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Research Article

Geospatial Mapping of Air Pollution and Health Risks in the Klang Valley: Insights for Industrial Sustainability

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Abstract

Air pollution is a significant environmental issue that poses serious health risks, particularly in industrial areas. This study focuses on evaluating the spatial distribution of air pollutants and their impact on public health in the industrial areas of Shah Alam and Petaling Jaya in the Klang Valley, Malaysia. This study examines concentrations of particulate matter (PM10 and PM2.5), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and carbon monoxide (CO) over a 2021, 2022, and 2023. Utilizing Geographic Information System (GIS) tools, the study maps the spatial distribution of the health risk in industrial are and correlates them with air pollutants data obtained from Department of Environmental, Malaysia (DOE). The trend of air quality in Shah Alam and Petaling Jaya reveals variation in pollutants concentrations, influenced by both natural and anthropogenic factors, with Shah Alam generally exhibiting higher level of SO_2, NO_2 and O_3, while Petaling Jaya shows elevated CO levels. The differences between Shah Alam and Petaling Jaya's air quality likely from varying meteorological factors, such as wind patterns, temperature, and humidity, which can influence the dispersion and concentration of pollutants. This underscores the critical need for targeted air quality management strategies to mitigate health risk associated with industrial pollution and urbanization in these regions.

Keywords: Geospatial, Air Pollution, Health Risks, Industrial, Sustainability

Introduction

Air pollution is a pressing environmental concern that poses significant health risks, particularly in urban industrial areas. According to the World Health Organization (WHO), air pollution refers to the contamination of air by gases and solids that alter its natural characteristics. Almost 99% of the global population breathes air that exceeds WHO guidelines, particularly in low and middle income countries, leading to significant health concerns [1]. Pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and particulate matter (PM2.5 and PM10) have detrimental effects on human health [2]. Exposure to these pollutants can lead to respiratory issues [3], reduced lung function, heart disease, stroke, and even premature death [4]. According to the Department of Environment, Malaysia (DOE), industrial activities, power generation, and construction activities are stationary contributors to pollution, compared to dominant contributors such as mobile sources or motor vehicles.

Particulate Matter (PM), due to its small size and inhalability, poses significant health risks, affecting ecosystems, forest species, and agricultural crops, leading to ecosystem contamination and species loss [5]. Despite the introduction of air quality regulations, policies, and legislation in Malaysia, their enforcement remains insufficient [7]. The inability to strictly enforce environmental legislation, coupled with poor environmental management and limited public awareness, exacerbates the situation. This issue is more prevalent in developing and underdeveloped countries, where the adverse effects on overall well-being are significant.

Malaysia have set up air quality monitoring stations to measure the concentrations of major air pollutants on a continuous basis. This is important as the measurement at these stations represents the actual air quality in the immediate surrounding areas. Based on the information provided by these monitoring stations, previous study conducted in Malaysia focused on analyse data from 20 monitoring stations and observed air pollution such as PM10 has varied significantly annual average concentration, while CO and NO_2 levels were more consistent, with exceptions at some sites [8]. Incorporating pollutants such as PM is essential because to its easily inhalable micro-size, which has significant negative health effects for ecosystems, forest species, and agricultural crops, resulting in forest species loss and ecosystem contamination [5,6]. The Environmental Quality Act 1974 (Act 127) describes laws, guidelines, and strategies for controlling air pollution. This shows the government's dedication to initiative in tackling air pollution challenges by enhancing several action plans and programs.

A Geographic Information System (GIS) integrates computer software and data to enable the entry, analysis, and presentation of data connected to specific locations on the earth's surface [9]. This GIS software offers a powerful means of mapping and analyzing the distribution of air pollutants, allowing for the identification of pollution hotspots and the assessment of associated health risks. Numerous studies in Malaysia have utilized GIS for air quality evaluation, demonstrating its effectiveness in predicting and managing air pollution [5,10-12]. This study focuses on evaluating outdoor air quality in the industrial areas of Shah Alam and Petaling Jaya, using GIS to map the spatial distribution of key pollutants and to correlate these findings with health risk data obtained from a local survey.

The objectives of this study are to identify the trend of industrial air pollution in Shah Alam and Petaling Jaya, assess the potential health risks posed by industrial air pollution to the residents, and develop a GIS-based mapping to visualize the spatial distribution of health risks due to air pollution in these

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areas. Shah Alam and Petaling Jaya were chosen for this study due to their importance as industrial centers. Shah Alam covers an area of approximately 290 km² and has 438,745 residents, known as the "Silicon Valley" of Selangor Golden Triangle. Petaling Jaya covers an area of around 97.2 km² and has 462,290 residents, known for being a major urban and commercial hub. Both locations of Continuous Air Quality Monitoring (CAQM) stations in these regions have been identified to provide data for the study. The analysis of Shah Alam and Petaling Jaya is done based on the spatial distribution of PM10, PM2.5, SO_2, NO_2, O_3, and CO pollutants recorded data from the Department of Environment, Malaysia (DOE).

Materials and Methods

Data Collection

The air quality data is taken from existing CAQM stations in Shah Alam and Petaling Jaya and is acquired from the DOE. The data obtained on the air quality conditions in Shah Alam and Petaling Jaya would act as the main references when carrying out this study. The Shah Alam CAQM station (N03° 06.287′, E101° 33.368′) at Taman Tun Dr. Ismail Primary School (TTDI Jaya) lies in a residential zone with lighter traffic, except during morning and evening rush hours. Meanwhile, Petaling Jaya CAQM station (N03° 06.612′, E101° 42.274′) is located at Sri Petaling Primary School, Selangor, near Kuala Lumpur's city centre and surrounded by industrial, residential, and commercial areas with heavy traffic.

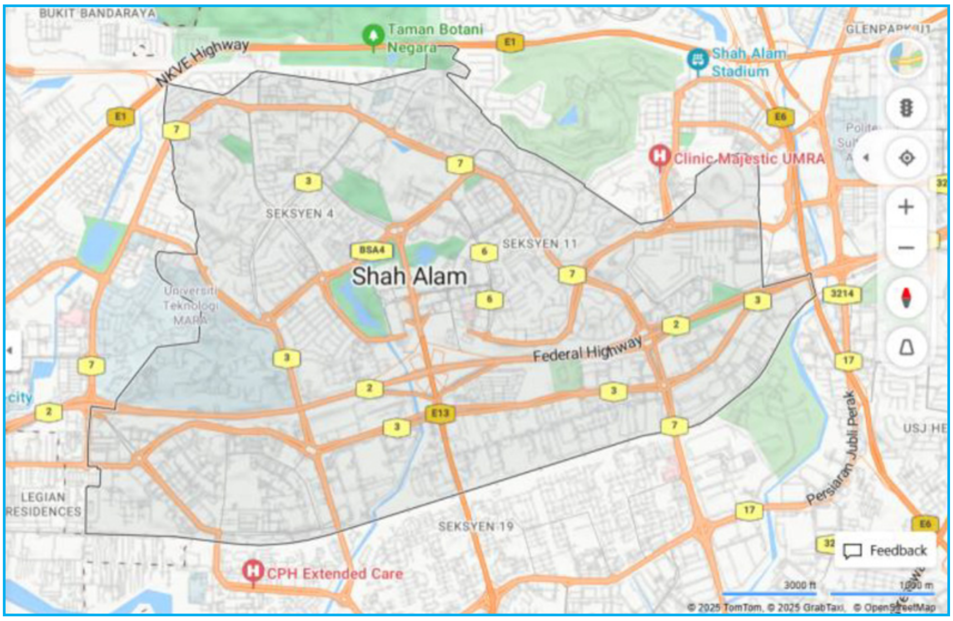

Figure 1. Study location in the Shah Alam industrial area

Questionnaire

The questionnaire was distributed to 100 residents of the Shah Alam and Petaling Jaya industrial areas, specifically those living within a 10 km radius of the industrial zones (Figures 1 and 2). The questionnaire includes several questions that explain the distinctive impacts of air pollution on the individual's physical and psychological health. The questionnaire is divided into four sections. This questionnaire aims to collect data to measure health risks among the residents in industrial areas. Participation in the survey was voluntary, and only respondents who provided consent proceeded to complete it.

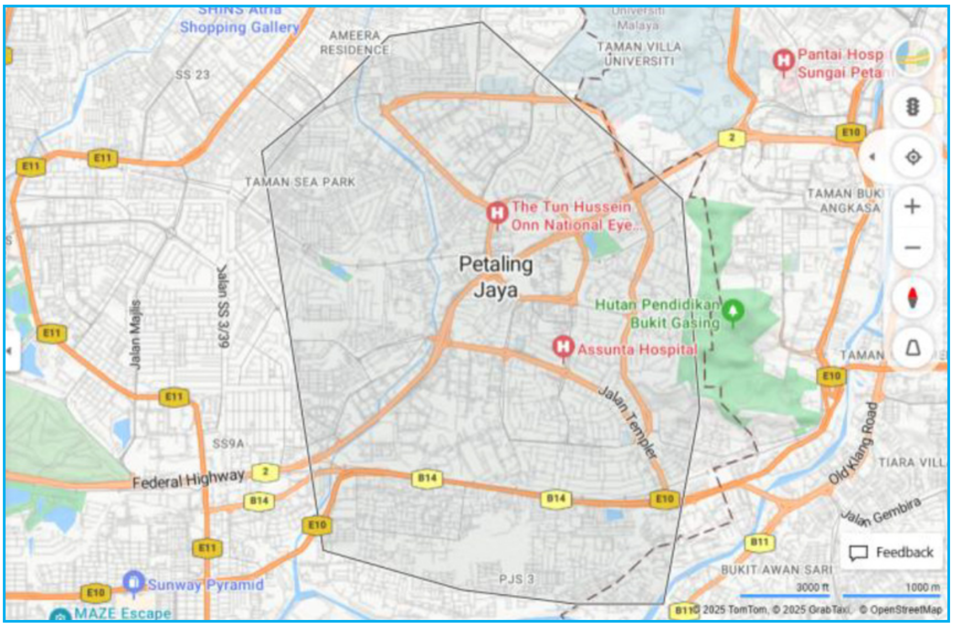

Figure 2. Study location in the Petaling Jaya industrial area

GIS Mapping and Distribution

The study's data will be presented and analyzed via ArcGIS Pro. Before using the ArcGIS Pro software, each respondent's location was marked using the SW Maps mobile application. The marked locations of respondents were then exported from the SW Maps application in a compatible format for further analysis. The exported data was prepared and cleaned to ensure accuracy and consistency, including verifying location points and correcting any discrepancies.

The cleaned data was imported into ArcGIS software, integrating the respondents locations with air pollutants data from DOE for Shah Alam and Petaling Jaya. This DOE data included air pollutant concentrations for PM10, PM2.5, SO_2, NO_2, O_3, and CO. This software can be used in mapping and analytics applications to evaluate geographical relationship, expect outcomes, and come up with improvements to decisions based on data. Furthermore, this software manages several tables and merges them seamlessly.

This analysis helped identify areas with high pollution levels. The spatial distribution of health risks due to air pollution was analyzed by correlating the questionnaire responses with the pollutant concentration data. This involved overlaying the health data with the pollutant maps to identify potential correlations. Detailed maps were then developed to visualize the spatial distribution of air pollutants and associated health risks, providing a clear visual representation of the impact of industrial air pollution on different regions within Shah Alam and Petaling Jaya.

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The final maps were interpreted to highlight pollution hotspots and areas with elevated health risks, providing actionable insights for policymakers and urban planners. Therefore, the Inverse Distance Weighted (IDW) interpolation technique was applied in the study. This analysis helps identify areas with high pollution levels by displaying significant heat map air pollutants for both regions.

RESULTS AND DISCUSSION

AIR QUALITY DATA

The stacked column above shows the concentrations of PM10, PM2.5, SO_2, NO_2, O_3, and CO in Shah Alam and Petaling Jaya over the year 2021, 2022, and 2023. The graph provides a visual comparison of parameter levels for each month across three years. Each month has three bars representing the average of the parameter's concentration for 2021, 2022, and 2023. It distinguished between two locations which are Shah Alam (yellow bars) and Petaling Jaya (Green bars). This graph identified the location specific trends and variations. Despite the importance of the need to control industrial air pollution for environmental and human health protection, interpreting gaseous pollutants and particulate levels in the atmosphere can be challenging. This complexity arises from the diverse emission sources, fluctuating atmospheric conditions, and the necessity for advanced monitoring techniques.

According to Figure 3, the highest PM10 concentrations in Shah Alam were observed in July 2022, reaching approximately 44.344 µg/m³, while the lowest concentration in Petaling Jaya was in January 2022, around 17.303 µg/m³. Additionally, the resuspension of exposed land and road dust, along with the generation of secondary organic aerosols, can influence PM10 concentrations [13]. Meteorological variables like wind speed and atmospheric stability significantly impact PM10 levels during air pollution episodes [14]. Consequently, air temperature and humidity are also related to PM10 levels [15]. Overall, the rise in PM10 levels results from a combination of natural and anthropogenic sources, as well as environmental and meteorological factors.

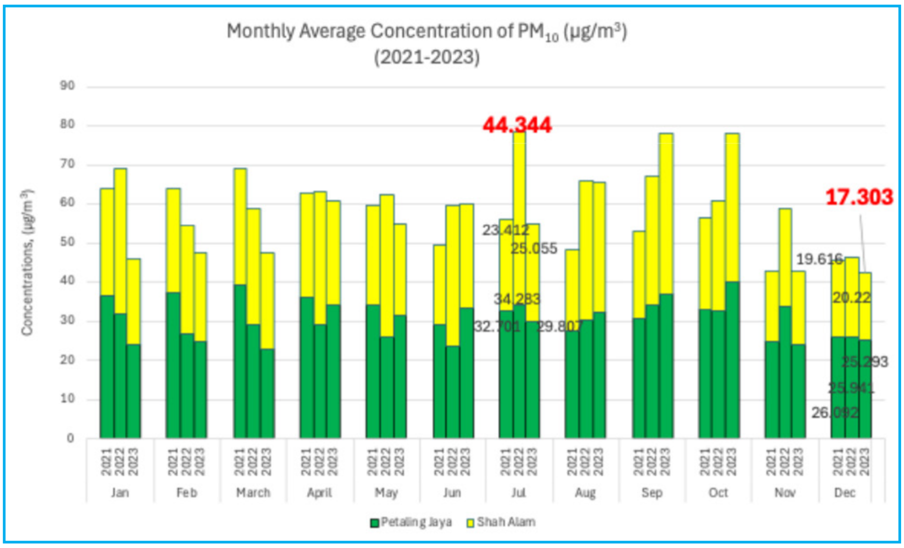

Figure 3. Monthly average concentration of PM10 over 2021, 2022, and 2023

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According to the graph of PM2.5 in Figure 4, the highest concentration was in September 2023 in Shah Alam, amounting to 36.083 µg/m³, while the lowest concentration was in July 2023 in Petaling Jaya, 16.391 µg/m³. PM2.5, which is known to vary in source and composition over time and space, is a complex pollutant harmful to biological health [16]. Meteorological variables, such as weather patterns and high temperatures, contribute to PM2.5 accumulation and are negatively correlated with wind speed, precipitation, and relative humidity [17]. Additionally, the presence of certain pollutants and chemicals, such as nitrogen oxides and volatile organic compounds, might contribute to higher PM2.5 levels [18]. Overall, the rise in PM2.5 concentrations is a complex process influenced by various factors, including both natural and anthropogenic sources, as well as meteorological accumulation.

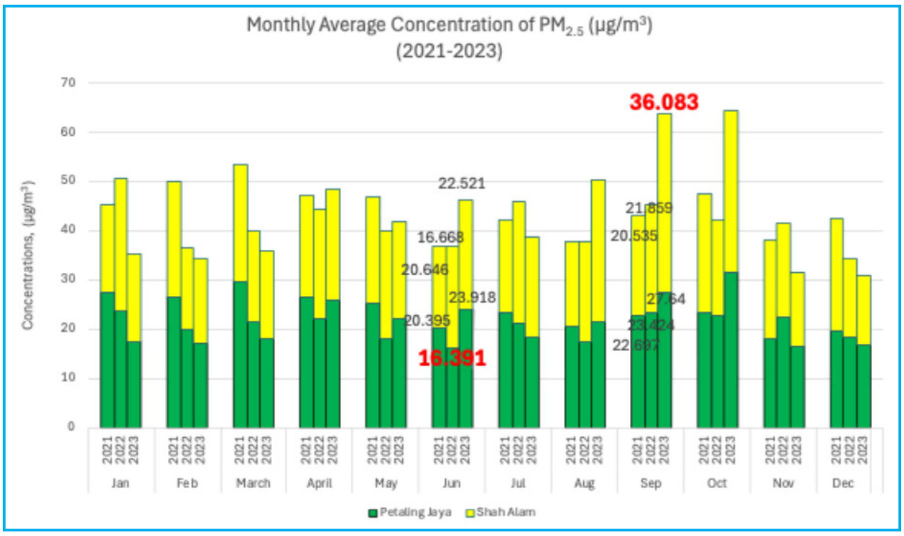

Figure 4. Monthly average concentration of PM2.5 over 2021, 2022, and 2023

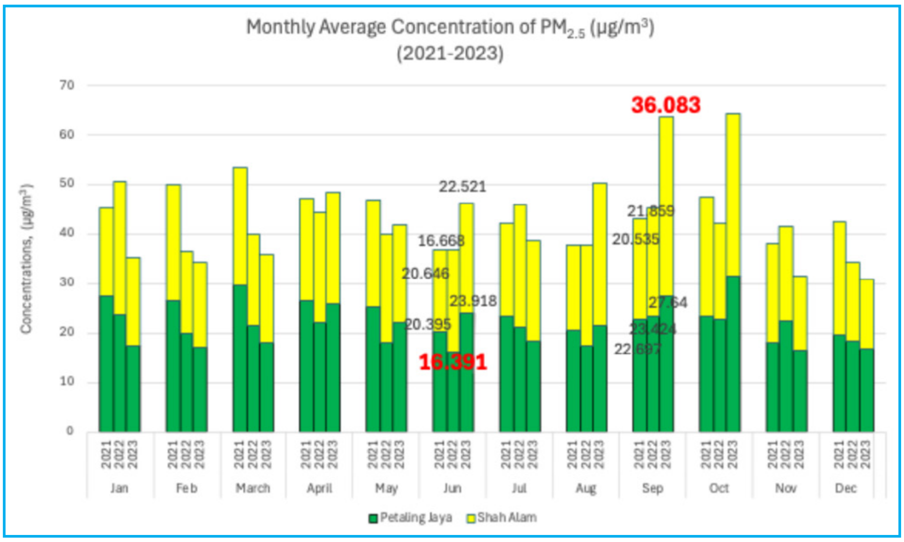

Figure 5. Monthly average concentration of SO_2 over 2021, 2022, and 2023

In 2022, the concentration of SO_2 pollution saw a sudden spike in March, reaching 0.0027 ppm (Figure 5). This increase can be influenced by meteorological and human activity factors. The secondary industry factor reflects the expansion of industrial scale in the area, leading to more SO_2 emissions [19]. Moreover, SO_2 contributes to acid rain, ozone depletion, and respiratory conditions such as asthma and cancer in humans [20].

Meanwhile, in Figure 6, NO_2 is a significant air pollutant, belonging to a category of gases known as nitrogen oxides produced by combustion activities [21]. In March 2021, the highest NO_2 concentration was recorded in Shah Alam at 0.0163 ppm, indicating a relatively high level compared to other months. At high levels, NO_2 can be poisonous when inhaled and may cause respiratory illnesses, coughing, dyspnea, and even pulmonary edema, as it penetrates deep into the lungs [11].

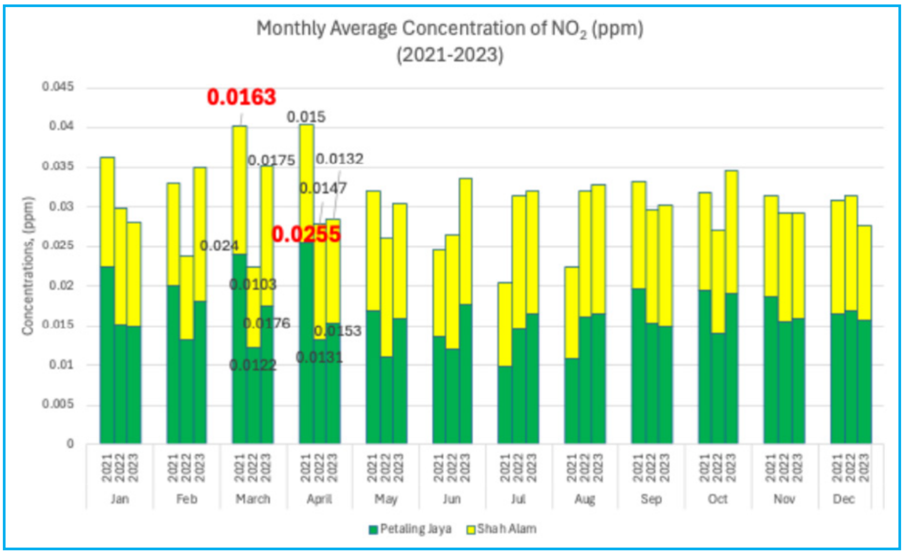

Figure 6. Monthly average concentration of NO_2 over 2021, 2022, and 2023

According to Figure 7, the charts provide valuable insight into trends and fluctuations in ozone (O_3) levels over three years for Shah Alam and Petaling Jaya. In February 2023, the highest O_3 concentration was recorded in Shah Alam at 0.0287 ppm, indicating a relatively high level compared to other months. The lowest concentration was in October 2021 in Petaling Jaya, at 0.0021 ppm. Higher O_3 concentrations in Shah Alam may be attributable to the extensive use of vehicles that emit SO_2. The main causes of increased SO_2 levels include industrialization, energy use, and economic development [22]. Additionally, coal burning emissions and the use of sulfur containing fertilizers contribute to SO_2 production [23].

Carbon monoxide (CO) is released into the environment through the incomplete combustion of carbonaceous materials [24]. According to Figure 8, CO concentrations in February 2023 show 0.849 ppm in Shah Alam, while Petaling Jaya had the lowest concentration of 0.409 ppm in November 2022. Several environmental factors influence CO exposure, including the CO content in ambient air, duration of exposure, oxygen concentration in ambient air, and altitude. In Figure 6, the higher CO levels in Shah Alam may be due to the expansion of the road network, and the development of road systems, which possibly increase traffic users [25]. Overall, the observed geographical

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distribution in air quality parameters indicates the impact of human activities, weather conditions, and regulatory measures on air pollution levels in both locations.

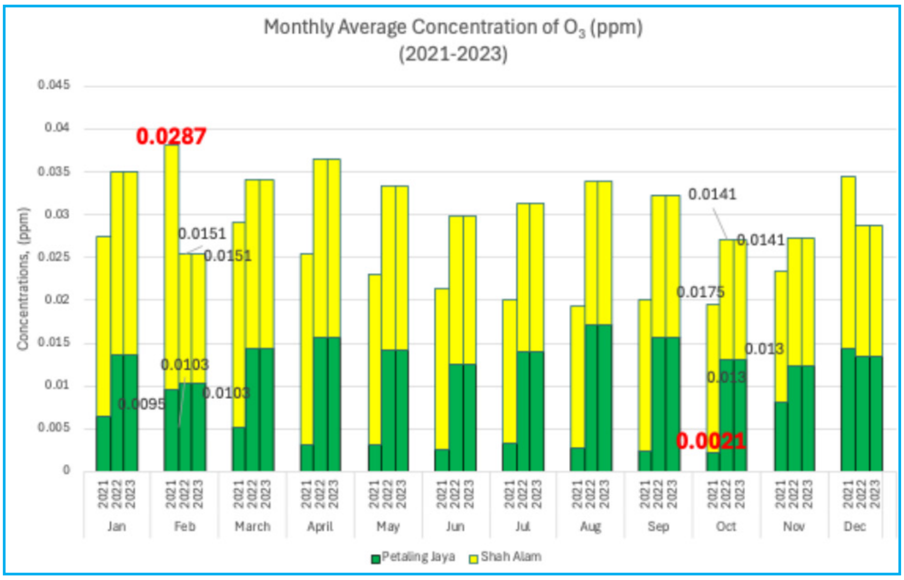

Figure 7. Monthly average concentration of O_3 over 2021, 2022, and 2023

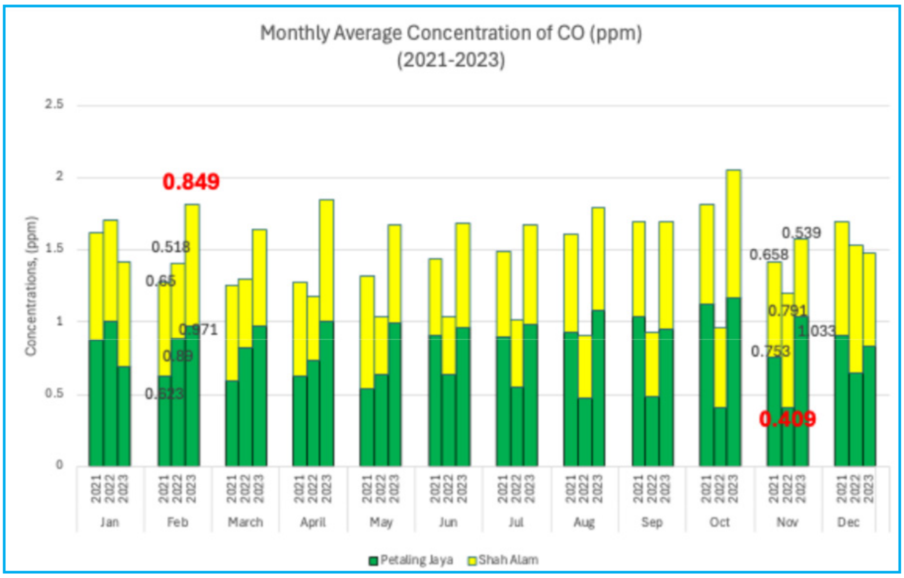

Figure 8. Monthly average concentration of CO over 2021, 2022, and 2023

Air Quality Data

Table 1 shows the results of questionnaires related to potential health risks posed by residents near Shah Alam and Petaling Jaya. Respondents reported a variety of physical symptoms due to air pollution, with the most common effects being experienced sometimes or often. For instance, 70% felt air pollution effects “sometimes”, while 8% experienced them “often”. ENT problems, sinusitis, and allergies were reported by 80% of respondents “sometimes” and by 20% “rarely”. Respiratory problems were less frequent, with 44% experiencing them “sometimes” and 6% “often”. Coughing and wheezing were also notable, with 42% experiencing these symptoms "sometimes" and 54% "rarely". Headaches and dizziness were felt "sometimes" by 50% and "rarely" by 42%. A reduced energy level was reported "sometimes" by 60% and "often" by 12%. Interestingly, sleeping disorders such as insomnia were notably frequent, with 54% experiencing them "sometimes", 38% "often", and 2% "always".

Overall, the data indicate that most physical health effects due to air pollution are felt "sometimes", highlighting the pervasive impact of environmental factors on health.

Table 1. Air pollution caused physical health effects reported by the respondent

Physical Effects	Always n (%)	Often n (%)	Sometimes n (%)	Rarely n (%)	Never n (%)
Felt air pollution effects	-	4 (8)	35 (70)	6 (12)	5 (10)
ENT problems/ sinusitis/ allergies	-	-	40 (80)	10 (20)	-
Respiratory problems	-	3 (6)	22 (44)	15 (30)	10 (20)
Coughing and wheezing	-	-	21 (42)	27 (54)	2 (4)
Headaches and dizziness	-	3 (6)	25 (50)	21 (42)	1 (2)
Reduced energy level	-	6 (12)	30 (60)	10 (20)	1 (2)
Sleeping disorder	1 (2)	19 (38)	27 (54)	2 (4)	1 (2)

Distribution Map of Air Pollution and Health Risk in Shah Alam and Petaling Jaya

Table 2, presents the air pollution averaging concentrations in Shah Alam and Petaling Jaya from 2021 to 2023. Both locations show slight year to year variations in pollutant levels. In Shah Alam, PM10 peaked in 2022 while PM2.5 gradually increased, indicating persistent fine particulate pollution. Petaling Jaya exhibited similar trends with minor fluctuations across PM and gaseous pollutants. Although SO_2, NO_2, and O_3 remained relatively stable, CO levels varied more notably, especially in 2023. Overall, both areas experienced moderate fluctuations, suggesting that local emission sources continue to influence air quality despite regulatory measures.

Table 2. Air pollution averaging concentrations for the year 2021, 2022 and 2023 in Shah Alam and Petaling Jaya.

Location of CAQM	Year	PM10 (μg/m³)	PM2.5 (μg/m³)	SO_2 (ppm)	NO_2 (ppm)	O_3 (ppm)	CO (ppm)
Shah Alam	2021	28.488	20.654	0.0010	0.0133	0.0120	0.6726
	2022	32.258	20.637	0.0012	0.0141	0.0174	0.5413
	2023	26.674	22.068	0.0014	0.0149	0.0184	0.7252
Petaling Jaya	2021	32.30	23.708	0.0012	0.0181	0.0052	0.8177
	2022	29.83	20.672	0.0015	0.0141	0.0139	0.6434
	2023	29.91	21.443	0.0014	0.0165	0.0164	0.9707

In comparison to the national ambient standard, PM10 levels in both areas remained below 40 μg/m³ throughout the year. Urban air composition and its fractions are impacted by anthropogenic pollution levels [26]. Traffic related pollution, heavy oil combustion, and industrial emissions raise PM10 levels [27]. Furthermore, the resuspension of exposed land and road dust, along with secondary organic aerosol generation, also influences PM10 concentrations [13].

Meteorological factors such as wind speed and atmospheric stability significantly affect PM10 levels during pollution episodes [14]. Consequently, air temperature and humidity are related to PM10 levels as well [15]. Overall, the increase in PM10 levels results from a blend of natural and anthropogenic sources, as well as environmental and meteorological factors.

Figure 9 shows the geographic distribution of the monthly average PM10 concentrations in 2023, indicating higher concentrations in Petaling Jaya than in Shah Alam. This pattern contrasts with PM2.5 results and may be influenced by heavier traffic and mixed industrial activities near Kuala Lumpur's city centre.

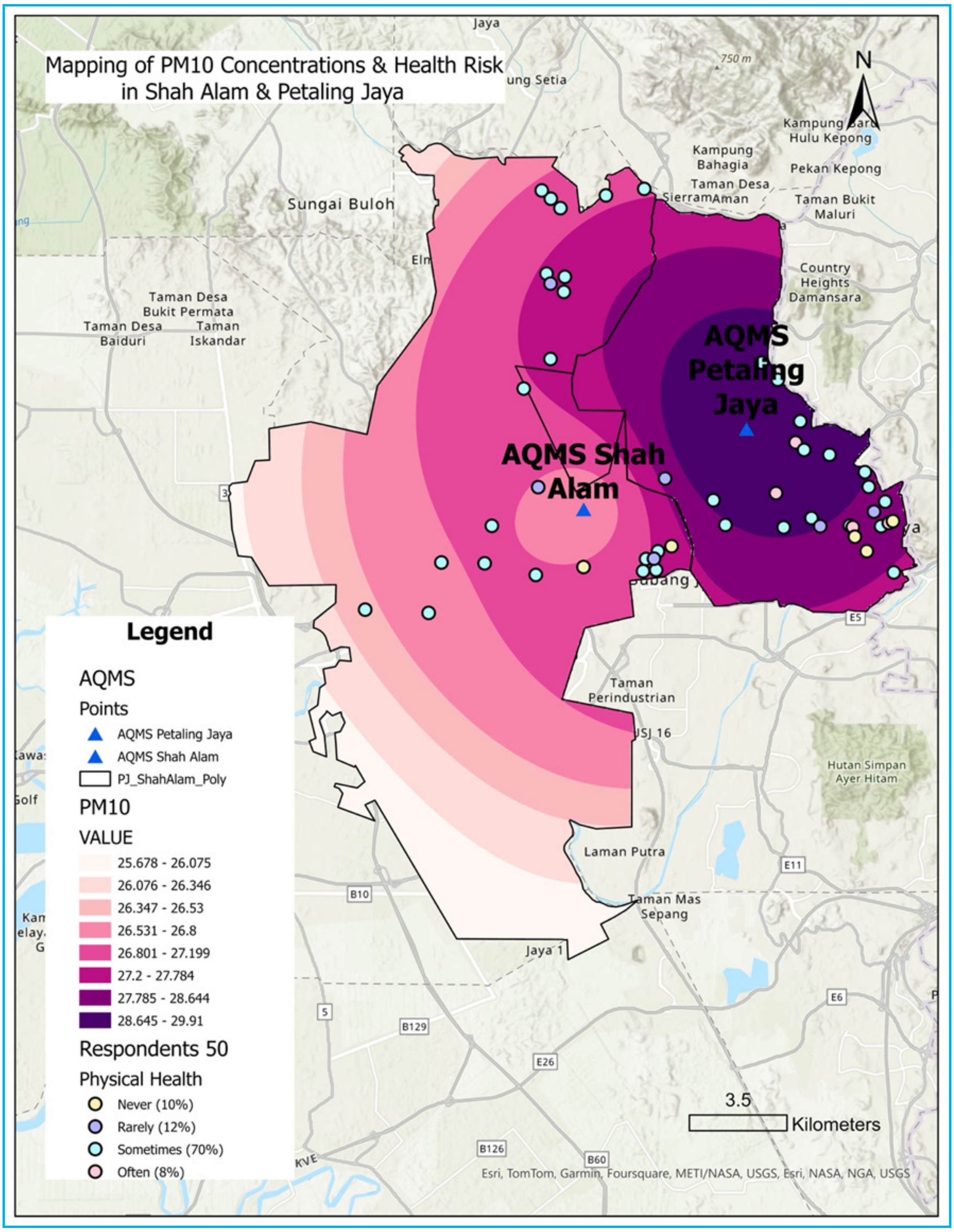

Figure 9. Mapping of air PM10 Concentrations & Health Risk in Shah Alam and Petaling Jaya

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Figure 10 illustrates the geographic distribution of monthly average PM2.5 concentrations in 2023. It shows that Shah Alam has the highest concentration compared to Petaling Jaya. The contrasting results between PM10 and PM2.5 concentrations in Shah Alam and Petaling Jaya could be due to differences in pollutant sources, particle size, and local conditions. Additionally, meteorological factors like wind speed, humidity, and atmospheric mixing can influence dispersion differently for coarse and fine particles, further explaining the inverse relationship.

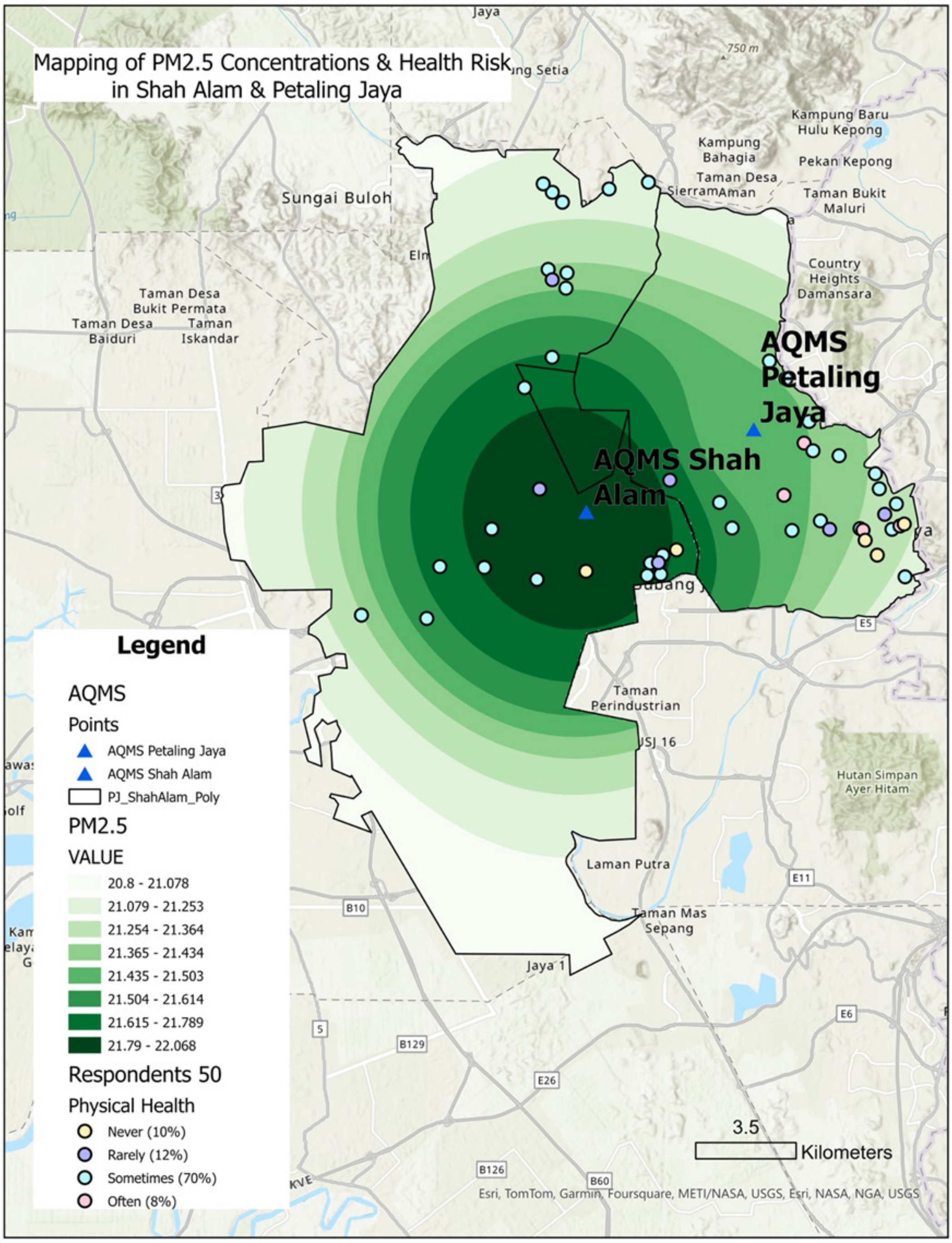

Figure 10. Mapping of air PM2.5 Concentrations & Health Risk in Shah Alam and Petaling Jaya

According to Table 2, the average concentration in Shah Alam is 22.068 µg/m³. This air pollutant varies in source and composition over time and space and is harmful to biological health [16]. PM2.5 consists of solid and liquid particles released into the air from various sources such as diesel use, road, and agricultural dust, and industrial activities [28]. Meteorological factors such as

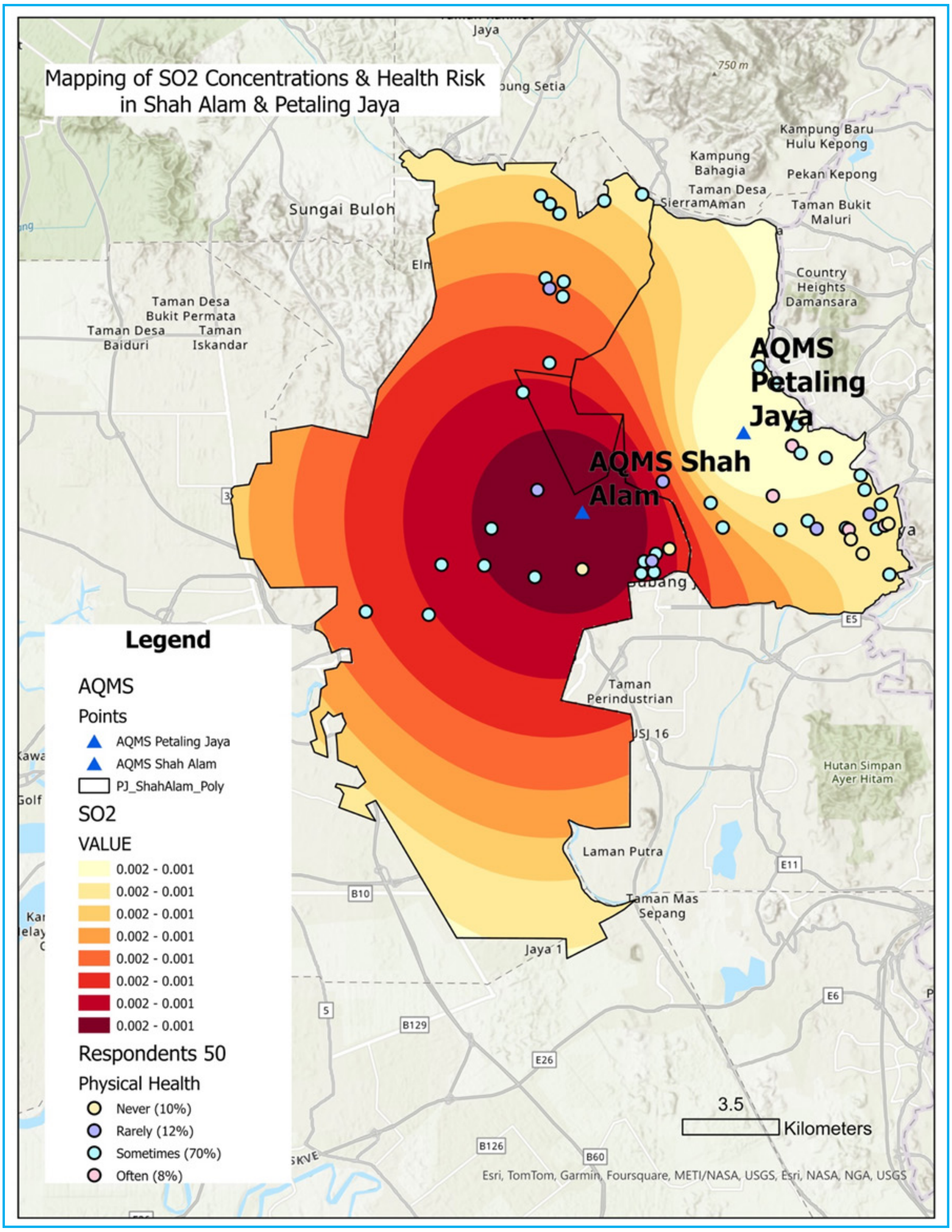

Figure 11. Mapping of air SO_2 Concentrations & Health Risk in Shah Alam and Petaling Jaya

weather patterns and high temperatures also contribute to PM2.5 accumulation, showing a negative correlation with wind speed, precipitation, and relative humidity [17]. Additionally, the presence of certain pollutants and chemicals,

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such as nitrogen oxides and volatile organic compounds, can contribute to higher PM2.5 levels [18]. Overall, the increase in PM2.5 concentrations is a complex process influenced by a variety of factors, including both natural and anthropogenic causes.

Figure 11, illustrates the geographic distribution of ambient SO_2 levels, with Shah Alam having higher concentrations than Petaling Jaya. The average SO_2 concentration in Shah Alam was 0.001433 ppm, while in Petaling Jaya it was

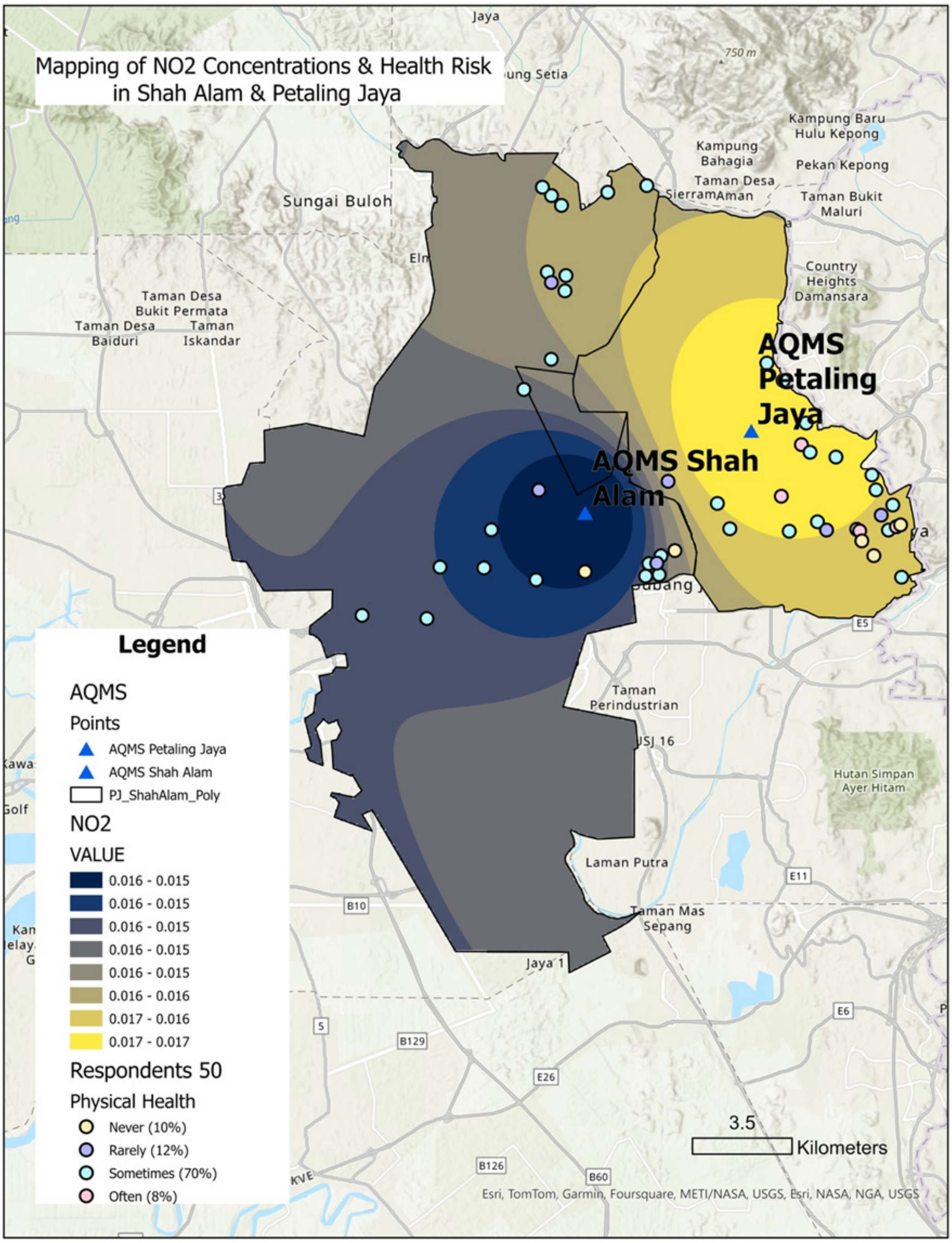

Figure 12. Mapping of air NO_2 Concentrations & Health Risk in Shah Alam and Petaling Jaya

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0.001408 ppm (Table 2). The higher SO_2 levels in Shah Alam may be due to the extensive use of vehicles emitting SO_2. The main causes of increased SO_2 levels are industrialisation, energy use, and economic development [22]. Additionally, coal burning emissions and the use of sulfur containing fertilizers also contribute to SO_2 production [23]. This increase could be attributed to heightened industrial activities and vehicular emissions, especially from factories and manufacturing plants that burn fossil fuels.

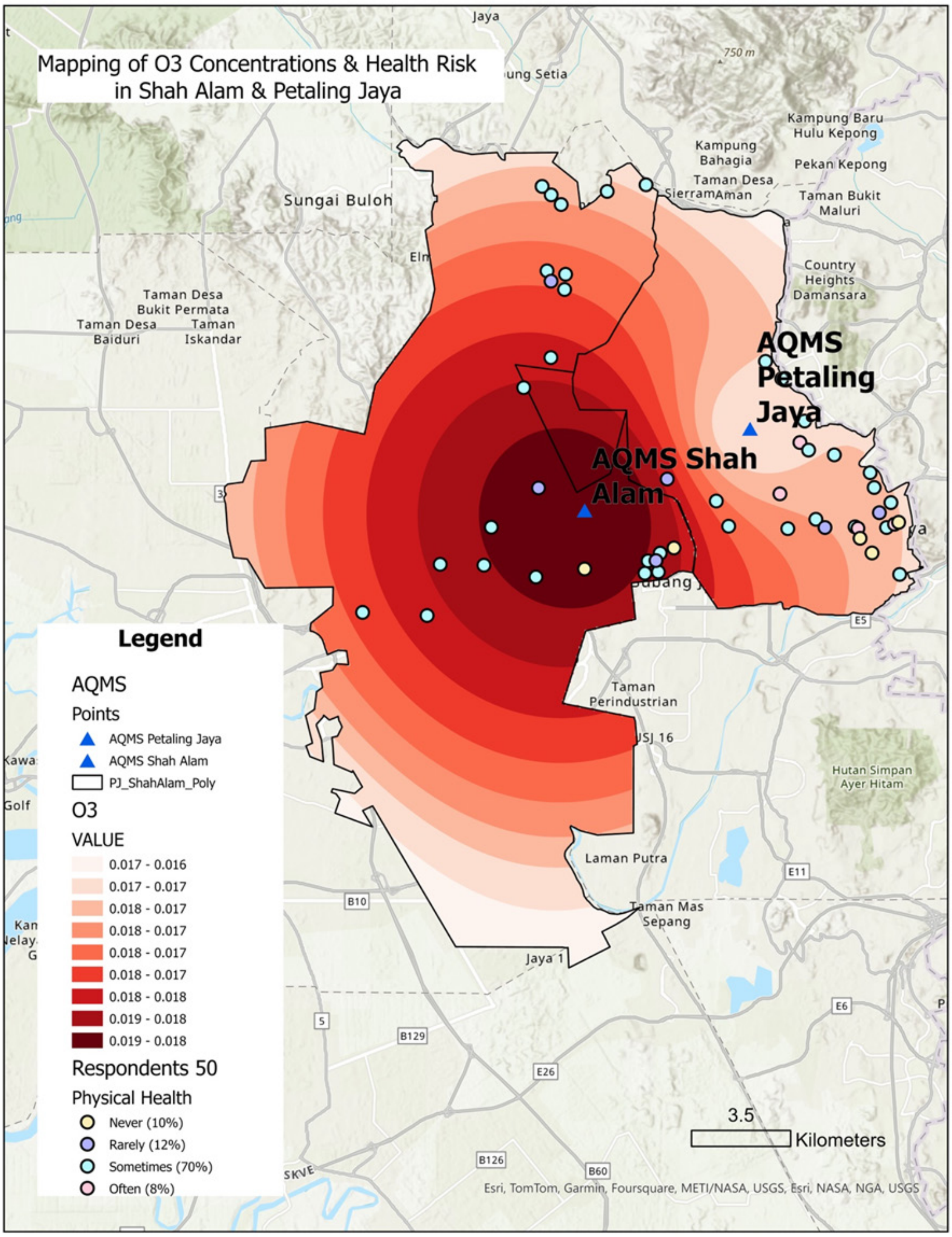

Figure 13. Mapping of air O_3 Concentrations & Health Risk in Shah Alam and Petaling Jaya

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In Figure 12, the geographic distribution analysis for NO_2 shows that Shah Alam has a higher concentration compared to Petaling Jaya. In 2023, the average NO_2 concentration in Shah Alam was 0.014892 ppm, while in Petaling Jaya, it was 0.016525 ppm (Table 2). Diesel vehicles, especially those with after treatment equipment, and anthropogenic factors such as population density, can produce substantial NO_2 emissions [29]. Traffic volume and other atmospheric pollutants have been strongly correlated with NO_2 levels [30].

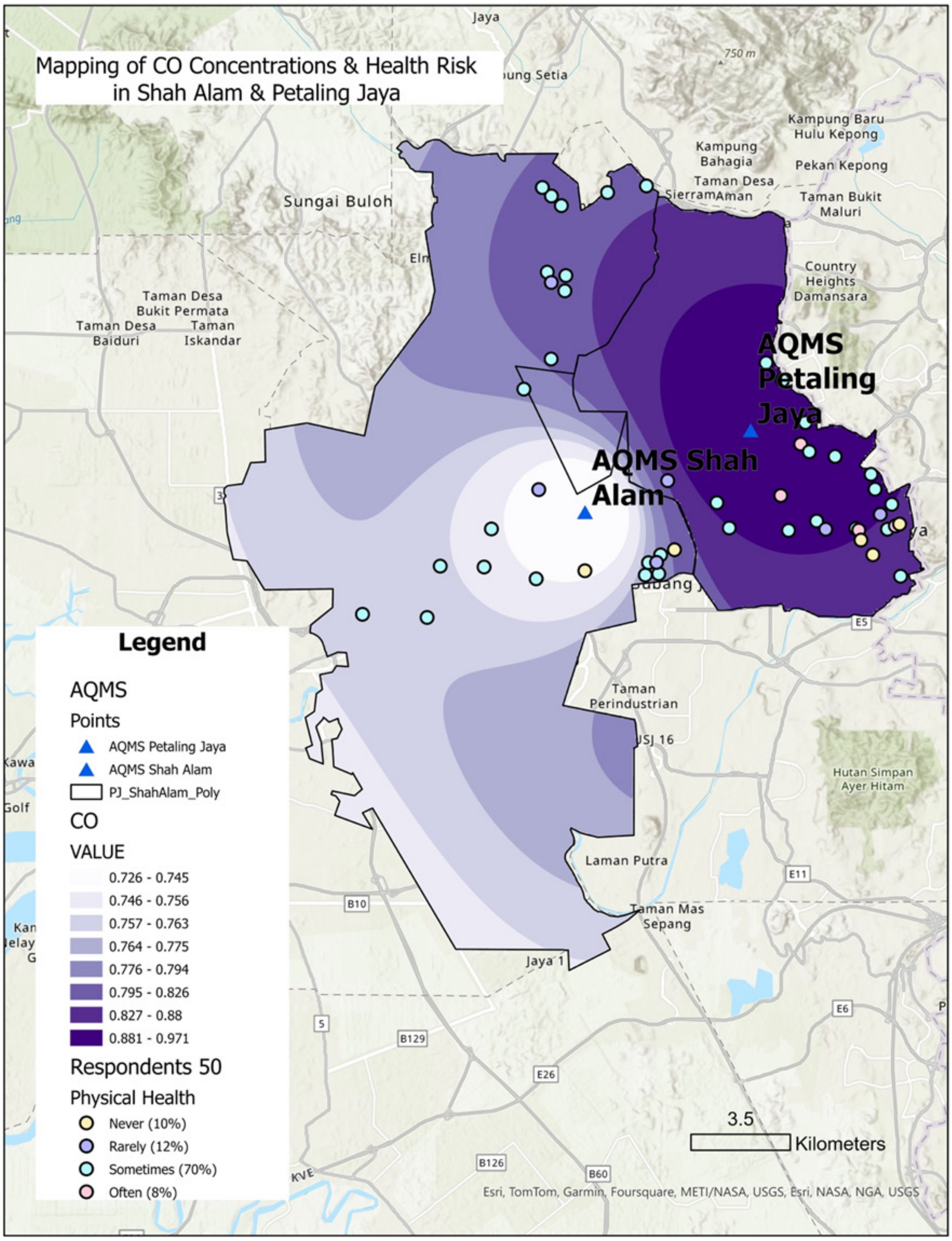

Figure 14. Mapping of air CO Concentrations & Health Risk in Shah Alam and Petaling Jaya

In Figure 13, ozone (O_3) levels in Shah Alam are notably higher compared to Petaling Jaya. The averages O_3 in Shah Alam was 0.018400 ppm, while Petaling has lower concentrations 0.016417 ppm. It can be linked to increased photochemical reactions in the atmosphere, driven by higher temperatures and sunlight. This ground-level on O_3 significantly formed when the sunlight reacts with nitrogen oxides (NOx) and volatile organic compounds (VOCs) [31]. Besides, ozone's is unique among pollutants due to it is not emitted directly from anthropogenic sources [32]. Natural fires, soil, vegetation, lights, and wetlands are the most common natural sources of ozone precursors, whereas anthropogenic sources include transportation, power plants, industrial and combustion activities [32].

Additionally, the geographic distribution of CO is also shown in Figure 14. The pattern of the CO, GIS map reveals that Petaling Jaya has higher concentrations compared to Shah Alam. The average CO concentration in Petaling Jaya is 0.970667 ppm, compared to 0.725167 ppm in Shah Alam. The higher CO levels in Petaling Jaya may be due to the growth of the road network, improvements in road systems, and public transportation, which have reduced traffic congestion [25]. Overall, the observed geographical distribution in air quality parameters highlights the significant impact of human activities, weather conditions, and regulatory measures on air pollution levels in both locations.

Conclusion

The analysis of air quality in Shah Alam and Petaling Jaya reveals significant variations in pollutant concentrations, influenced by both natural and anthropogenic factors. Shah Alam generally exhibits higher levels of particulate matter, specifically PM2.5 and NO_2, as well as elevated concentrations of SO_2 and O_3. In contrast, Petaling Jaya shows elevated levels of PM10 and CO, a pollutant often associated with vehicle emissions, particularly in urbanized areas with heavy traffic. The high density of vehicles and the associated traffic congestion in Petaling Jaya lead to increased CO levels, posing serious health risks, especially for vulnerable populations such as children and the elderly. The urban landscape, characterized by high rise buildings and limited green spaces, further exacerbates the accumulation of pollutants in the air. The differences between Shah Alam and Petaling Jaya's air quality likely stem from varying meteorological factors, such as wind patterns, temperature, and humidity, which can influence the dispersion and concentration of pollutants.

These findings underscore the important need for targeted air quality management strategies to mitigate health risks associated with industrial pollution and urbanization in these regions. Effective measures could include stricter regulations on emissions from industrial sources, the promotion of cleaner technologies, and the enhancement of public transportation systems to reduce vehicular emissions. Additionally, increasing green spaces and implementing urban planning strategies that prioritize air quality can help improve the overall environmental health of Shah Alam and Petaling Jaya.

Public awareness campaigns are also essential to educate residents about the sources and effects of air pollution, encouraging community involvement in air

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quality monitoring and advocacy for cleaner air initiatives. By addressing both the natural and anthropogenic factors contributing to air pollution, stakeholders can work towards creating healthier living environments for the residents of Shah Alam and Petaling Jaya, ultimately reducing the health risks associated with poor air quality.

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Conflicts of Interest

The authors declare no conflicts of interest

Author Contributions

Hanna Humaira Patrick: conceptualization, methodology, investigation, writing-original draft preparation. **Syarifuddin Misbari:** software, vizualization. **Norsaffarina Aziz:** formal analysis, writing-reviewing and editing. **Sao Vibol:** validation. **Mohammad Adam Adman:** supervision, writing-reviewing and editing.

Data Availability Statement

The data used to support the findings of this study are included within the article.

Declaration of Generative Ai and Ai-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT to enhance the clarity of the writing. After using the ChatGPT, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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