution in the nation due to the Movement Control Order (MCO) enforced by the Government of Malaysia during the pandemic of COVID-19. Abdullah et al. [9] found that there was a reduction of up to 58.4% in the concentration of $PM_{2.5}$ during implementation of the MCO. Air quality has been impacted by rapid development and urbanization, which has sparked interest in researching $PM_{2.5}$ causes and impacts. While Khan et al. [16] discovered that motor vehicle emissions, secondary inorganic aerosol, and coal-fired power plants are the main sources of $PM_{2.5}$, Rusmili et al. [15] and Sinkemani et al. [17] suggested that $PM_{2.5}$ originates from fuel burning, vehicular exhaust, and certain industrial activities. According to studies [18-20], industrial and intensive commercial activities are the source of PM_{10} and $PM_{2.5}$ as well. According to Li et al. [21], airborne dust occurrences may have played a role in the high $PM_{2.5}$ concentrations observed in Middle Eastern nations like Saudi Arabia, Kuwait, Iraq, and Iran [22, 23]. The uncontrolled burning of Indonesian forests has resulted in Southeast Asian haze occurrences, which have been connected to high concentrations of $PM_{2.5}$ in Malaysia [22-25]. These patterns demonstrate that $PM_{2.5}$ is a serious issue that must be addressed immediately with regulations and strategies to solve the issue on a worldwide scale [26-28]. As a developing nation, Malaysia must implement the measurement of $PM_{2.5}$ for its inhabitants, which requires a robust air quality monitoring system [29-31]. Incorporating continuous $PM_{2.5}$ measurement into the national environmental monitoring program is a new enhancement to the air quality monitoring network of the Malaysian Department of Environment (DOE) [19, 20, 32]. In mid-2017, $PM_{2.5}$ standards and guidelines were introduced. Compared to PM_{10}, $PM_{2.5}$ monitoring better captures the real condition of high particulate matter concentration from combustion, such as from burning biomass and vehicle emissions [24-28]. This explains why $PM_{2.5}$ has decreased somewhat in 2019 and 2020 because of MCO [9].

Figure 2(a) shows that distant peaks of the SO_2 were recorded, where the concentration of the SO_2 exceeds 0.007 ppm. Exceeds SO_2 in this study is supported by Mansor et al. [10] that concentrations of SO_2 are most likely due to industrial activities, where the combustion of sulfur compounds and fossil fuels (coals and heavy oils) and biomass burning take place. Besides, Mansor et al. [10], and Hashim et al. [11] also stated that the increment of NO_2 as shown in Figure 2(b) is usually caused by the emission of NO_2 from motor vehicles in the surrounding area. The transportation industry, the combustion of coal and gasoline and the energy sector which processes natural gas are the main contributors to the pollution of NO_2. The concentration of O_3 was at its highest peak, almost reaching 0.07 ppm in September 2018 due to dry weather and the kind of weather substantially positively correlated with the concentration of O_3 in the air as had been explained by Ramli et al. [12]. Mohd Napi et al. [13] suspected that concentrations of the O_3 were produced from the surrounding human activities such as open burning, mobile sources, and others. Literature from Mansor et al. [10] supported concentrations of CO as illustrated are believed emitted from motor vehicles as the CO is produced from the incomplete combustion of fuels.

Figure 3(a) shows a uniform trend of wind speed and there was an upward trend of the wind speed from October to December observed over the years. Upwards of wind speed between October to December is suspected due to the northeast monsoon season when the east coast area receives strong wind speed and heavy rain as described by Nizamani et al. [14]. The trend of relative humidity shows a downward trend from January to June/July and an upward trend from July/August to December. However, the trend of ambient temperature shows an upward trend from January to June/July and shows downward from July/August to December. According to the Meteorological Department, Malaysia, the highest temperature in east coast states of Malaysia is in April and May, and Terengganu receives minimum relative humidity in March [33].

3.2 Variation effect of air pollutants and meteorological factors on concentration of $PM_{2.5}$

The result of the correlation analysis is tabulated in Table 2. The result shows that there is a significant strong positive correlation between $PM_{2.5}$ with PM_{10} ($r = 0.900$, $p < 0.05$), which is similar to the result of a study done by He and Lu [34], where the concentration of $PM_{2.5}$ with PM_{10} within same monitoring network were strongly correlated with each other. Besides, $PM_{2.5}$ is also significantly strongly correlated with CO ($r = 0.500$, $p< 0.05$). Ucheje et al. [35] explained the contribution of CO to the concentration of $PM_{2.5}$ is most likely due to the surrounding traffic volume [29, 32], which is supported by a statement from a study done by Roslan et al. [36] that CO is emitted into the ambient air from incomplete combustion when there is partial oxidation of carbon in the fuel. Meanwhile, there is no correlation between $PM_{2.5}$ with O_3 but CO and O_3 has high correlation ($r= 0.949$, $p<0.05$).

Table 2. Correlation analysis between air pollutants and meteorological parameters

	$PM_{2.5}$	PM_{10}	O_3	CO	WS	RH	AT
$PM_{2.5}$	1.000						
PM_{10}	.900*	1.000					
O_3	.580	.369	1.000				
CO	.500*	.200	.949*	1.000			
WS	-.035*	-.300	-.527	-.300	1.000		
RH	-.020*	-0.990**	-.369	-.200	.300	1.000	
AT	.200	.100	-.527	-.400	.900*	-.100	1.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Results of the analysis also indicate that there is a significant weak correlation between the $PM_{2.5}$ with wind speed ($r = -0.035$, $p <0.05$), and relative humidity ($r = -0.020$, $p < 0.05$). The direction of the correlation of the variables is similar to the result of analysis done by Amnuaylojaroen et al. [37] in north Thailand where $PM_{2.5}$ is positively correlated with temperature and negatively correlated with wind speed and relative humidity. As cited by Nguyen et al. [38], complicated interactions between the variables are the main challenge to deepening understanding of the effect of the meteorological factors on concentration of the $PM_{2.5}$.

Anthropogenic emissions from industries, vehicles, power plants, burning biomass, and other sources are primarily responsible for atmospheric $PM_{2.5}$. One of the main sources of $PM_{2.5}$ is coal burning, especially in Asia during the wet season [26, 27]. But as more and more cars are driven through metropolitan areas of megacities, their contribution to air pollution, including NOx and particulates, is growing [26]. Furthermore, during the post-harvest months of May to June and October to November, burning biomass is a significant source of $PM_{2.5}$ [28]. Pollution episodes are often brought on by the build-up of human contaminants in sluggish weather conditions. Furthermore, the gas-to-particle conversions of CO, NOx, and VOCs also play a significant role in the generation of $PM_{2.5}$ pollution, especially in conditions of high relative humidity. Approximately 77% of the total mass of $PM_{2.5}$ is composed of the secondary inorganic species NO_3^-, NH_4^+ and SO_4^{2-} and this showed the relationship between $PM_{2.5}$ with CO in this study [26-29].

4. CONCLUSIONS

This study identifies the trend of particulate matter, gaseous pollutants, and meteorological factors from 2018 until 2022. The results demonstrate that over the 5 years, the trend of concentration of the $PM_{2.5}$ and $PM_{10,}$ SO_2, $NO_{2,}$ $O_{3,}$ CO, wind speed, relative humidity, and ambient temperature were in a uniform pattern. However, there were also unusual spikes in the concentration of the pollutants and the meteorological parameters had been recorded due to other external factors such as haze episodes and man-made activities. Correlation analysis shows that there is a significantly strong relationship of $PM_{2.5}$ between PM_{10} and CO and a moderately significant correlation with NO_2. $PM_{2.5}$ shows a weak correlation with SO_2, O_3, and all meteorological factors involved in this study. This demonstrates how crucial it is to ascertain the relationships between each component to reduce the concentration of $PM_{2.5}$ and go forward with future predictions. This is particularly crucial for local authorities as an early warning if there are usual events in that particular place.

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