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Research Article

Assessment of the trend in PM_{10} and $PM_{2.5}$ concentrations during the period 2018-2021 in the Hanoi area

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Abstract: The implementation of monitoring to evaluate the concentrations of PM_{10} and $PM_{2.5}$ dust in recent times, especially in major cities, is deemed essential as these are major contributors to adverse health effects. This study has preliminarily assessed the trends of dust concentrations at different monitoring stations, specifically 10 monitoring stations in Hanoi during the period 2018-2021. The non-parametric Mann-Kendall test and Sen's slope estimator were applied to determine the trend and significance of pollutants. The results indicate that the average concentration of PM10 was approximately 70.49 µg/m^3 and $PM_{2.5}$ was around 40.51 µg/m^3, both exceeding QCVN 05:2023/BTNMT standards. The trend in PM_{10} and $PM_{2.5}$ concentrations showed a general decrease, although the decrease in PM10 was more significant (5/10 stations with $p < 0.05$), the decrease in PM2.5 was not significant (0/10 stations with $p < 0.05$). The study's findings have also contributed to aiding managers in monitoring and devising specific measures to reduce dust pollution in urban areas in the future.

Keywords: Mann-Kendall; Trend; PM_{10}, $PM_{2.5}$ Dust.

1. Introduction

Air pollution is one of the most critical environmental issues worldwide, especially in rapidly urbanizing areas where population density and human activities exert immense pressure on the environment. Pollution arises from diverse sources such as motor vehicle emissions, industrial activities, construction dust, open waste burning, and residential heating. These activities contribute to the release of a variety of pollutants into the atmosphere, including fine particulate matter (PM_{10} and $PM_{2.5}$), greenhouse gases, and toxic chemicals. In recent years, there has been increasing global attention on detecting and assessing pollution trends, motivated by the growing evidence of the detrimental effects of air pollution on human health, ecosystems, and climate systems. Previous studies have extensively analyzed trends and distributions of major pollutants, including PM_{10}, $PM_{2.5}$, NO_2, and SO_2, across various urban environments using advanced monitoring and modeling techniques [1–3].

In the Vietnamese context, research into air pollution has gained prominence due to the rapid urbanization and industrialization of major cities like Hanoi. As the capital and a central economic hub of Vietnam, Hanoi had an estimated population of 8.6 million in 2023 [4]. The city's rapid economic growth, coupled with dense traffic, construction activities, and waste management challenges, has exacerbated its air pollution issues, particularly concerning fine particulate matter (PM_{10} and $PM_{2.5}$). Numerous studies in Hanoi have focused on key aspects of air pollution, including quantifying PM_{10} and $PM_{2.5}$ emissions [5–7]; Multiple studies have documented a significant increase in these particulate matter pollutants, particularly during the winter months identifying the sources and chemical compositions of $PM_{2.5}$ [5, 8–10], analyzing the spatial and temporal distributions of $PM_{2.5}$ [11–14], investigating the role of meteorological factors in pollutant dispersion [14–17], and evaluating the health impacts of $PM_{2.5}$ exposure [8, 18, 19]. Two studies in 2022 [18, 19] identified key factors contributing to severe air pollution episodes during winter seasons. These factors included meteorological conditions such as low wind speeds and temperature inversions, as well as increased emissions from residential heating and vehicular traffic. The study highlighted the alarming levels of $PM_{2.5}$, with concentrations frequently exceeding the World Health Organization's (WHO) air quality guidelines. Research conducted by [16] revealed the impact of meteorological conditions and long-range transport on $PM_{2.5}$ levels in Hanoi. The study analyzed $PM_{2.5}$ concentrations at multiple sites across the city. The findings indicated that meteorological factors, such as wind speed and direction, played a crucial role in determining $PM_{2.5}$ levels, particularly during periods of stagnant air. Additionally, the study identified the influence of long-range transport of pollutants from neighboring regions on air quality in Hanoi.

Globally, numerous methodologies have been developed to assess air pollution trends and their influencing factors. These include emissions inventory modeling, which quantifies pollution from sources such as public transportation, elevated railway systems, and waste incineration, as well as advanced statistical and mathematical techniques for analyzing air quality time-series data. Among these, trend detection has been instrumental in evaluating pollutant fluctuations over time and identifying critical periods of pollution increase or decline. For example, the Mann-Kendall test, a robust non-parametric statistical method, has been widely applied for detecting monotonic trends in time-series air pollution data [3]. This approach is particularly useful for datasets that are non-normally distributed or exhibit autocorrelation.

The study area, Hanoi, is characterized by a mix of densely populated urban centers, peri-urban zones, and suburban residential areas, each contributing uniquely to the city's air pollution profile. Previous research has identified traffic, industrial emissions, and waste burning as significant contributors to air pollution in the city. This study aims to address existing research gaps by applying the Mann-Kendall test to analyze the temporal trends of PM_{10} and $PM_{2.5}$ levels in Hanoi over the period 2018-2021. By combining a rigorous statistical approach with a focus on Hanoi's unique socio-environmental characteristics, the study seeks to provide insights into the patterns and potential drivers of particulate pollution in the city.

2. Materials and Methods

2.1. Description of study area

Figure 1 shows a map of automated air quality monitoring stations in Hanoi, primarily concentrated in the central areas of the city. A total of 10 monitoring stations are identified, including Bac Tu Liem, Pham Van Dong, the Environmental Protection Agency, Tay Mo, My Dinh, Hang Dau, Hoan Kiem, Thanh Cong, Kim Lien, and Hoang Mai.

These stations are strategically distributed to ensure comprehensive data collection on air quality parameters such as $PM_{2.5}$, PM_{10}, SO_2, NO_x, and meteorological factors. The map also includes geographical coordinates and the spatial scale of the study area at 1:750,000, providing a clear overview of the spatial distribution of the monitoring network within Hanoi's geographical context.

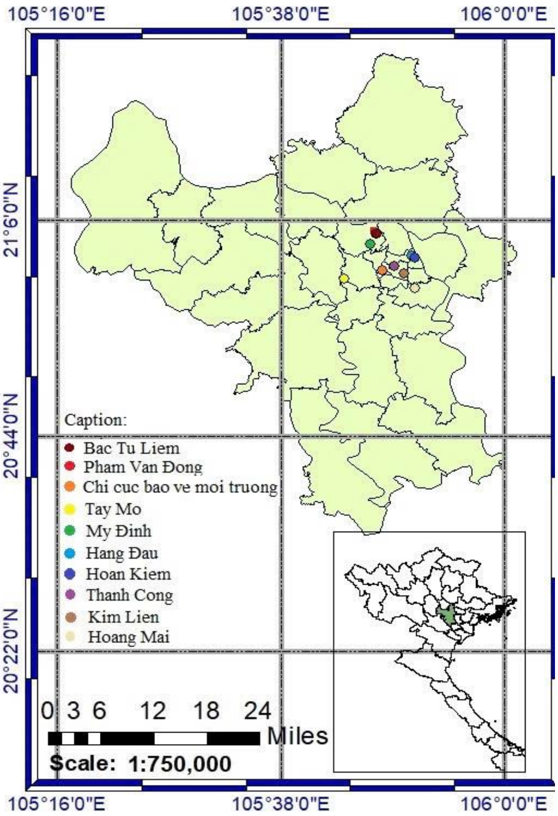

Figure 1. Map of air monitoring stations in Hanoi.

2.2. Methodology

The research method used is the Mann-Kendall (MK) test, developed by Mann [20] and Kendall [21] which is widely applied in assessing seasonal trends in time series data.

For trend analysis of PM_{10} and $PM_{2.5}$ concentrations, this study employs the non-parametric Mann-Kendall (MK) test. Robert Hirsch further adapted the MK test to detect trends in concentrations of substances and climate variables. The MK test is applied to monthly and seasonal datasets and is particularly resilient to cases of missing or erroneous data [22].

The structure of study was implemented by 4 stages, include: Data collection, Data processing, Trend calculation and Trend analysis. All stages are described in Figure 2.

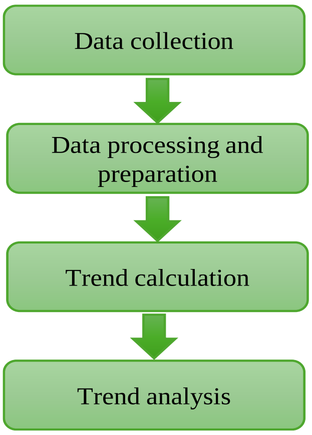

Figure 2. A flowchart of the study structure.

The Mann-Kendall non-parametric test is designed to identify trends in a time-ordered dataset (sample). This method compares the relative magnitude of elements in the series rather than their absolute values. This approach helps prevent artificial trends that could result from local extreme values, which might occur with standard linear trend calculations using the least squares method. Another advantage of this method is that it does not require the sample to follow any specific distribution. The calculation formulas for this method are briefly described below [23].

Assume a monthly time-series dataset ($x_{i1}, x_{i2}, \ldots, x_{in}$) where x_i represents the data at time i for the years 1, 2, …, n.

The Mann-Kendall statistic for month i (S_i) is calculated as follows:

$$S_i = \sum_{k=1}^{n_i-1} \sum_{j=k+1}^{n_i} \operatorname{sgn}(x_{ij} - x_{ik}) \qquad (1)$$

where $\operatorname{sgn}(x_{ij} - x_{ik}) = 1$ when $x_{ij} - x_{ik} > 0$; $\operatorname{sgn}(x_{ij} - x_{ik}) = 0$ when $x_{ij} - x_{ik} > 0$; $\operatorname{sgn}(x_{ij} - x_{ik}) = -1$ when $x_{ij} - x_{ik} < 0$.

The Mann-Kendall statistic for all months (S′) is calculated as follows:

$$S' = \sum_{i=1}^{m} S_i \tag{2}$$

where m is the number of months in a year, with m = 12m.

$$Z_{SK} = \begin{Bmatrix} \dfrac{S'-1}{\sqrt{VAR\left(S'\right)}} & \text{if} & S' > 0 \\ 0 & \text{if} & S' = 0 \\ \dfrac{S'+1}{\sqrt{VAR\left(S'\right)}} & \text{if} & S' < 0 \end{Bmatrix} \tag{3}$$

with $VAR(S')$ being the variance of S’, calculated as:

$$VAR(S') = \sum_{i=1}^{m} VAR(S_i) \tag{4}$$

$VAR(S_i)$ being the variance of S_i, calculated as:

$$VAR(S_i) = \frac{1}{18}\left[n_i(n_i-1)(2n_i+5) - \sum_{p=1}^{gi}\left[t_{ip}(t_{ip}-1)(2t_{ip}+5)\right]\right] \tag{5}$$

where g_i is the number of groups in month i and t_{ip} is the number of elements in group p in month i

Z_{SK} follows a normalized distribution N(0,1). A positive Z_{SK} value indicates an increasing trend in the series, while a negative Z_{SK} value indicates a decreasing trend. Since $Z \in N(0,1)$ testing for the presence of a trend in the series becomes straightforward.

The magnitude of the MK trend slope is estimated using the Theil-Sen slope estimator [24] conventionally known as the Sen slope. The Sen slope and MK test have been applied in numerous pollution studies [1, 2, 20, 25, 26]. The degree of change in the wet deposition trend is determined through the Sen slope and the mean value.

2.3. Data Collection

The research data consists of the monthly average concentrations of PM_{10} and $PM_{2.5}$ at monitoring stations within the network of the Hanoi Department of Natural Resources and Environment (Table 1). The data was collected from 2018 to 2021. In the study area, there are two fixed air quality monitoring stations (Minh Khai and Trung Yen 3), while the remaining eight stations are automatic air quality monitoring stations.

Table 1. Location of monitoring stations.

N	Monitoring Points	Longitude	Latitude	Location	Parameters
I	**Fixed Station**				
1	Minh Khai Street - Bac Tu Liem District (BTL)	21°02’57.8”	105°44’31.0”	People's Committee of Minh Khai Ward	PM_{10}, $PM_{2.5}$, $NO/NO_2/NOx$, SO_2, O_3, CO, Meteorological parameters
2	No.17, Trung Yen 3 Street, Trung Hoa Ward, Cau Giay District (Department of Environmental Protection) (CCBVMT).	21°00'55.1”	105°47'59.6”	Hanoi Department of Environmental Protection	PM_{10}, $PM_{2.5}$, $NO/NO_2/NOx$, SO_2, O_3, CO, Meteorological parameters
II	**Sensor Station**				
3	No. 36A Pham Van Dong Street (PVD)	21°03’04.3”	105°46’54.6”	Hanoi Center for Environmental and Natural Resource Monitoring	PM_{10}, $PM_{2.5}$, NO_2, CO, Meteorological parameters

N	Monitoring Points	Longitude	Latitude	Location	Parameters
4	Lang Hoa Lac Intersection - Road 70 (Tay Mo)	21°00’45.2”	105°44’48.1”	People’s Committee of Tay Mo Ward	PM_{10}, $PM_{2.5}$, NO_2, CO, Meteorological parameters
5	Me Tri Urban Area, (My Dinh)	21°01’10.5”	105°46’13.3”	People’s Committee of My Dinh 1 Ward	PM_{10}, $PM_{2.5}$, NO_2, CO, Meteorological parameters
6	Old Quarter (Hang Dau Flower Garden) (Hang Dau)	21°02’25.7”	105°50’44.5”	Hang Ma Ward Police	PM_{10}, $PM_{2.5}$, NO_2, CO, Meteorological parameters
7	Hoan Kiem Lake Area (Hoan Kiem)	21°01’35.5”	105°51’11.9”	Hoan Kiem District Police	PM_{10}, $PM_{2.5}$, NO_2, CO, Meteorological parameters
8	Kim Lien - Trung Tu Area (Kim Lien)	21°00’24.8”	105°50’11.3”	Kim Lien Kindergarten	PM_{10}, $PM_{2.5}$, NO_2, CO, Meteorological parameters
9	Thanh Cong Apartment Complex (Thanh Cong)	21°01’11.0”	105°48’53.0”	Thanh Cong Park	PM_{10}, $PM_{2.5}$, NO_2, CO, Meteorological parameters
10	Hoang Mai Mixed Residential Area (Tan Mai)	20°59’18.0”	105°51’17.6”	People’s Committee of Hoang Van Thu Ward	PM_{10}, $PM_{2.5}$, NO_2, CO, Meteorological parameters

3. Results

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

The data presented in Table 2 shows that the average concentrations of PM_{10} and $PM_{2.5}$ at the monitoring stations significantly surpass the thresholds established by QCVN 05:2023/BTNMT. Specifically, the mean PM10 concentration is approximately 70.49 µg/m^3, and the mean $PM_{2.5}$ concentration is around 40.51 µg/m^3. These values exceed the QCVN 05:2023/BTNMT standards by 1.4 and 1.6 times, respectively.

Table 2. Average Concentrations of PM_{10} and $PM_{2.5}$ from 2018 to 2021 (µg/m^3).

N	Station	PM_{10}	$PM_{2.5}$
1	BTL	95.1 ± 25.76	49.21 ± 15.02
2	CCBVMT	68.32 ± 22.07	41.5 ± 14.25
3	PVD	92.17 ± 24.03	49.65 ± 13.79
4	Tay Mo	53.84 ± 19.53	32.98 ± 11.44
5	My Dinh	57.55 ± 18.96	35.03 ± 12.48
6	Hang Dau	90.13 ± 25.77	48.72 ± 14.29
7	Hoan Kiem	59.78 ± 19.35	36.4 ± 12.88
8	Kim Lien	55.44 ± 19.08	34.69 ± 13.35
9	Thanh Cong	81.05 ± 23.14	44.96 ± 15.52
10	Tan Mai	51.54 ± 17.86	31.92 ± 11.01
	Average	**70.49**	**40.51**

The observed average concentration of PM_{10} ranged from 51.54 to 95.1 µg/m^3, with no area falling below the threshold set by QCVN 05:2023/BTNMT. These findings are consistent with previous research of Ngo and his colleagues [27], which reported a modeled average concentration of approximately 77.1 µg/m^3. Additionally, the annual average $PM_{2.5}$ concentrations at the monitoring stations ranged from 31.92 to 49.21 µg/m^3, aligning with research which implemented by [28], which documented an average concentration of 40.2 µg/m^3, and study of [10] which reported 46 µg/m^3.

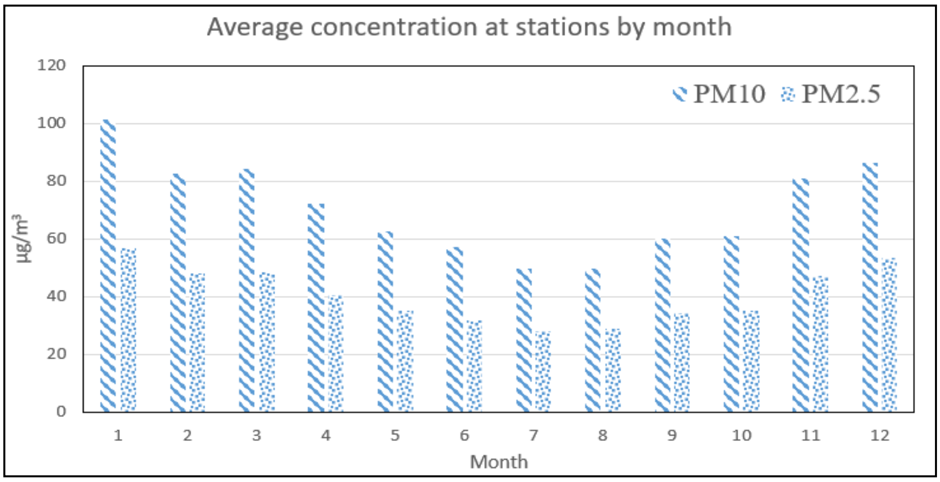

Figure 3. Monthly average concentrations of PM_{10} and $PM_{2.5}$.

The analysis of PM_{10} and $PM_{2.5}$ concentrations by season (Figure 3) emphasizes a noticeable difference between the dry and rainy seasons, with higher levels observed during the dry season and lower levels during the rainy season. This observation is in line with previous research [29–32], which has shown that concentrations of air pollutants such as $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, and O_3 vary significantly by season, with peak levels in winter and the lowest levels in summer. These variations are largely due to seasonal changes in boundary layer height and atmospheric conditions.

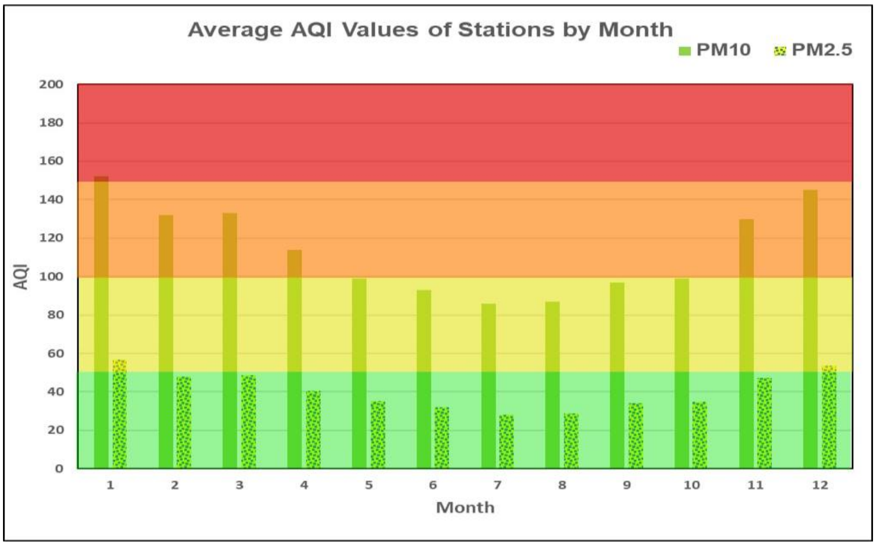

Figure 4. AQI index based on average dust concentration by month.

Figure 4 describes the average AQI for PM_{10} and $PM_{2.5}$ by month, alongside the air quality classification table, indicates significant seasonal variations in air quality. The AQI for PM_{10} varies between 50 and 150, indicating a range from “Moderate” to “Unhealthy for Sensitive Groups”, whereas $PM_{2.5}$ generally falls within the “Good” to “Moderate” range. The poorest air quality is observed in January and December, with PM_{10} AQI nearing 150, likely due to winter inversion phenomena that elevate dust levels. In contrast, from May to September, air quality substantially improves owing to frequent rainfall, keeping $PM_{2.5}$ often in the “Good” range. PM_{10} consistently records higher AQI values compared to $PM_{2.5}$, yet both types of particulate matter have detrimental health effects, especially for sensitive groups. During months when the AQI exceeds 100, it is recommended that sensitive individuals limit prolonged outdoor activities to protect their health. This trend highlights the considerable influence of weather and climate on air quality.

3.2. Trend of PM_{10} and $PM_{2.5}$ concentrations

The Sen Slope statistics and p-values derived from the Mann-Kendall test present both the slope and significance levels, with p-values less than 0.05 deemed statistically significant. The trend analysis utilizing the Mann-Kendall test indicated a downward trend in PM_{10} concentrations over the period from 2018 to 2021 (Table 3). Among the 10 monitoring stations, 5 displayed a statistically significant decreasing trend with p-values below 0.01, and 2 stations exhibited a decreasing trend with p-values less than 0.1. In contrast, for $PM_{2.5}$, 3 out of 10 stations demonstrated an increasing trend, while 7 stations exhibited a decreasing trend, with one station showing a significant decreasing trend at $p < 0.1$.

Table 3. Trend of PM_{10} and $PM_{2.5}$ changes from 2018 to 2021.

N	**Station**	**PM_{10}**			**$PM_{2.5}$**		
		p	**Sen Slope**	**The significance level**	**p**	**Sen Slope**	**The significance level**
1	BTL	**0.0090**	-0.7944	***	0.1212	-0.3033	
2	CCBVMT	0.2337	-0.2787		0.9292	0.0185	
3	PVD	0.0572	-0.4198	*	0.4238	-0.1238	
4	TayMo	**0.0000**	-0.8761	***	0.0572	-0.2201	*
5	MyDinh	**0.0050**	-0.6253	***	0.6568	-0.0829	
6	HangDau	0.1602	-0.2902		0.5816	-0.0648	
7	Hoankiem	0.0698	-0.3926	*	0.8035	0.0430	
8	KimLien	**0.0065**	-0.5699	***	0.9433	-0.0092	
9	ThanhCong	0.8869	-0.0227		0.4341	0.0855	
10	TanMai	**0.0000**	-0.7485	***	0.1449	-0.1600	

Note: * corresponds to $p < 0.1$; ** corresponds to $p < 0.05$; *** corresponds to $p < 0.01$.

The stations BTL, Tay Mo, My Dinh, Kim Lien, and Tan Mai showed a clear decreasing trend in PM_{10} with $p < 0.01$, while other stations exhibited a reduction with an unclear trend. As for the $PM_{2.5}$ concentration, no clear trend was found yet (not meeting the significance level $p < 0.05$) (Figure 5). The decreasing trend for PM_{10} and $PM_{2.5}$ concentrations aligns with findings from several global studies [1–3]. The average reduction rate for PM_{10} was about 0.71 µg/m^3 per year, while the average reduction for $PM_{2.5}$ was about 0.2 µg/m^3 per year. The results indicate a larger reduction rate for PM_{10} compared to $PM_{2.5}$.

These results suggest that air pollution reduction policies in Hanoi have had some effectiveness. However, the PM_{10} and $PM_{2.5}$ concentrations in the city still exceed the QCVN 05:2023/BTNMT standard, indicating the need for stronger and more decisive measures to further reduce fine particulate pollution in the region.

4. Conclusion

Research findings show that the fine dust pollution levels in Hanoi remain elevated, with average concentrations of PM_{10} at approximately 70.49 µg/m^3 and $PM_{2.5}$ at around 40.51 µg/m^3, surpassing the QCVN 05:2023/BTNMT standards by 1.4 and 1.6 times, respectively. The Mann-Kendall test results indicate a significant decreasing trend in PM_{10}, while $PM_{2.5}$ levels do not exhibit a clear reduction trend.

Based on the collected data, the research team has suggested several specific measures to address air pollution, including limiting the use of petrol-powered vehicles in urban areas, implementing technical improvements to reduce dust dispersion in construction projects, utilizing low-carbon emission equipment, and promoting environmentally friendly lifestyles among the public…

While the collected data is substantial and spans a lengthy period, further detailed evaluations of each monitoring station to establish and zone polluted areas could be addressed in future studies. Regular updates to the data enhance the reliability of the results. These findings support policymakers in developing appropriate strategies to mitigate the impacts of fine dust pollution, with an aim towards fostering green growth and sustainable urban development. These findings collectively underscore the critical need for comprehensive air quality management strategies in Hanoi to mitigate the adverse health and environmental impacts of PM_{10} and $PM_{2.5}$ pollution. Effective measures may include reducing emissions from transportation, industrial activities, and residential sources, as well as implementing policies to improve urban planning and green infrastructure.

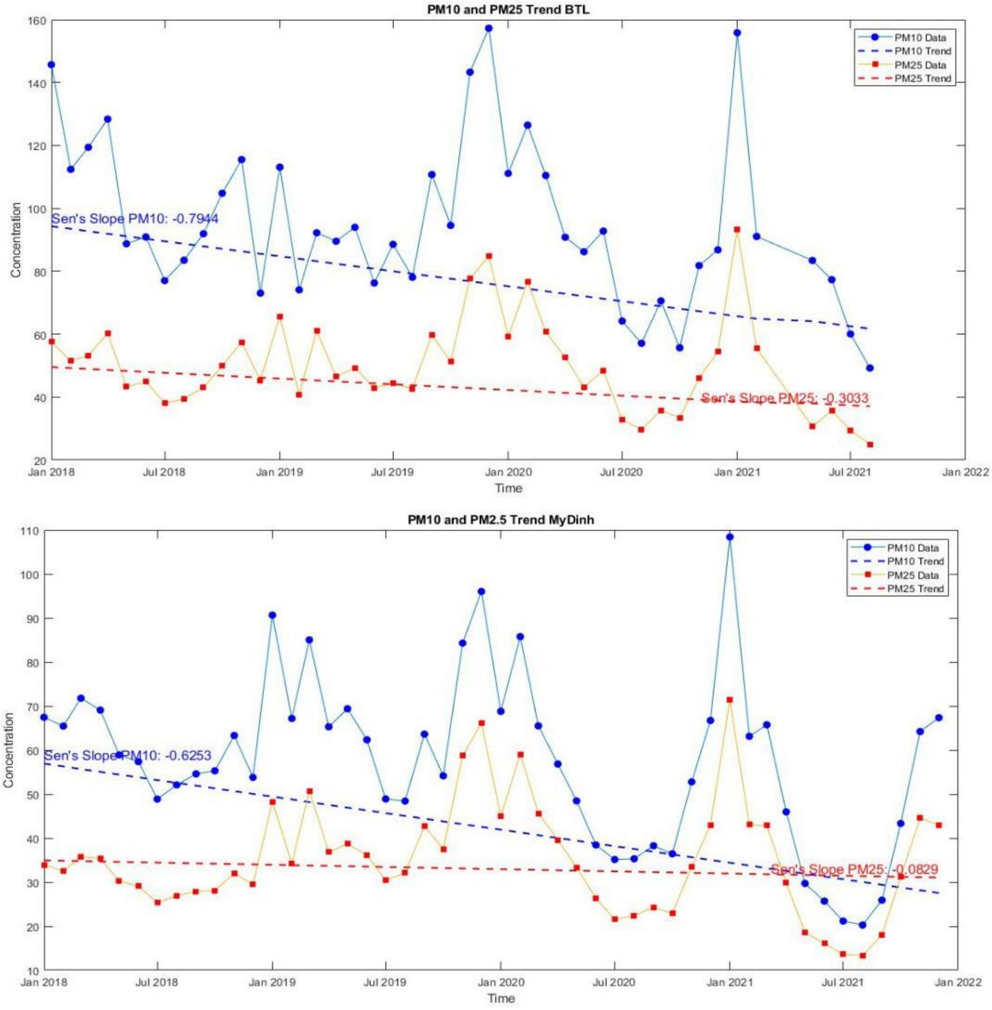

Figure 5. Trends and concentration changes at BLT and My Dinh Stations.

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