

RESEARCH ARTICLE

GIS-based mapping of air pollution exposure and health effects in industrial area of Kuantan, Pahang, Malaysia: A pilot study

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Abstract - Serious health concerns in developing regions are largely driven by air pollution. The Malaysian Department of Environment has measured that air pollution in industrial areas is much greater than in other areas of the country. This pilot study intends to evaluate outdoor air quality and human health effects in the industrial area of Kuantan. Two Continuous Air Quality Monitoring Stations situated in Balok and Indera Mahkota were chosen to explore how air quality varies across different areas of Kuantan. A structured questionnaire was distributed to residents living nearby, aiming to collect information on any health issues they may be experiencing. The spatial distribution of air pollution was mapped using Geographic Information System (GIS), allowing for a clearer understanding of how these pollutants relate to the health symptoms reported by the local population. The findings revealed that concentrations of PM₁₀, PM_{2.5}, and SO₂ were significantly higher in Balok compared to Indera Mahkota, while NO₂ levels were an exception to this trend. These differences are likely tied to variations in land use between the two areas, which appear to have a strong influence on local air pollution levels. The findings support targeted health actions and better urban planning to protect public well-being.

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1. Introduction

Malaysia, as a developing country, faces significant urban air pollution issues. Major contributors include open burning, vehicles, industrial activity, and domestic combustion. Particulate matter (PM), along with nitrogen dioxide (NO₂) and Sulphur Dioxide (SO₂), poses serious health risks [1]. Both indoor and outdoor air pollution are linked to respiratory illnesses and increased rates of disease and death [2]. According to the Department of Environment, Malaysia (DOE), mobile sources, especially transportation, account for a larger share of air pollution than stationary sources such as industry and power generation. Air pollution impacts many people in terms of safety, health, and other aspects [3]. For example, air pollution increases the likelihood of headaches, coughing, and breathing difficulties during commutes. It also exacerbates respiratory disorders, particularly asthma, in individuals of all ages, particularly in the elderly and children [4]. In addition, several factors make this situation even worse, including the inability to strictly enforce environmental laws and regulations, the building of congested roads, the poor management and regulation of the environment, the lack of public awareness of the harmful physical and psychological effects of pollution, and poor environmental management [5, 6]. While numerous studies in Malaysia have examined general air pollution trends and their health effects, most have focused on major urban centres like Kuala Lumpur or Johor Bahru, with limited attention to medium-sized industrial cities such as Kuantan. This issue is problematic because it degrades quality of life and adversely affects public health. In Malaysia, the use of Geographic Information Systems (GIS) to study air pollution has been well documented, particularly in mapping particulate matter and its health impacts [7]. This study underscores the importance of using GIS technology to track and manage air pollution. In Kuantan, GIS serves as a valuable tool for pinpointing areas with high pollution levels and evaluating the potential health risks they pose. The information gathered through this approach enables more focused and effective strategies to improve air quality [8]. Building on this, the research aims to evaluate outdoor air quality and its impact on public health, particularly in Kuantan's industrial regions. By integrating spatial data with public health indicators, this study seeks to provide localised evidence that can guide targeted policy interventions and sustainable urban planning. The novelty of this study lies in its focus on Kuantan as a developing industrial hub and in its use of GIS to link pollution patterns with public health outcomes, an area that remains underexplored in the Malaysian context.

2. Materials and Methods

A cross-sectional study was conducted from September 2023 to November 2023, focusing on dwellers in the Kuantan area. Kuantan is the capital of Pahang. Kuantan is located on the east coast of Peninsular Malaysia, facing the South China Sea. It serves as an important transportation and economic hub, supported by a well-developed road network that connects it to major cities across the peninsula. In recent years, Kuantan has experienced rapid urban and industrial growth, transforming it into a modern commercial centre. Air quality data were obtained from the Department of Environment Malaysia (DOE) for the period between 2021 and 2022. Two Continuous Air Quality Monitoring Stations (CAQMS) located in Kuantan were selected to analyse the spatial distribution of air quality: the Indera Mahkota station (3.81920840° N, 103.29659379° E) and the Balok station (3.96077505° N, 103.38216984° E). These stations were chosen for their strategic locations within urban and industrial zones, thereby providing comprehensive spatial coverage for assessing air

quality variations within the study area. The CAQMS network continuously records major air pollutants, including particulate matter (PM_{2.5} and PM₁₀), NO₂, and SO₂, as reported by the DOE. The data were collected hourly and undergo automated calibration and validation procedures to ensure data quality and reliability. This dataset provides a comprehensive representation of air quality conditions in Kuantan, enabling spatial assessment of pollution patterns and potential health implications associated with exposure in both urban and industrial environments. For this study, the validated hourly data were aggregated into annual averages to examine both fluctuations and long-term spatial patterns of air pollutants across the two sites.

A questionnaire survey was conducted to complement the air quality data. The questionnaire is distributed to Kuantan dwellers working outdoors within a 10 km radius of the air quality monitoring station (Figure 1). This survey aims to gather information on demographics, health conditions, and perceptions of air quality from workers' perspectives. The questionnaire has four sections. Two sections examine how air pollution affects behaviour and physical health, while the other two focus on knowledge and perceptions of air pollution and its health risks and effects on physical health. This survey aims to collect data on the health issues faced by dwellers who work outdoors. The questionnaire is adapted from a previous study [6]. A total of 26 respondents participated in this pilot study, comprising outdoor workers such as street hawkers, building security personnel, and parking attendants. Participation in the survey was entirely voluntary, and only respondents who agreed to take part proceeded to answer and complete the survey. The survey results aim to provide insights into the health challenges and risk perceptions faced by individuals with direct, prolonged exposure to outdoor air pollution.

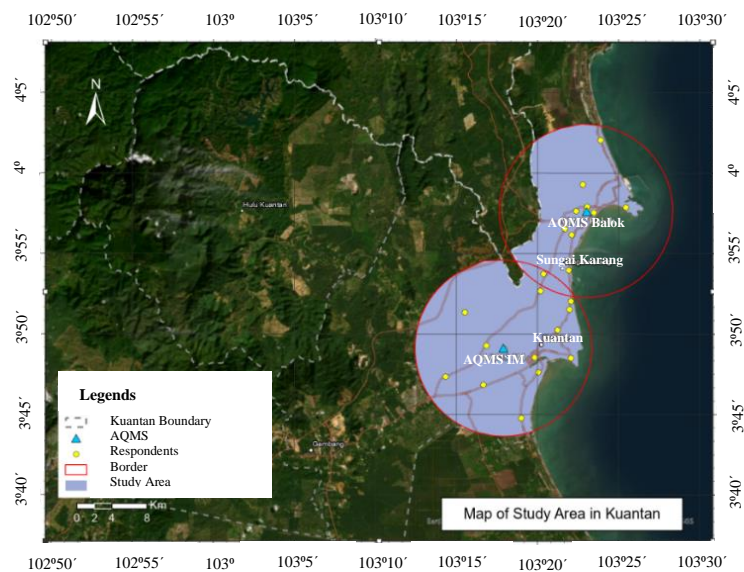


Figure 1. Map of the study area and the location of respondents in Kuantan

The spatial data were processed and analysed using ArcGIS Pro software. The Inverse Distance Weighting (IDW) interpolation method was employed to estimate pollutant concentrations at unsampled locations within the study area. IDW was selected because it effectively generates a continuous surface representation of pollutant distribution from point-based monitoring data, allowing visualisation of spatial variations in air quality. The resulting interpolation maps depict the pollutant surface density and spatial gradients across Kuantan, highlighting areas with potentially higher exposure levels. The integrated analysis combines the spatial patterns of air quality with health survey responses to explore possible associations between pollution intensity and reported health effects among outdoor workers. This geospatial visualisation provides a clearer understanding of how environmental conditions may influence community health within the study area.

3. Results and Discussion

This pilot study's findings are based on the health effects of Kuantan outdoor workers, which are linked to air quality in the designated areas. The outcome produces visualisations of geospatial data based on air quality data from air monitoring stations and health effects in Kuantan.

3.1 Air Quality Monitoring

Table 1 presents the annual average concentrations of key air pollutants (PM₁₀, PM_{2.5}, SO₂, and NO₂) recorded at the Indera Mahkota and Balok CAQMS for 2021 and 2022. Throughout both years of observation, particulate matter levels, specifically PM₁₀ and PM_{2.5}, were consistently higher in Balok than in Indera Mahkota. In 2021, PM₁₀ concentrations in Balok reached 26.14 µg/m³, notably higher than the 16.47 µg/m³ recorded in Indera Mahkota. This trend continued into 2022, with Balok reporting 24.86 µg/m³, while Indera Mahkota saw a slight drop to 15.45 µg/m³. Although PM_{2.5} levels in both locations stayed below the annual limit of 15 µg/m³ set by the New Malaysia Ambient Air Quality Standard (NMAAQS), readings in Balok were consistently nearer to the threshold, indicating a heavier pollution load in the area. The elevated particulate concentrations observed in Balok are likely attributable to its proximity to the Gebeng Industrial Estate and Kuantan Port, where industrial combustion, metal processing, and transportation activities are known to emit significant levels of PM₁₀ and PM_{2.5} [7, 8]. Coastal winds may also contribute to the dispersion and recirculation of dust

and fine particles, thereby sustaining elevated pollutant levels [9]. In contrast, Indera Mahkota’s comparatively lower levels reflect its more residential and commercial character, with vehicular traffic being the dominant emission source.

Table 1. Annual air pollution average at the Indera Mahkota and Balok areas (2021-2022)

CAQM Stations	Year	PM ₁₀ (µg/ m ³)	PM _{2.5} (µg/ m ³)	SO ₂ (ppm)	NO ₂ (ppm)
Indera Mahkota	2021	16.47	10.36	0.001044	0.004429
	2022	15.45	9.49	0.001344	0.005467
Balok	2021	26.14	12.05	0.001401	0.004674
	2022	24.86	11.43	0.002145	0.005015

SO₂ levels Balok exhibited a steady increase from 0.001401 ppm in 2021 to 0.002145 ppm in 2022, while Indera Mahkota recorded lower concentrations with a moderate rise from 0.001044 ppm to 0.001344 ppm over the same period. The increasing SO₂ trend in Balok is likely due to industrial fuel combustion and maritime activities that utilise high-sulphur fuels. Although these values remain below the NMAAQs threshold of 0.04 ppm (annual average), the upward trend warrants continued monitoring given SO₂’s role in forming secondary pollutants, such as sulphate aerosols and acid deposition. Meanwhile, NO₂ concentrations showed a somewhat different pattern. Indera Mahkota recorded a noticeable increase from 0.004429 ppm in 2021 to 0.005467 ppm in 2022, surpassing Balok’s levels. While Balok had a slightly higher NO₂ concentration in 2021 (0.004674 ppm), it declined marginally to 0.005015 ppm in 2022. This increase in Indera Mahkota may be associated with intensified urban traffic and localised emissions from commercial activities. Previous studies in Malaysian urban areas have reported similar patterns, where NO₂ levels are largely driven by vehicle exhaust and urban congestion [4, 10]. These results indicate that Balok generally faces higher levels of both particulate and gaseous pollutants, likely influenced by industrial activities and coastal operations such as transportation and port-related emissions. Overall, the data emphasise the spatial differences in air pollution across Kuantan and underline the need for area-specific strategies to effectively manage air quality and safeguard public health.

3.2 Questionnaire Survey Data

The survey had 26 respondents from Kuantan. Table 2 shows that the Balok area had a higher participation rate (53.8%) than the Indera Mahkota area (46.2%). Individuals of all ages and genders were involved. The majority of respondents, 38.5%, were over 31 years old and female (61.5%). The initial section of the questionnaire aimed to evaluate participants’ physical health conditions in relation to air pollution exposure. Table 3 presents the reported frequency of physical symptoms potentially linked to air pollution.

Table 2. Demographics of the respondents in Kuantan (N=26)

Variables	Number (%)	Variables	Number (%)	Variables	Number (%)
Location		Smoking status		Age (Years)	
Indera Mahkota	12 (46.2)	Yes	3 (11.5)	16–20	5 (19.2)
Balok	14 (53.8)	No	23 (88.5)	21-25	5 (19.2)
Gender		Chronic Disease		26-30	6 (23.1)
Male	10 (38.5)	Yes	1 (3.8)	≥ 31	10 (38.5)
Female	16 (61.5)	No	25 (96.2)		

Table 3. Physical Health Effects Among Respondents in Kuantan Attributed to Air Pollution (N=26)

Physical Health Effects	Always (%)	Often (%)	Sometime (%)	Rarely (%)	Never (%)
Felt air pollution effects	5 (19.2)	8 (30.8)	8 (30.8)	5 (19.2)	0 (0)
ENT Irritation/ Allergies	3 (11.5)	4 (15.4)	12 (46.2)	7 (26.9)	0 (0)
Respiratory problems	1 (3.8)	0 (0)	3 (11.5)	9 (34.6)	13 (50)
Coughing or wheezing	2 (7.7)	1 (3.8)	10 (38.5)	9 (34.6)	4 (15.4)
Headaches and dizziness	0 (0)	7 (26.9)	10 (38.5)	5 (19.2)	4 (15.4)
Reduced energy level	1 (3.8)	5 (19.2)	9 (34.6)	10 (38.5)	1 (3.8)
Sleeping disorder, i.e., insomnia	1 (3.8)	5 (19.2)	5 (19.2)	6 (23.1)	9 (34.6)

Approximately 80.8% (n=21) of respondents, categorised as “Always,” “Often,” or “Sometimes”, reported experiencing negative health effects potentially linked to air pollution, highlighting its significance as a pressing public health concern in Kuantan. ENT irritation or allergic reactions were noted by 73.1% (n=19), suggesting a strong association with upper respiratory issues. Additionally, 15.3% (n=4) reported respiratory illnesses, while 50% (n=13) experienced coughing and wheezing. Headaches and dizziness were noted by 65.4% (n=17), and 57.6% (n=15) indicated feeling less energetic. Lastly, 42.2% (n=11) consistently reported sleep disturbances, possibly associated with exposure to polluted air. These findings align with previous study that have identified air pollution as a significant contributor to

respiratory symptoms [1]. The second section of the questionnaire examined the behavioural and psychological impacts of air pollution. A total of 53.8% (n=14), 76.9% (n=20), and 65.4% (n=17) of respondents reported experiencing feelings of depression or low mood, reduced frequency or intensity of exercise or jogging, and slower walking pace, respectively, which the effects that may be linked to air pollution exposure. Moreover, 38.5% (n=10) of respondents reported experiencing anxiety or frustration on cloudy days, while 46.2% (n=12) mentioned feeling more irritable or aggressive during hot weather. These findings suggest that air pollution could be linked to shifts in mood and behaviour, possibly affecting the overall well-being and quality of life of those exposed. The third section of the questionnaire examined the preventive measures respondents adopted to mitigate the adverse effects of air pollution. Among the participants, 84.6% (n=22) reported wearing masks to cover their noses and mouths, while 42.3% (n=11) used eyeglasses or goggles for eye protection. All respondents (100%, n=26) reported increasing their water intake to help eliminate toxins, and 73.1% (n=19) reported following a healthy diet to strengthen their immune system. These findings reflect a relatively high level of self-initiated preventive behaviour, showing that the community is taking steps to protect itself, although more structured awareness programs may enhance these efforts. The final section of the questionnaire evaluated respondents' awareness and perceptions regarding air pollution. Nearly all respondents 96.2% (n=25) agreed that smoking should be banned in public areas and limited to designated zones. Additionally, 84.6% (n=22) recognised that air pollution is associated with a major cause of mortality. However, the majority, 92.3% (n=24), were unaware that key pollutants such as SO₂ and NO₂ are toxic components commonly found in haze. This indicates that while general awareness of air pollution's health risks is high, knowledge about specific pollutants remains limited, highlighting the need for improved educational outreach and public health messaging.

3.3 GIS Mapping and Distribution

The parameters investigated in this study included PM₁₀, PM_{2.5}, SO₂, and NO₂. ArcGIS Pro was used to create a distribution map of ambient concentrations in Kuantan via IDW spatial interpolation. Figures 2 through 5 illustrate the spatial distribution of each pollutant in 2022, highlighting variation across urban and industrial zones. This geospatial analysis provides valuable insight into pollution hotspots and potential health implications for residents, particularly those working outdoors. Figure 2 displays the spatial distribution of PM₁₀ concentrations. reveals that the highest levels were observed in Balok, reaching 24.86 µg/m³, while Indera Mahkota recorded lower concentrations at 15.45 µg/m³. Both areas remained below the annual limit of 40 µg/m³ set by the NMAAQs. Nevertheless, the consistent difference between the two locations reflects the influence of local emission sources. Anthropogenic sources such as traffic-related pollution, heavy oil combustion, and industrial emissions increase PM₁₀ levels [11, 12]. Meteorological variables, such as wind speed and atmospheric stability, substantially affect PM₁₀ levels during air pollution episodes [13]. Thus, the spatial variability observed in PM₁₀ can be attributed to a combination of emission intensity and environmental factors.

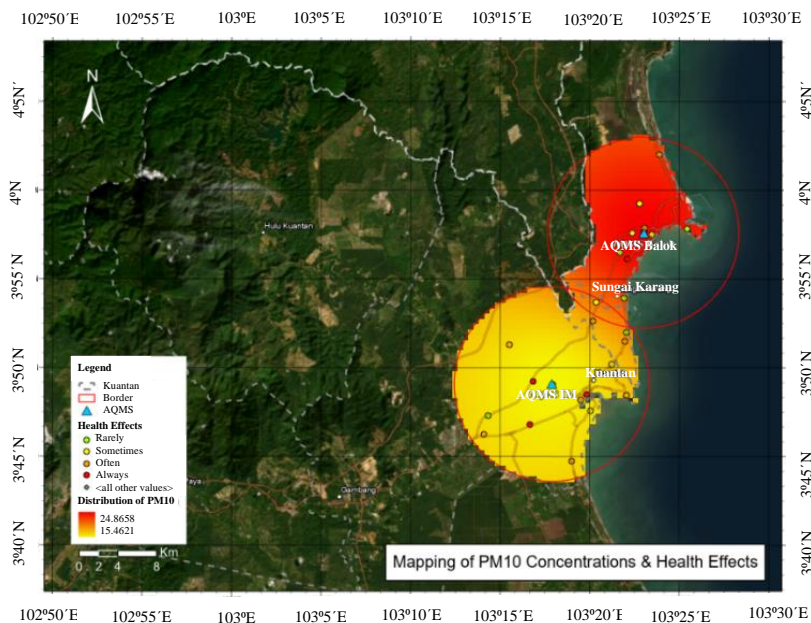


Figure 2. Mapping of PM₁₀ concentrations and health effects in study area

Figure 3 illustrates the spatial distribution of PM_{2.5} concentrations in 2022. Similar to PM₁₀, the highest concentration was recorded in Balok (11.43 µg/m³), compared to Indera Mahkota (9.5 µg/m³). Both values were within the national annual standard limit of 15 µg/m³; however, the higher readings in Balok suggest a stronger presence of fine particulate sources. PM_{2.5} particles originate mainly from secondary aerosols, carbonaceous compounds, and organic matter [14]. Environmental conditions such as low wind speeds and elevated temperatures promote the accumulation of fine particulates, further exacerbating air quality issues [15, 16]. Elevated PM_{2.5} concentrations are of particular concern as these fine particles penetrate deep into the respiratory tract, posing serious health risks over long-term exposure.

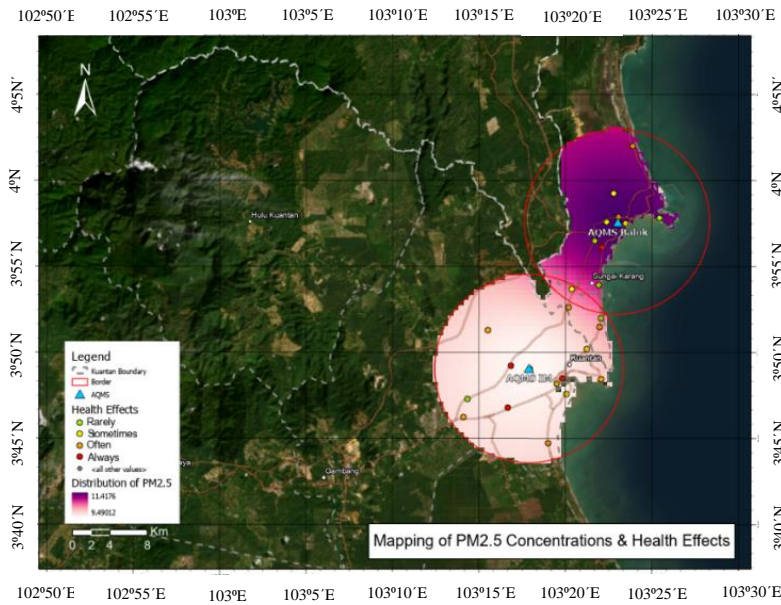


Figure 3. Mapping of PM_{2.5} concentrations and health effects in study area

Figure 4 presents the spatial distribution of SO₂ concentrations. The results indicate that Balok had higher average levels (0.006026 ppm) than Indera Mahkota (0.001038 ppm), reflecting the influence of industrial and port-related emissions. SO₂ is primarily emitted from fossil fuel combustion, industrial processes, and shipping activities, all of which are prevalent in the Balok area. Previous research has shown that industrial growth and energy consumption strongly contribute to rising SO₂ emissions [17]. Furthermore, sulphur-based fertilisers and coal combustion are additional contributors to localised SO₂ pollution [18]. These findings suggest that industrial operations in Balok significantly affect local concentrations of sulphur compounds, thereby lowering air quality in surrounding communities.

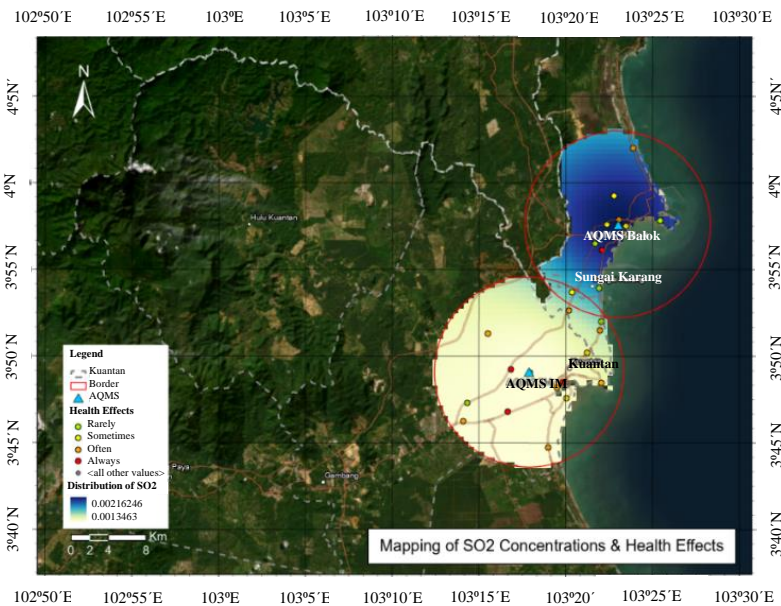


Figure 4. Mapping of SO₂ concentrations and health effects in study area

Figure 5 the distribution of NO₂ concentrations, which were higher in Indera Mahkota (0.006314 ppm) than in Balok (0.004556 ppm). This pattern indicates that vehicular emissions are the primary contributor to NO₂ pollution in the urbanised areas of Kuantan. NO₂ is strongly associated with high traffic density, diesel vehicle exhaust, and combustion-related activities [19, 20]. As Indera Mahkota serves as a commercial and residential hub with heavy traffic flow, the elevated NO₂ levels reflect the impact of transportation emissions. Moreover, local atmospheric conditions and proximity to road networks intensify pollutant accumulation, particularly during peak traffic hours.

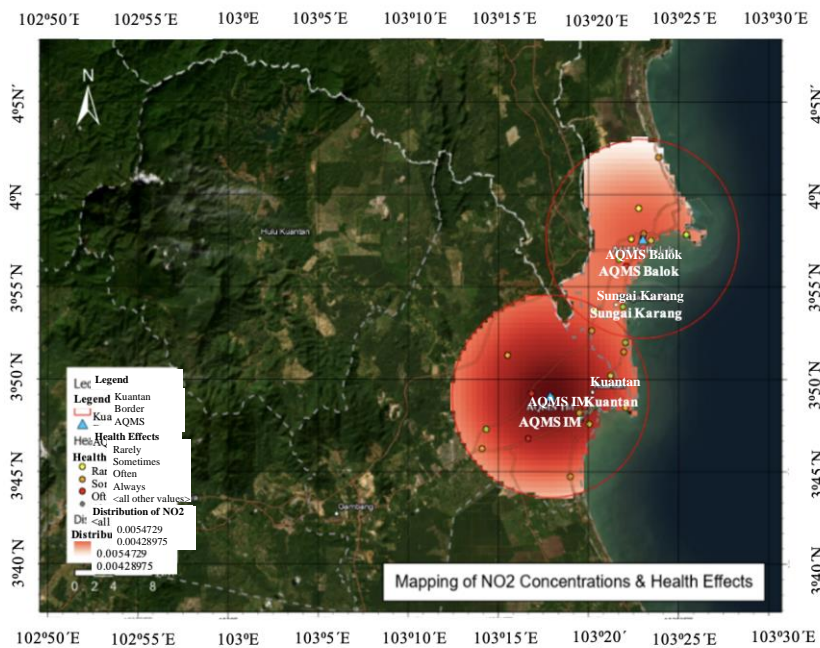


Figure 5. Mapping of NO₂ concentrations and health effects in study area

Collectively, the spatial maps reveal distinct patterns between industrial and urban zones. The air quality in Balok is markedly poorer than in Indera Mahkota, with elevated concentrations of PM₁₀, PM_{2.5}, and SO₂ attributed to industrial emissions and port-related activities. In contrast, Indera Mahkota exhibits higher NO₂ levels, consistent with urban traffic emissions. These findings align with previous studies, which confirm that industrial zones contribute substantially to local air pollution [21]. Industrial facilities have been identified as sources of air pollution, with consequences for nearby urban industrial districts [22]. Moreover, road density and the urban morphology index in a large proximal area of a city significantly impact the air pollutants at any site. Additionally, proximity to industry significantly impacts health [23]. Overall, the findings reveal clear spatial variations in air quality across Kuantan, with industrial areas (Balok) exhibiting higher particulate and sulphur-based pollutants, while urban zones (Indera Mahkota) show a rise in traffic-related NO₂ emissions. These differences highlight the influence of land use, emission sources, and meteorological conditions on local air quality. The results underscore the importance of developing area-specific air quality management strategies. For example, stricter industrial emission controls in Balok and improved traffic management or green mobility initiatives in Indera Mahkota. Integrating such measures is crucial to achieving long-term compliance with NMAAQs and reducing the health burden associated with air pollution exposure among Kuantan's residents, particularly those working outdoors. Despite these important findings, several limitations must be acknowledged. The health data were derived from a relatively small sample size and relied on self-reported questionnaires, which may introduce response bias. Additionally, the absence of clinical or physiological assessments limits the ability to establish direct causal relationships between air pollution exposure and specific health outcomes. Therefore, future studies should include larger, more diverse populations, along with clinical health evaluations and long-term monitoring, to provide a more comprehensive understanding of the health impacts of outdoor air pollution in Kuantan.

4. Conclusion

The findings of this study revealed a considerable relationship between ambient air pollution levels with the health effects. As a result, this article is significant because it provides a thorough overview of the geospatial aspects of air quality and the primary contaminants that have influenced Kuantan's air quality level. This study sheds light on future strategies for pollution reduction and urban development. Air pollution has caused respondents to experience several negative physical effects, including respiratory illnesses and ENT problems. The responders were aware of the most common air pollutants, where they originated, and the severity of haze and pollution. The air quality in Balok is significantly lower than in Indera Mahkota. Balok is one of Kuantan's industrial regions. Compared to Indera Mahkota, the Balok area has greater concentrations of PM₁₀, PM_{2.5}, and SO₂, except for NO₂. It is recommended that governmental and non-governmental organisations, including environmental protection agencies, use effective communication strategies to increase the public's awareness and understanding of the health risks associated with air pollution at the individual, family, and community levels. This will encourage them to take precautions and defend themselves. Increasing public awareness of risk perceptions will lead to a better understanding of public opinion, without adversely affecting public behaviour.

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Declaration of Competing Interest

The author declares no conflicts of interest.

CRedit Authorship Contribution Statement

Lavender Miriam Lee (Investigation; Writing - original draft; Formal analysis)

Norsaffarina Aziz (Investigation; Writing - Review & editing)

Syarifuddin Misbari (Methodology; Software; Visualisation; Validation)

Ahmad Rizal Alias (Resources; Validation)

Mohammad Adam Adman (Conceptualization; Methodology; Writing - Review & editing; Formal analysis; Funding acquisition; Project administration; Supervision)

Availability of Data and Materials

The data supporting this study's findings are available on request from the corresponding author.

Ethics Declarations

This study did not involve human participants or animals. Ethical approval was therefore not required.

Generative Artificial Intelligence Declarations

The authors claim that artificially intelligent-assisted technologies, such as generative AI, were not used to generate content, ideas, or theories. We have just utilised AI to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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