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Variation of NOX and O3 Level in Malaysia Urban Environment

Dhiban Raaj Ravi[1], Norazian Mohamed Noor

Faculty of Civil Engineering & Technology, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia

KEYWORDS

Air quality
Air quality modeling NO2
NO NOX O3

ABSTRACT

Air pollution, particularly Nitrogen Oxides (NOX) and Ozone (O3) present significant challenges to human health and environmental sustainability in Malaysian urban areas. This research addresses the critical need for analyse temporal trends of NOX and O3 pollution in six major urban cities across Peninsula Malaysia: Seberang Jaya, Tasek Ipoh, Shah Alam, Seremban, Bandaraya Melaka, and Kuala Terengganu. Using almost two decades (2005 to 2023) from the Department of Environment (DOE) Malaysia. The dataset contains the daily-mean air quality data of PM_{10}, SO_2, NO, NO_2, NOX, O_3, CO, relative humidity (RH), solar radiation (S), and ambient temperature (Ta). Graphical analyses used to evaluate pollution patterns across study areas. The results aim to identify dominant NOX sources and highlight regional differences. This research supports Malaysia's environmental strategies, offering insights for policy formulation, air quality management, and sustainable urban development.

1. INTRODUCTION

In 2019, it caused 4.2 million premature deaths globally, linked to respiratory, cardiovascular diseases, and cancers [1]. Pollutants like CO_2 and methane accelerate climate change, while CFCs damage the ozone layer [2]. Primary pollutants (CO, NOX, PM) are emitted directly, while secondary pollutants, such as ozone (O_3), form from reactions with NOX and VOCs [3].

Vehicle emissions dominate urban air pollution, releasing NO, NO_2, and PM_{10}. NOX is of concern as it drives O_3 and acid rain formation [4]. Long-term NO_2 exposure impairs lung function and increases mortality [5]. Urbanization intensifies these impacts due to rising energy demand and poor dispersion [6]. In Malaysia, NO_2 exposure is linked to respiratory and cardiovascular hospitalizations [7].

This research examines long-term temporal trends of NOX and O_3 in Malaysia to support mitigation strategies and national goals. The study hypothesizes that NOX shows an increasing trend in densely populated and high- traffic areas. Higher NOX levels are expected to contribute to increased O_3 formation under favourable meteorological conditions.

The research focuses on six urban sites in Peninsular Malaysia: Seberang Jaya, Tasek Ipoh, Shah Alam, Seremban, Bandaraya Melaka, and Kuala Terengganu. A 20-year hourly dataset (2005–2023) was obtained from DOE Malaysia's CAQM stations. The dataset includes pollutants (PM_{10}, SO_2, NO, NO_2, NOX, O_3, CO) and meteorological parameters (RH, S, Ta). Data were processed into monthly and annual datasets for analysis.

2. EXPERIMENTAL PROCEDURE

2.1. Data Acquisition

Six urban sites across Peninsular Malaysia were selected due to high NOX pollution: Seberang Jaya (SA1), Tasek Ipoh (SA2), Shah Alam (SA3), Seremban (SA4), Bandaraya Melaka (SA5), and Kuala Terengganu (SA6). Air quality in these areas is monitored by DOE Malaysia's Continuous Air Quality Monitoring (CAQM) stations: CA06P, CA11A, CA20B, CA24N, CA28M, and CA44T, respectively for SA1, SA2, SA3, SA4, SA5, and SA6.

Two decade dataset (2005–2024) was obtained, comprising daily mean values of pollutants (PM_{10}, SO_2, NO, NO_2, NOX, O_3, CO) and meteorological parameters (RH, S, Ta) Units were standardized: PM_{10} (µg/m³), SO_2 (ppb), NO (ppb), NO_2 (ppb), NOX (ppb), O_3 (ppb), CO (ppm), RH (%), S (W/m²), and Ta (°C). Data was processed into monthly and annual. Mean values were calculated using equation (1) [8], and Microsoft Excel was used for sorting and unit conversion.

$$\text{Mean}, \bar{x} = \Sigma x/n \quad (1)$$

Where, Σx is the total observed data; and n is the number of observations.

2.2. Data Analysis

By using the annual- and monthly-mean dataset of pollutants majorly associated with NOX and O3 pollution. For this research, time- series plots and box plots were chosen to present the temporal analyses. The purpose of this chart is to compare the major contributor of NOX pollution across the study areas. From this chart, we can compare the severity of NOX pollution among the study

*Corresponding author norazian@unimap.edu.my

areas. This chart was also built using Microsoft Excel.

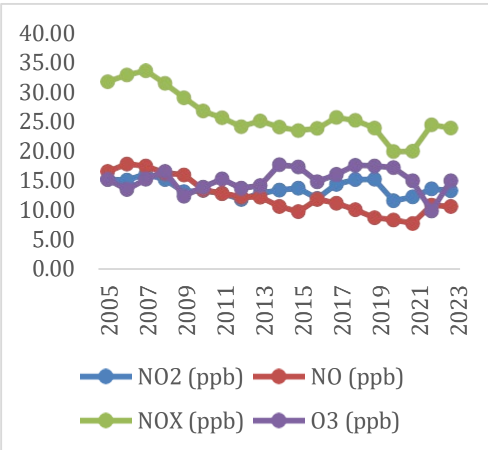
Based on the findings, a NOX assessment framework was developed to help DOE improve air quality. The findings will be shared in academic publications.

3. RESULTS AND DISCUSSION

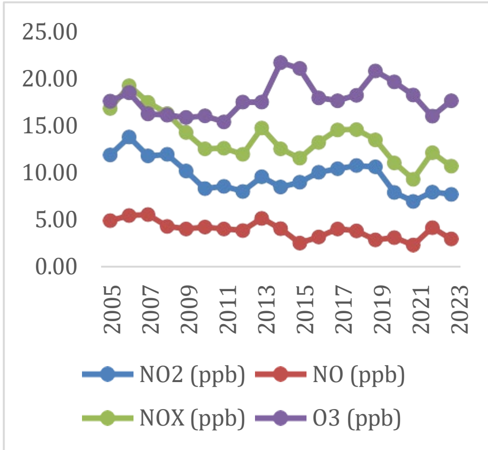
3.1. Annual Variations of NO2, NO, NOX, and O3 Trends from 2005 to 2023

Figure 1 shows the annual trends of NO_2, NO, NO_x, and O_3 from 2005 to 2023 across study areas. SA1 and SA3 exhibit the highest NOX levels in earlier years, with a gradual decline over time, while O_3 levels remain relatively steady or slightly increase in recent years. SA4 shows moderate but persistent NOX levels, accompanied by consistently high O_3 concentrations. In contrast, SA2 and SA5 maintain comparatively low NOX and NO_2 levels, while O_3 is more variable, especially in SA2.

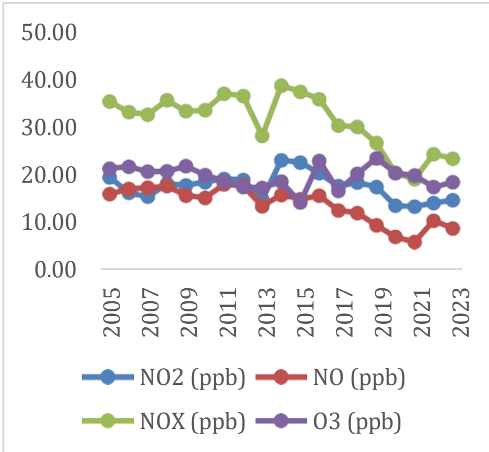
In summary, the decline in NO_x levels, particularly in urban and industrial areas like SA1 and SA3, is likely due to stricter vehicle emission standards and industrial pollution control measures implemented over the past two decades [9]. Meanwhile, the stable or rising O_3 levels despite reduced NOX suggest enhanced photochemical activity, a trend observed in other urban regions with declining primary emissions [10]. Therefore, pollution trends depend on both natural and human factors.



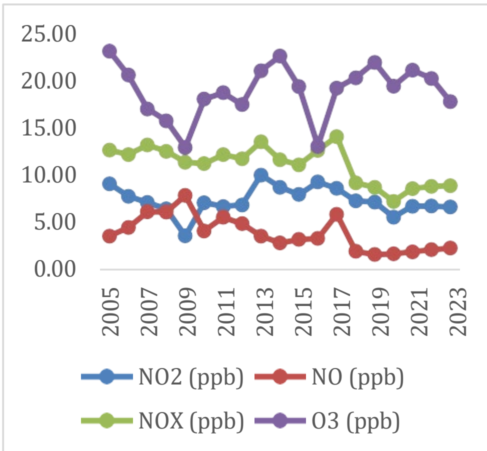
(a) Seberang Jaya (SA1)



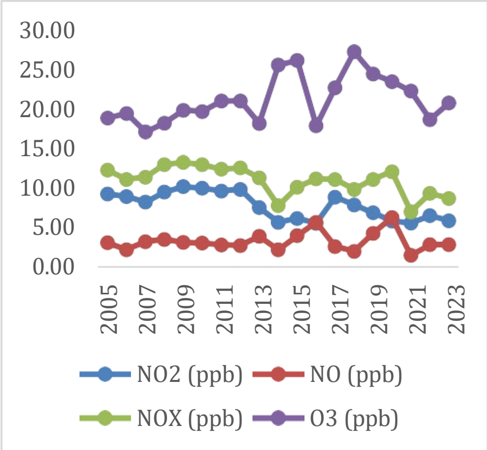
(b) Tasek Ipoh (SA2)



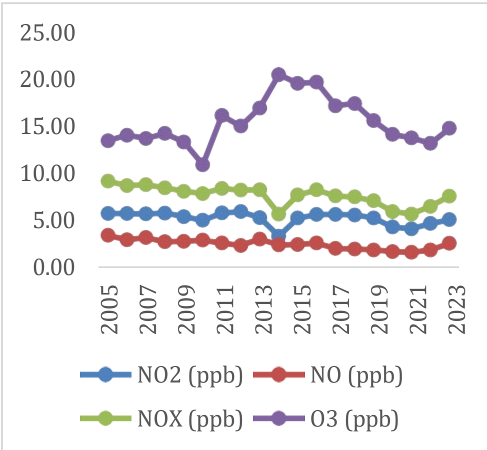
(c) Shah Alam (SA3)



(d) Seremban (SA4)



(e) Bandaraya Melaka (SA5)



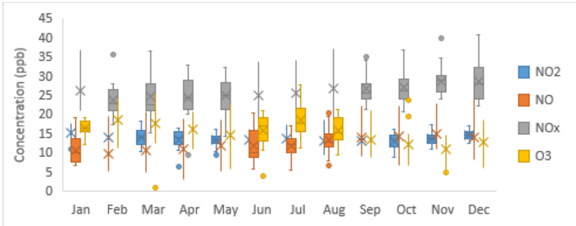
(f) Kuala Terengganu (SA6)

Figure 1. Time-series Charts of Annual NO_2, NO, NOX, and O_3 Trends from 2005 to 2023 **(a)** Seberang Jaya **(b)** Tasek Ipoh **(c)** Shah Alam **(d)** Seremban **(e)** Bandaraya Melaka **(f)** Kuala Terengganu.

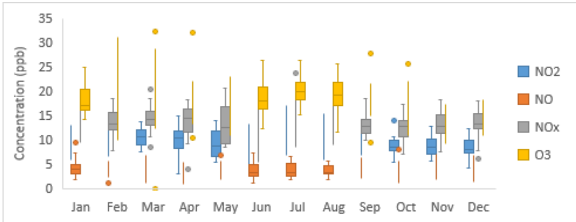
3.2. Monthly Variations of NO2, NO, NOX, and O3 Trends from 2005 to 2023

Figure 2 shows the monthly variation of NO_2, NO, NOX, and O_3 concentrations across study areas. Overall, NOX levels are consistently higher in SA3 and SA1 throughout the year, while O_3 concentrations are notably elevated in SA3, SA4, and SA5, particularly from May to September. SA2 and SA6 generally record lower NO_2 and NO levels but display seasonal peaks in O_3 during May to August, likely linked to higher photochemical activity in these months. Across most locations, NOX pollutants show less seasonal fluctuation compared to O_3, which exhibits more pronounced monthly variability.

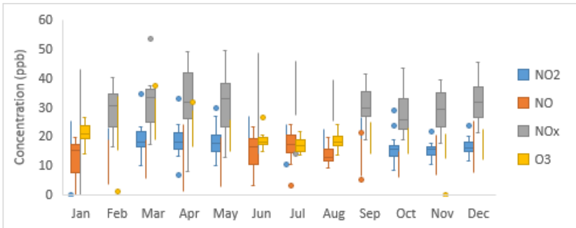
Notably, SA1 and SA3 consistently recorded higher NOX levels. [11] blames dense traffic networks, industrial activities, and proximity to major highways that contribute significant combustion emissions in those areas. In addition, O_3 trends peaks seasonally from May to September. This phenomenon mainly driven by stronger solar radiation and higher temperatures during the Southwest Monsoon (SWM), which enhance photochemical reactions between NO_x and VOCs [9]. It shows that weather and climate having an impact on pollution trends.



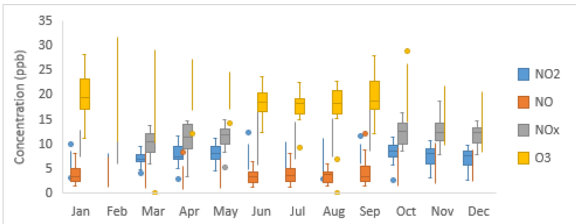
(a) Seberang Jaya (SA1)



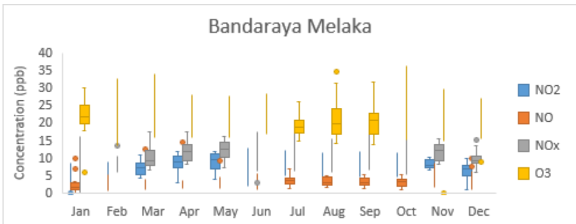
(b) Tasek Ipoh (SA2)



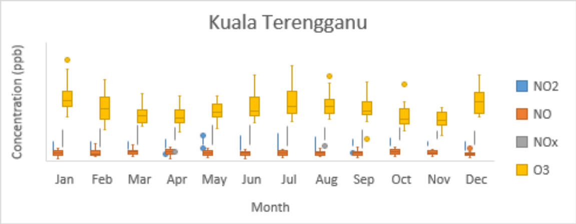
(c) Shah Alam (SA3)



(d) Seremban (SA4)



(e) Bandaraya Melaka (SA5)



(a) Kuala Terengganu (SA6)

Figure 2. Boxplots of Monthly NO_2, NO, NOX, and O_3 Trends from 2005 to 2023 **(a)** Seberang Jaya **(b)** Tasek Ipoh **(c)** Shah Alam **(d)** Seremban **(e)** Bandaraya Melaka **(f)** Kuala Terengganu.

4. CONCLUSION

This research analysed long-term trends of NOX and O_3 in six urban areas of Peninsular Malaysia. Yearly trends showed a decline in NOX, especially at SA1 and SA3, due to stricter emission controls. O_3 levels remained stable or slightly increased, indicating strong photochemical activity. Monthly variation showed NOX peaks at SA1 and SA3, while O_3 reached seasonal highs from May to September during the Southwest Monsoon. These findings support targeted policies for cleaner air and healthier cities. The research also aligns with national and global goals such as Net Zero Emissions 2050.

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