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SPATIOTEMPORAL OF NITROGEN DIOXIDE (NO_2) CONCENTRATION IN THE URBAN ENVIRONMENT OF KLANG VALLEY, MALAYSIA

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Abstract

The high concentration of nitrogen dioxide (NO2) directly results in Klang Valley's air quality deterioration, causing a public health risk. This study was conducted to analyse the daily-averaged and annual concentration of nitrogen dioxide (NO2) on a spatial-temporal scale at five continuous monitoring stations under the Department of Environment (DOE) in Klang Valley, namely, Klang, Shah Alam, Petaling Jaya, Kajang, and Cheras from 2000 to 2009 using Man-Kendall statistical analysis and interpolation technique in Geographic Information System (GIS). The result clearly showed that the Petaling Jaya station was identified as the most polluted compared to other stations, with an average concentration of more than 0.050 ppm every year and reaching the maximum concentration of 0.069 ppm where the mean was 0.030 in 2001. Based on the p-value derived from the Mann-Kendall statistical analysis, the Klang, Petaling Jaya, Shah Alam, and Cheras stations recorded a significant trend with p-values < 0.05 at 0.0001 and 0.020, respectively. The annual concentration of NO2 in all the stations was in the range of 0.015 to 0.04 ppm from 2004 to 2009, compared to 0.005 to 0.01 ppm from 2000 to 2003. The highest annual-averaged NO2 concentration was reported at the Petaling Jaya station between 0.035 and 0.004 ppm for all years except 2007 and 2009 when concentrations were in the 0.03 to 0.035 ppm. Notably, the Petaling Jaya station had the highest annual NO2 concentration, which ranged from 0.025 to 0.04 ppm due to emissions from motor vehicles. The major pressure on road infrastructure was recognised, mainly a lack of space to accommodate the effect of the maximum density of motor vehicles and traffic, resulting in traffic congestion in the city centre.

Keywords: Air Quality, NO2 Concentration, Spatiotemporal Analysis, Man-Kendall Statistical Analysis, Interpolation Technique GIS, Klang Valley, Malaysia

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INTRODUCTION

Currently, air pollution is a significant cause of mortality and disability. The World Health Organisation (WHO) estimates that urban and rural outdoor air pollution causes 3.7 million deaths annually (WHO, 2014). The Worldwide Burden of Disease (GBD) (2015) and the World Bank (2016) have identified air pollution as a global health risk factor. Numerous research has examined the links between air pollution and unfavourable health consequences (Dehghani et al., 2018; Delikhoon et al., 2018). Around 90% of children worldwide are exposed to air pollution above WHO recommended limits (WHO, 2018a), posing immediate and long-term health concerns. Notably, nitrogen dioxide (NO_2) is a toxic gas that is linked with both outdoor (e.g. traffic) and indoor (e.g. gas cooking) sources. In outdoor urban environments, NO_2 is derived primarily from the oxidation of nitric oxide (NO) a primary traffic pollutant (Huangfu & Atkinson, 2020).

Therefore, NO_2 along with particulate matter and ozone, is a significant air contaminant that requires frequent monitoring. Urbanisation has exposed 5% of Europe's population to NO_2 concentrations over the EU's yearly limit value of 40 g/m3 (EEA, 2019). Road mobility is the primary source of urban air pollution (San et al., 2021), accounting for 39% of the total NOx emissions in European cities in 2017. The EU and WHO have established critical levels to protect the population from gaseous NO_2 influence on health. NO_2 has negative health effects at levels below the WHO recommended limits, with 92% of paediatric asthma cases occurring in places with annual exposures below WHO NO_2 limits (Achakulwisut et al., 2019).

The deterioration of NO_2 pollution in recent years has caused severe risks to public health while also increasing the economic cost (Eum et al., 2019; Fenech & Aquilina, 2020). According to existing studies, the most significant source is the burning of fossil fuels, specifically the presence of coal-fired power stations (Liu et al., 2019). The population and motor vehicles are other major contributors (Abdullah et al., 2024).

Numerous studies have confirmed that NO_2 pollution affects the risks of all-cause mortality, respiratory mortality, cardiovascular mortality, and asthma (He et al., 2020; Lu et al., 2020; Hoon Leh et al., 2011). A meta-analysis of 23 and 48 publications concluded that NO_2 pollution increased the fatality rate of the inhabitants significantly (Atkinson et al., 2018). Brønnum-Hansen et al. (2018) examined the effect of NO_2 on the life expectancy of inhabitants. According to the research, decreasing NO_2 levels in metropolitan areas to the levels demonstrated in rural areas would enhance urban inhabitants' life expectancy by two years. Through meta-analyses, Khreis et al. (2017) discovered a strong positive connection between NO_2 pollution and asthma. Two national-scale cross-sectional studies in Australia and Vietnam have verified the statistically significant correlation that is identified above (Knibbs et al., 2018). Therefore, this study aims to analyse the daily average on a temporal scale and the annual concentration of NO_2 in spatial aspects at five continuous monitoring stations under the Department of Environment (DOE) in Klang Valley, namely, Klang, Shah Alam, Petaling Jaya, Kajang, and Cheras, from 2000 to 2009.

MATERIALS AND METHODS

Study Area: Klang Valley

Centred in Kuala Lumpur, the Klang Valley is a significant area in Malaysia, encompassing 2911.5 km^2, including the surrounding towns and cities (Rahman et al., 2015). With a population of 8.3 million in 2020, it is the main focus of Malaysian property, industry, and commerce developments (DOE, 2020). The region is known for its rapid urbanisation, population growth, industrial activities, and high traffic volume, making it vulnerable to air quality issues. The Air Pollution Index (API) determines air quality in the Klang Valley, with 52 air monitoring stations that are located in industrial, urban, and suburban areas. This research examined the average annual concentration level of NO_2 from 2000 to 2009 using five DOE air quality monitoring stations, including Klang, Petaling Jaya, Shah Alam, Cheras, and Kajang. Figure 1 and Table 1 provide detailed information on the features of DOE air quality monitoring stations in the Klang Valley.

Data Sources

The main data input for NO_2 concentration in this study comes from the Air Quality Division of the Malaysian Department of Environment (DOE), which was the average annual concentration at the Klang, Petaling Jaya, Kajang, Shah Alam, and Cheras stations, from 2000 to 2009. Since 1995, the Department of Environment (DOE) of Malaysia has appointed Alam Sekitar Malaysia Sdn Bhd (ASMA) for the monitoring of NO_2 concentration data and conducting air monitoring. Before being distributed to the stakeholders, the DOE will verify and validate the data set that ASMA has prepared. ASMA employed an ambient air gas analyser device to test NO_2 for the study. Hourly data is used to manage the data, which is then averaged daily and annually for additional study.

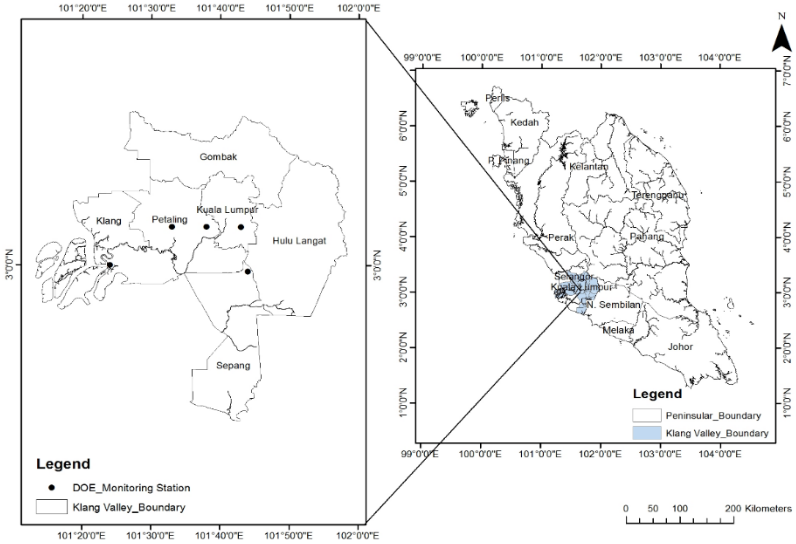


Figure 1: Map of Peninsular Malaysia and DOE monitoring station sites in the Klang Valley.

Table 1: Detailed Information on the Air Quality Monitoring Stations in the Klang Valley

Site Id	Site Location	Area	Coordinates	Area Category
CAC 011	SM (P) Raja Zarina, Klang	Klang	101 24.484’E 3 0.620’N	Urban
CAC 016	SK Sri Petaling, Petaling Jaya	Petaling Jaya	101 42.274’E 3 6.612’N	Industrial
CAC 023	Country Heights, Kajang	Kajang	101 44.417’E 2 59.645’N	Residential
CAC 025	Sekolah TTDI Jaya, Shah Alam	Shah Alam	101 33.368’E 3 6.278’N	Urban
CAC 054	SMK Seri Permaisuri, Cheras	Cheras	101 43.072’E 3 6.376’N	Urban

Mann-Kendall Statistical Trend Analysis

Temporal trend analysis of NO_2 concentration at Klang, Petaling Jaya, Kajang, Shah Alam, and Cheras stations using daily NO_2 concentration data input from 1^{st}. January 2000 to 31^{st}. December 2009 by passing the Mann-Kendall trend test in XLSTAT software.

Statistical trends are patterns of significant data change over time, detected through parametric and nonparametric tests. Through this study, the daily concentration trend of NO_2 at five monitoring stations, namely, Klang, Petaling Jaya, Kajang, Shah Alam, and Cheras was analysed using the Mann-Kendall train test and sen-slope value to determine the magnitude of the NO_2 concentration trend. The Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975) serves to assess rainfall distribution patterns and is a nonparametric test characterised by having no conditions on normal data. The MK test is conducted based on the null hypothesis (H0), which shows that there is no trend of change in annual rainfall distribution, as well as the alternative hypothesis (Ha), which explains that there is a trend pattern of change in rainfall distribution data at study stations (Gadedjisso-Tossou et al., 2021). In terms of the increasing or decreasing trend flow, it is determined by the sen-slope value, i.e., a positive value to show the increasing trend of annual rainfall distribution, and a negative value represents the decreasing trend of rainfall distribution. MK trend analysis was performed using Equation 2 and Equation 3 below:

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} \mathrm{sgn}(x_j - x_k) \tag{2}$$

Where:
xi and xk are sequential data series and:

$$sgn\left(x_j - x_i\right) = \begin{Bmatrix} 1 & if\ x_j - x_i & > 0 \\ 0 & if\ x_j - x_i & = 0 \\ -1 & if\ x_j - x_i & < 0 \end{Bmatrix} \tag{3}$$

The value of variance S is estimated using Equation 4 below:

$$\mathrm{VAR}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p-1}^{g} t_p\,(t_p - 1)(2t_p + 5)\right] \tag{4}$$

Where:
tp = determine the pth value relationship
q = number of bound values

The standard static test for the Mann - Kendall (Z) test is calculated using Equation 5 below:

$$Z = \begin{Bmatrix} \dfrac{s-1}{\sqrt{var\ (s)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{s+1}{\sqrt{var\ (s)}} & if\ S < 0 \end{Bmatrix} \tag{5}$$

Where:
Z = trend direction. A negative Z value indicates a downward trend and vice versa. At the 5% significance level, the null hypothesis (H0), i.e., no trend is rejected if the absolute value of Z is higher than 1.64.

Spatial Interpolation Analysis
Geographical Information Systems (GIS) is a crucial research tool in environmental science and engineering, enabling various methods such as description, explanation, pattern prediction, and model creation (Mandelmilch et al., 2020). Spatial analysis techniques monitor on-the-ground conditions, quantify temporal changes, compare populations, and transmit actionable data to impacted individuals, governmental organisations, and politicians. Spatial analysis is increasingly used to evaluate proximity exposure to air pollution, reducing exposure misclassifications and improving the accuracy of proximity model assessments.

Correspondingly, interpolation techniques use data from sampled locations to estimate the value of a parameter in an un-sampled place, revealing spatial patterns in concentrations across geographical scales. This allows for the examination of patterns in concentration due to specific occurrences, such as air quality episodes. Interpolated findings can be used in empirical models or to produce estimated exposure patterns. Some interpolation methods produce error and probability surfaces, analysing uncertainty in geographic estimations and the likelihood of the violation of air quality regulations. Significantly, estimating error can help to determine the placement of additional monitoring stations, resulting in more accurate interpolated surfaces.

The inverse distance weighted (IDW) interpolation approach weights the contribution of each input (control) point by the normalised inverse of the distance between the control and interpolated point. According to IDW, each input point has a local affect that decreases with distance. It gives more weight to points closest to the processing sites than to those further away. The output value for each location is determined by a set number of points or by all the points within a defined radius. In the IDW interpolator, the power parameter governs the impact of the surrounding points on the interpolated value. A greater power means less impact from distant spots. In this study, the IDW equation used was Equation 1:

$$z(x) = \frac{\sum_{i=1}^{n} w_i(x) z_i}{\sum_{j=1}^{n} w_j(x)}, w_i(x) = \frac{1}{d\,(x, x_i)^p} (1)$$

Where:
Z (x) = predicted value at the interpolated point; x_i = value of the *i-th* known sample point, i.e., the annual average concentration of NO_2 at five air quality stations; d = distance between the known sample point and the prediction point; n = total number of the known sample points and refers to the five air quality stations, namely, Klang, Petaling Jaya, Kajang, Shah Alam, and Cheras; w_i = weight assigned to *i-th* known sample point and p = weighting power and commonly this value was considered as 2.

The five DOE air quality station in this investigation represented the Klang Valley region. Default settings interpolate the distribution of NO_2 concentration in the IDW spatial interpolation method. In this case, it was predicted that the closest sites would have greater or nearly identical concentrations, and vice versa with ArcMap version 10.3 in ArcGIS.

RESULT AND DISCUSSION

The annual average of NO_2 at all Klang Valley was found to be lower than the standard RMAQG from 2000 to 2009. The Petaling Jaya station was identified as the most polluted of the five stations, with an average concentration of more than 0.050 ppm annually, the maximum reaching 0.069 ppm and the mean was 0.030 in 2001. In addition, Klang and Cheras were the second most polluted stations, with NO_2 levels ranging from 0.035 ppm to 0.054 ppm between 2000 and 2009. In 2002 and 2004, the maximum NO_2 concentrations were reported at the Klang and Cheras stations, both at 0.054 ppm. The Shah Alam station is the fourth station to report the highest NO_2 levels, at 0.048 ppm in 2008, compared to previous years. The lowest NO_2 concentration station is Kajang, which only reported a maximum average of 0.033 ppm in 2008, with a mean of 0.013.

Daily-averaged of NO_2 Concentrations

Based on the p-value derived from the Mann-Kendall statistical analysis in Table 2, there was an average trend in NO_2 concentration as observed at the Klang, Petaling Jaya, Shah Alam, and Cheras stations. The Klang, Petaling Jaya, Shah Alam, and Cheras stations all recorded a significant trend with p-values < 0.05 at 0.0001 and 0.020, respectively, demonstrating this condition. However, the situation is different at the Kajang station, which shows no significant trend, and has a p-value > 0.05, i.e., 0.490, indicating that NO_2 concentrations have not changed from 2000 to 2009. In terms of trend shape, either growing or decreasing, the sen-slope values obtained are negative values of -3.737E-7, -6.614E-7, and -2.055E-6, respectively, throughout the 10 years of the research; this also demonstrates that Klang, Petaling Jaya, and Cheras stations display a downward trend. This condition clearly demonstrates that the NO_2 concentrations in Klang, Petaling Jaya, and Cheras have dropped between 2000 and 2009. From 2000 to 2009, the cumulative daily concentration of NO_2 at Petaling Jaya station did not surpass 0.07 ppm, with the maximum reading being 0.069 ppm on November 29, 2001. However, from 2004 to 2009, the NO_2 concentration started to fall below 0.06 ppm, with the exception of August 8, 2007, when a NO_2 concentration of 0.061 was reported. Apart from that, the Klang station reported NO_2 readings of less than 0.05 ppm from 2000 to 2009, with the exception of 0.054 ppm and 0.051 ppm on 14th. March 2002 and 22nd. February 2002, respectively. Except for a few days when the NO_2 concentration was higher than 0.04 ppm, the NO_2 concentration fell to 0.04 ppm. In reality, the Cheras station demonstrated the same condition, with a declining trend in daily NO_2 concentrations from 2004 to 2009, with an overall concentration of less than 0.05 ppm. However, compared to the other days, the 14th of October 2004 had the highest daily NO_2 concentration of 0.054 ppm. This circumstance directly indicated that the daily NO_2 concentrations were high in 2004-2005 and then fell below 0.04 ppm from 2006 to 2009, with the exception of a few days in August 2009, when high concentration of 0.047 ppm and 0.042 ppm were reported.

Table 2: Statistical analysis of Mann-Kendall and sen-slope trends of NO_2 concentration in the Klang Valley

Station	Sen Slope	Kendall tau (t)	Mann-Kendall (s)	p-value	Alpha	Interpretation
Klang	-3.737E-7	-0.052	-335826.00	< 0.0001	0.05	Reject H0
Petaling Jaya	-6.614E-7	-0.059	-389540.00	< 0.0001	0.05	Reject H0
Kajang	0	0.008	50638.00	0.490	0.05	Accept H0
Shah Alam	0	-0.026	-170482.00	0.020	0.05	Reject H0
Cheras	-2.055E-6	-0.147	-345065.00	< 0.0001	0.05	Reject H0

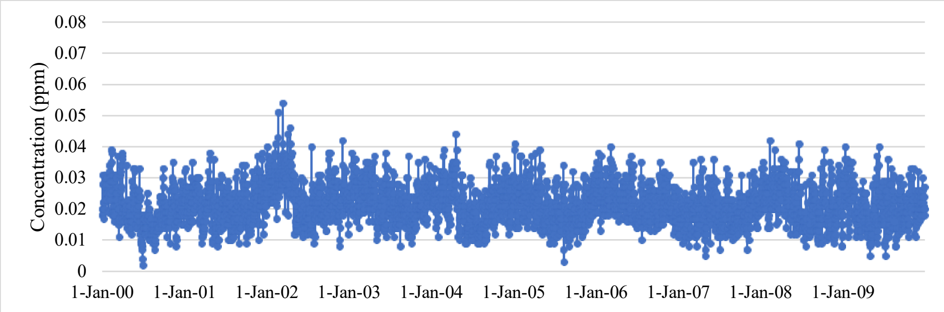


Figure 2: Daily-Averaged of NO_2 Concentration Trend in Klang Station from 2000 to 2009

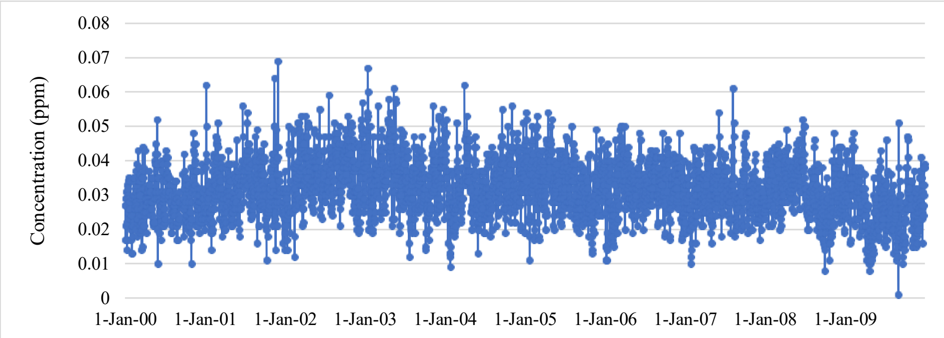


Figure 3: Daily-Averaged of NO_2 Concentration Trend in Petaling Jaya Station from 2000 to 2009

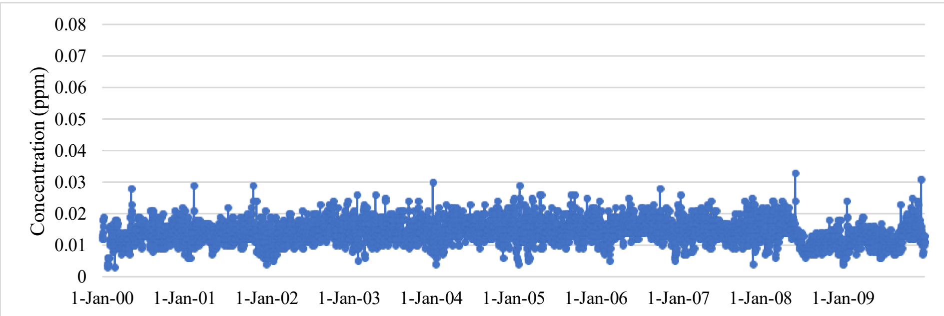


Figure 4: Daily-Averaged of NO_2 Concentration Trend in Kajang Station from 2000 to 2009

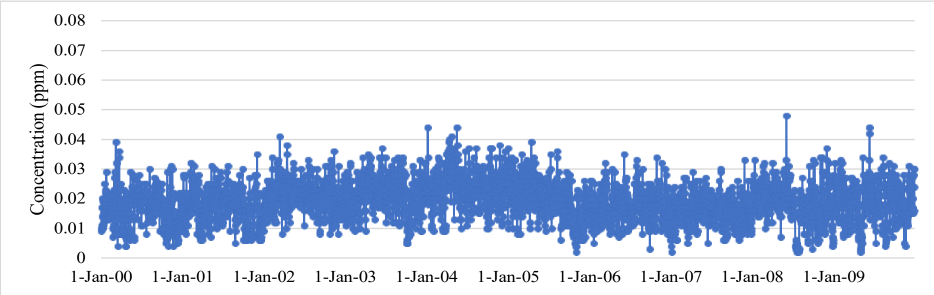


Figure 5: Daily-Averaged of NO_2 Concentration Trend in Shah Alam Station from 2000 to 2009

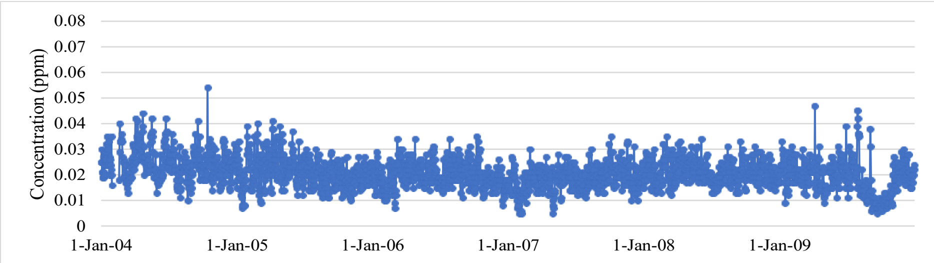
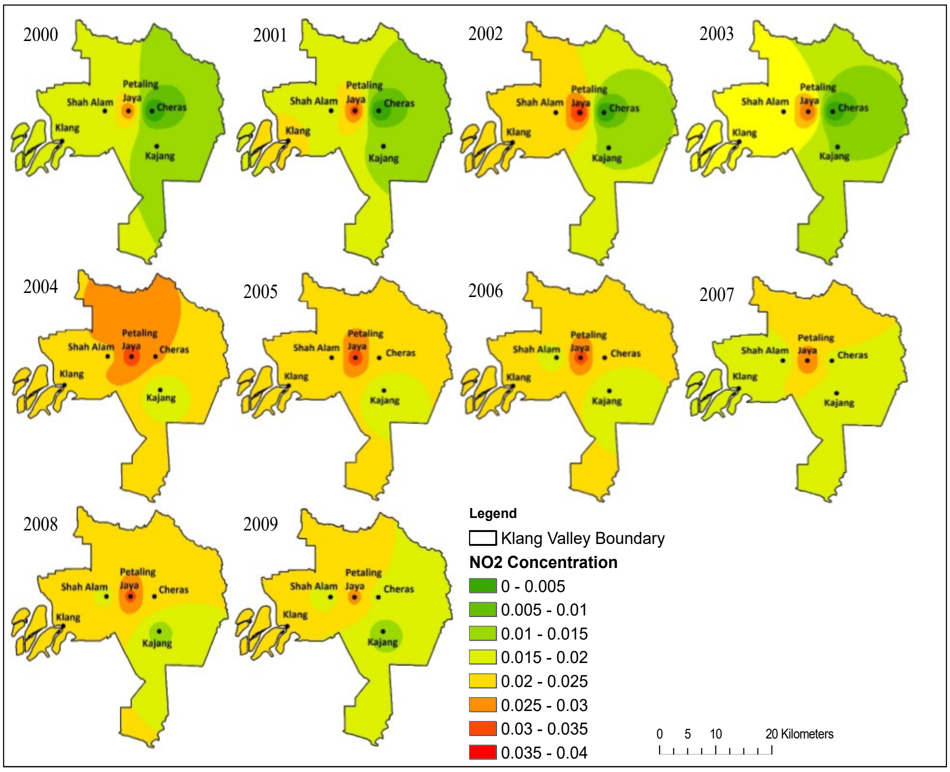


Figure 6: Daily-Averaged of NO_2 Concentration Trend in Cheras Station from 2000 to 2009

From 2000 to 2009, there was no trend in NO_2 content at the Kajang and Shah Alam stations; The Kajang station is the lowest, with a daily NO_2 concentration of less than 0.03 ppm on average. However, on June 4th., 2008, and December 15th, 2009, the daily NO_2 concentrations were greater than 0.03 ppm, with 0.033 ppm and 0.031 ppm, respectively. In reality, the Shah Alam station reported a general daily reading of less than 0.04 ppm from 2000 to 2009, with the exception of a few days when they were 0.048 ppm on 4th. June 2008, 0.04 ppm on 12th. June 2009, and 0.042 ppm on 14th. June 2009. This circumstance demonstrates that, in contrast to 2004 and 2005, the daily concentration of NO_2 has been rather high for a few days in 2009.

Spatial Distribution of Annual-averaged of NO_2 Concentrations

The spatial distribution of annual-averaged NO_2 concentrations at Klang, Shah Alam, Petaling Jaya, Kajang, and Cheras stations increased from 2004 to 2009, according to IDW interpolation analysis. The annual concentration of NO_2 in all the stations was in the range of 0.015 to 0.04 ppm from 2004 to 2009, compared to 0.005 to 0.01 ppm from 2000 to 2003. The highest annual-averaged NO_2 concentration was reported at the Petaling Jaya station, which was between 0.035 and 0.004 ppm for all years except 2007 and 2009, when concentrations were in the 0.03 to 0.035 ppm range. Klang is the second highest station, with an annual average level of NO_2 between 0.025 and 0.03 ppm in most years, including 2001, 2002, 2004–2006, 2008, and 2009. However, the Klang station recorded a minimal annual-averaged NO_2 concentration of 0.02 to 0.025 ppm in 2003 and 0.01 to 0.015 ppm in 2000. The Cheras station, for example, showed a rather high annual-averaged NO_2 concentration of 0.03 to 0.035 ppm in 2004, as well as 0.025 to 0.03 ppm in 2005, 2006, and 2008. Lower annual-averaged NO_2 readings in the range of 0.015 to 0.02 ppm were observed in 2007 and 2009. However, the Shah Alam station, which reported the highest annual-averaged NO_2 content of approximately 0.02 to 0.025 ppm for several years, namely, 2002, 2004, and 2005, demonstrated a contrasting scenario. However, the annual-averaged NO_2 level at Shah Alam station declined from 0.015 to 0.02 ppm between 2006 and 2009. The Kajang station had the lowest annual NO_2 concentration, which was only 0.005 to 0.015 ppm from 2000 to 2003, starting from 0.015 to 0.02 ppm from 2004 to 2007, and then decreasing back to 0.01 to 0.015 ppm in 2008 and 2009.



Petaling Jaya station clearly had the highest annual NO_2 concentration, which ranged from 0.025 to 0.04 ppm due to a number of factors. The major cause of the deterioration of air quality in Malaysia is due to the emissions from motor vehicles. In fact, motor cars and traffic have been demonstrated to be the primary and dominating sources of urban air pollution in Malaysia.

The Malaysian Road Transport Department (MRTD) reported an 8.16 per cent increase in the number of motor vehicles registered in the country from 4,335,863 units in 2003 to 28,224,407 units in 2017, driven by economic development factors. The cumulative Gross Domestic Product (GDP) per capita has been steadily increasing alongside the number of registered motor vehicles. This trend, which began in 2001 with 11,302,545 units and reached 25,044,872 units in 2015 (WDI, 2017), significantly increases individuals' buying power and spending capacity, promoting product and service mobilisation.

The high density of motor vehicles and traffic in cities such as Kuala Lumpur has led to significant pressure on road infrastructure, causing traffic congestion. In 2010, urban building saturation increased by 114.82%, compared to a loss of 70.2% in green space (Rosni et al., 2016). This high concentration of built-up areas causes traffic congestion, especially at intersections and traffic signals. According to Bajcinovci (2017), the physical structure of a city and busy traffic conditions directly influence air pollution levels. The crowded and dense transportation network and urban area with numerous active service activities contribute to this issue. Significantly, urban traffic pollution has severe consequences for agriculture, ecosystems, buildings, human eyesight, and lung health.

Individual exposure to pollution is exacerbating the issue, especially near major metropolitan roadways. The intensity and frequency of traffic flow, especially during peak hours, contribute to the growing exposure. High pollution levels are worsened by the distance between emission sources and city centres, as well as the dispersion and fluidity of pollutants in the air. Climate factors, such as wind, temperature, and humidity, and topography also influence air chemical reactions. High urban surface roughness, especially in city centres, increases pollution concentrations.

CONCLUSION

A serious urban air quality deterioration occurs in the Klang Valley due to the production and release of air pollutants, especially from motor vehicles. The results of the study summarised that Petaling Jaya station was identified as the most polluted of the five stations, with an average concentration of more than 0.050 ppm every year with the maximum reaching 0.069 ppm whereby the mean was 0.030 in 2001. In terms of spatiotemporal, Klang, Petaling Jaya, Shah Alam, and Cheras stations recorded a significant trend with p-values < 0.05 at 0.0001 and 0.020, respectively. The obtained sen-slope values were negative, demonstrating that the NO2 concentrations in Klang, Petaling Jaya, and Cheras had decreased between 2000 and 2009. Furthermore, the highest annual-averaged

NO2 concentration was reported at the Petaling Jaya station, which was between 0.035 and 0.004 ppm for all years except 2007 and 2009, when concentrations were in the 0.03 to 0.035 ppm range. This situation is evidenced by the maximum total number of motor vehicles that are recorded in Wilayah Persekutuan, Kuala Lumpur, i.e., 2,301,024 units, compared to a total of 906,432 units that represent the state of Selangor throughout the years 2000 to 2009. This situation is indicated by the number and types of private vehicles and goods identified as the main cause of increased production and release of pollutants. The major pressure on the road infrastructure was recognised to be mainly due to a lack of space to accommodate the effect of the maximum density of motor vehicles and traffic, resulting in traffic congestion in the city centre.

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CONFLICTS OF INTERESTS

The author declared no conflict of interest.

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