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RESEARCH ARTICLE

Distribution Mapping of Building Classification and Air Pollution Exposure in the Urban City Areas by Using GIS-Based Application: A Pilot Study

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ABSTRACT - This study explores the association between the locations of building classification and air pollution, focusing on the particulate matter concentrations ($PM_{2.5}$) in Kuantan city. It emphasizes the influence of building classification on selected locations in the urban city area and $PM_{2.5}$-related health hazards. $PM_{2.5}$ were measured at selected areas that have been classified as high-rise and low-rise building areas in the Kuantan city centre. The selected study locations were also mapped with the GIS mobile application to have a better understanding through visualization. Locations that has been identified as the high-rise buildings area had a greater $PM_{2.5}$ concentrations than the low-rise buildings area due to constrained airflow. To minimize the $PM_{2.5}$ pollution, it is recommended to consider building design, air pollutant dispersion strategies, and introducing green spaces in the urban city area. A further study is needed to address these mitigation factors to improve the ambient air quality in the urban city area.

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1. INTRODUCTION

According to the World Economic Forum, building construction consumes 40% of energy, 40% of carbon emissions, and 20% of water. Global emissions come from building energy use. Inefficient building infrastructure wastes energy and emits greenhouse gases, hence green buildings must be energy efficient. Population expansion and urbanization have raised infrastructure energy demand, consuming many resources. Urban classification's excessive energy use pollutes and alters climates, harming society [1].

Air pollution is a global environmental issue. According to the WHO, air pollution kills 4.2 million people annually. "Air pollution" refers to toxic gases, particles, and chemicals in the air. Traffic, garbage burning, solid fuel combustion, industry, and agrochemical activities emit large amounts of air pollutants, including primary pollutants such as particulate matter (PM). NO_2 and volatile organic molecules react under sunlight to form ozone (O_3). Air pollution exceeds WHO limits for 90% of the world's population. Air quality monitoring is crucial for understanding pollution levels, assessing public health risks, and informing policy decisions [2,3]. However, there are several challenges that make air quality monitoring complex and sometimes unreliable. In many regions, air quality monitoring stations are often sparse and concentrated in urban areas or specific industrial zones [4]. It leads to pollution levels in other areas may go unmonitored, leading to data gaps. The lack of real-time data, underreporting, and limited public access to information further hinder effective action [5]. Enhancing the reliability and accessibility of air quality data is essential for better understanding pollution impacts and mitigating its risks.

Management of spatial data in the form of map layers, which can be used to visualize real objects using vector and raster data formats, as well as graphs and multimedia presentations, is a primary capability of the GIS. One of the next steps is data analysis within the GIS frame. The ability of the GIS to address a wide range of urban-related environmental issues is described by a number of definitions. Geographic Information System (GIS) is a powerful set of tools that can be used to collect, store, retrieve, transform, and display real-world spatial data for a specific set of purposes. The GIS has a wide range of spatial and temporal comparisons that make it possible to perform and display output data in the GIS's layers. Air pollution maps can be useful tools for epidemiological research, especially in urban areas. The GIS mapping can assist in locating the higher density locations that require special monitoring or investigation.

GIS capabilities primarily involve managing spatial data in vector and raster data formats and map layers that allow visualization of real-world objects through graphics and multimedia presentations. GIS includes a variety of spatial analyses and temporal comparisons that enable the performance and display of output data in GIS layers. Planar visualization is shown to improve its interpretability and show hotspots where the highest contamination occurs. This is easily recognizable by using appropriate colour gradients to represent contamination levels [6]. Therefore, this study aims to examine the spatial distribution of $PM_{2.5}$ concentrations at low-rise and high-rise buildings area in Kuantan.

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2. RELATED WORK

The buildings sector in Malaysia is occupied by residential, commercial, and industrial buildings, along with government institutions and administrative offices. In this study, two different kinds of buildings are been focused on which are high-rise buildings and low-rise buildings. The Uniform Building by Law (UBBL) defines a high-rise building as one that has 15 to 18 meters or more in height and has at least four floors, [7]. Building engineers, inspectors, architects, and other professionals often define a high-rise as a structure that is at least 75 feet (23 meters) tall. Hotels, libraries, shops, public halls, schools, nurseries, and apartments are all examples of such establishments. Meanwhile, the low-rise buildings contradicted the definition of high-rise buildings. Buildings of single-story and residential buildings are both instances of low-rise buildings. Low-rise residential buildings are at least three stories and are constructed in significant quantities. The occurrence of a building with a lower height ensures that the occupancy perceives conditions that are even more temperate. A previous study stated that heights are increased, the air temperature declines and the average wind speed increases [8].

Among the many types of air pollutants, particulate matter-sized 2.5-micron meter ($PM_{2.5}$) pollution can reduce visibility and cause health problems when microscopic particles are inhaled into the human body. $PM_{2.5}$, which is almost the same length as a typical bacterium, is associated with various health risks, including cardiovascular and respiratory disease, birth defects, and chronic diseases. It has been shown in a significant body of research that particulate matter (PM) is the most prevalent type of air pollution and is responsible for harmful impacts on both the quality of the environment and the health of humans, [9]. As a result of this, some studies have been carried out to comprehend the nexus of cause and effect for PM.

Regarding its effects on human health, PM is a significant environmental risk factor for diseases that affect people and are brought on by immune system imbalances. Epidemiological studies show that PM exacerbates allergic rhinitis and asthma, especially in industrialized urban areas, and increases pulmonary morbidity and mortality [10]. As is well known, $PM_{2.5}$ has been shown to have a stronger association with adverse effects on human health when compared to PM_{10} to relationships between PM exposure and health effects [11]. It has also been determined that transportation-related factors are significant contributors to $PM_{2.5}$ concentrations. A high road intensity, which may be defined as either a large number of kilometers or an area occupied by roads, is indicative of an increase in the volume of transportation and, as a result, of greater pollution levels. Major highways, frequently linked with high traffic, might be another contributor to excessive levels of $PM_{2.5}$ in nearby areas.

This study assisted Air Quality Management by monitoring the air quality for a predetermined time at specific stations and applying GIS to predict pollution levels between sampling locations. Among different air pollution modelling techniques, the interpolation method is chosen in comply with GIS capabilities. GIS is an effective tool for managing air quality because it has significant time- and location-dependent data. The manager at various levels can decide on the localization of building classification areas, the transfer of air pollution producers in a way that has the most negligible impact on air pollution areas, the creation of places that require clean air, and the identification of regions that need to create green space by using time-position analysis and identifying critical pollution. The spatial variability of air pollution can be mapped using GIS. Estimates based on interpolation between ground observations and dispersion models can be improved with the additional spatial information provided [12]. The concentrations of air pollutants can be more clearly visualized when presented as an image (a spatial map). In this century, it is recommended to provide the facts in ways that are both concise and packed with information.

3. METHODOLOGY

3.1 Interview Session, Collection on Location of Building Classification

The study was conducted in Kuantan in June 2023. Kuantan, the capital of Pahang state in Malaysia, is located on the east coast of Peninsular Malaysia, facing the South China Sea. Its coordinates are 3° 49′ 0″ N latitude and 102° 20′ 0″ E longitude [13]. According to the Department of Statistics Malaysia (2023) has a population of 128,247 people. Kuantan has a diverse economy, with key strengths in manufacturing, agriculture, tourism, logistics, and services. Its strategic coastal location positions Kuantan to continue thriving through regional trade, industrial expansion, and the growth of its services sector [14]. The study selection of study locations requires accurate identification. An interview with the Kuantan City Council District Officer was conducted to acquire essential data for this study. The officer provided insights on the limits of Kuantan City and shared an accurate map of Kuala Kuantan 1 (KK1). The map depicted existing building classifications in Kuantan City sites, which were then imported into GIS software. This method enabled the precise identification of high-rise and low-rise buildings in the metropolis. The study precisely labelled the sampling points by utilising the detailed map and building list. This information allowed us to distinguish between high-rise and low-rise structures and analyse their spatial distribution throughout Kuantan City. Interviews with city officials and this data allowed for a detailed investigation of the city's spatial patterns and building characteristics. Figure 1 illustrates the shaded area on the Kuala Kuantan map representing Kuantan City, with high-rise buildings area in red and low-rise buildings area in green. The precision of the map, as well as the District Officer's approval, added to the reliability of the findings. Due to this rigorous approach, the study gained valuable insights into Kuantan City's building classification and its relationship with air pollution.

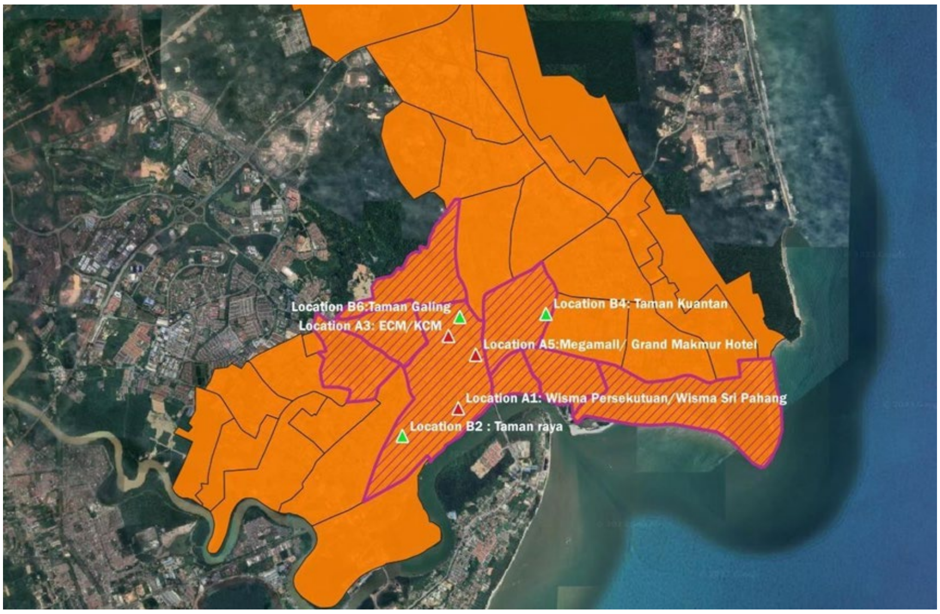

Figure 1. Sampling points (Red colour indicated as a high-rise building area and green colour as a low-rise building areas)

3.2 Data Collection on Air Pollution

The research paper compares Location A and Location B. Within a one-kilometer radius, Location A consists of high-rise buildings. In contrast, Location B consists of low-rise buildings. The Aeroqual 500 Gas Sensing equipment is utilized for air quality monitoring due to its portability and ability to measure up to 30 pollutants, including $PM_{2.5}$. The monitoring period lasts three weeks, with data collected every Friday. Six sampling points were chosen, uniformly dispersed between locations A and B in Kuantan City (as indicated in Table 1). Each sampling location takes one hour to perform the air quality monitoring, which includes six 10-minute readings. The sampling points selected represent clusters of buildings rather than a single type of building. For example, Location A1 will be monitored for air quality between the buildings for an hour during the first week, while Location B2 will be observed as the second sampling point. The same approach will be repeated at the chosen sampling stations in the coming weeks.

Table 1. Sampling points

Sampling points	Locations	Classifications	Time period (hrs/day)	Total readings recorded per day (10 min intervals)
1	Wisma Persekutuan, Wisma Sri Pahang, Masjid Negeri Pahang, and Cimb Bank Tower,	Location A1 (High-rise buildings area)	1	6
2	Taman Raya	Location B2 (Low-rise buildings area)	1	6
3	East Cost Mall, Kuantan City Mall, Hotel Zenith and Affin Bank Tower	Location A3 (High-rise buildings area)	1	6
4	Taman Kuantan	Location B4 (Low-rise buildings area)	1	6
5	Grand Darul Makmur Hotel, Berjaya Megamall, Hotel Grand Continental and Tenaga Nasional Berhad Tower	Location A5 (High-rise buildings area)	1	6
6	Taman Galing	Location B6 (Low-rise buildings area)	1	6

3.3 Geographic Information System Mapping and Distribution

The data collected was transferred to a GIS file using the mobile mapping application (SW Maps) recommended by the Kuantan City Council's District Officer. All recorded databases might be saved using the application. The information was saved in the 'Shapefile' format, a geospatial vector data format used by GIS tools. This approach allowed researchers to investigate the association between the distribution of building classification and $PM_{2.5}$ air quality in the study area. GIS is a computer-based technology that analyses geographic spatial relationships, patterns, and trends. It collects, analyses, and visualizes data relating to geographic positions on the Earth's surface, such as $PM_{2.5}$ air monitoring data and sampling sites representing high-rise and low-rise structures. The study employs GIS to create geographic visualizations regarding air exposure associated with the building classification sector in Kuantan City.

3.4 Design of Study

Figure 2 outlines this study's techniques for conducting the project. It shows the flow chart for forming the distribution mapping of building infrastructure and air pollution exposure in Kuantan city, linked to the GIS application software ArcGIS for performing the delineation processes for this study. This figure highlights the relationships between the various stages of the research process while outlining the systematic approach used in the study.

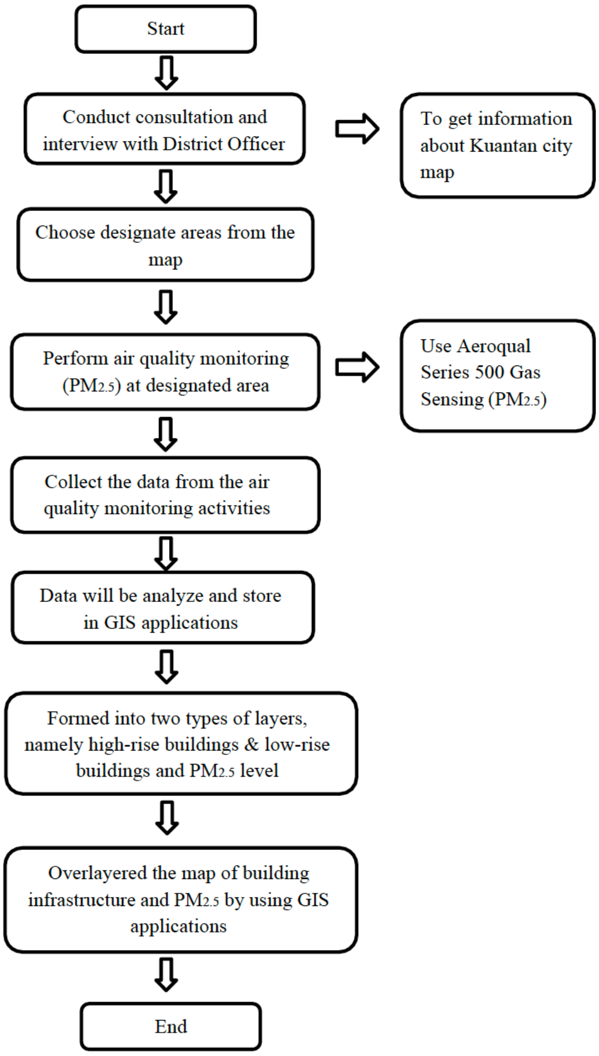

Figure 2. Flow chart of the study

Table 2 shows the latitude and longitude of all study locations. The advantage of utilizing the GIS application software ArcGIS is that it can precisely define the study region and analyse the spatial distribution of building infrastructure and air pollution. Integrating its software makes the study methodology more effective and precise, allowing for accurate and thorough mapping of the studied factors.

Table 2. The study locations with their latitude and longitude

Locations	Latitude	Longitude
Location A1	3.808169	103.328699
Location B2	3.804277	103.320691
Location A3	3.818115	103.327312
Location B4	3.821170	103.341162
Location A5	3.815511	103.331186
Location B6	3.820685	103.328885

4. EXPERIMENTAL RESULTS

According to Table 3, interpretation of P-values, the data obtained from locations A1, A3, and A5, as well as B2, B4, and B6, are statistically significant. The p-values were calculated using Excel, yielding a value of 0.003, less than the significance limit of 0.05. This suggests that the average values of the two groups differ significantly. As a result, the data acquired at these sample locations provide compelling evidence to support the hypotheses being tested. Our findings are supported by another study in Bangladesh that found changes in building height with poor air pollution [15].

Table 3. Average $PM_{2.5}$ levels at the sampling points

Sampling points of the high-rise building areas	Average values (μg/m³)	Sampling points of the low-rise building areas	Average values (μg/m³)
Location A1	33	Location B2	8
Location A3	36	Location B4	10
Location A5	41	Location B6	9

4.1 Monitoring Value of $PM_{2.5}$ in the Week 1, Week 2 and Week 3

Figures 3, 4, and 5 show that high-rise buildings have higher $PM_{2.5}$ concentrations than low-rise buildings. Tall buildings block wind flow, causing air pollutants to remain in the atmosphere for prolonged periods. As a result, airflow within the high-rise building region moves slower, allowing $PM_{2.5}$ particles to stay suspended in the air. On the other hand, low-rise buildings do not obstruct airflow, allowing the air to circulate freely and disperse the $PM_{2.5}$ particles. Another study in Hong Kong also confirmed that the movement of pollutants is primarily influenced by the interaction between wind and high-rise buildings, as these structures can significantly alter wind patterns and affect how pollutants disperse in the surrounding environment [16].

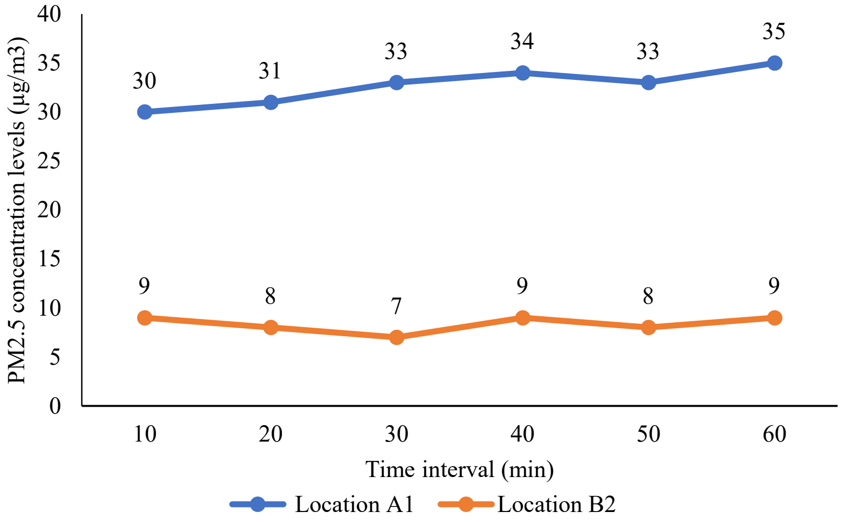

Figure 3. $PM_{2.5}$ level reading in week 1 at the location A1 and B2

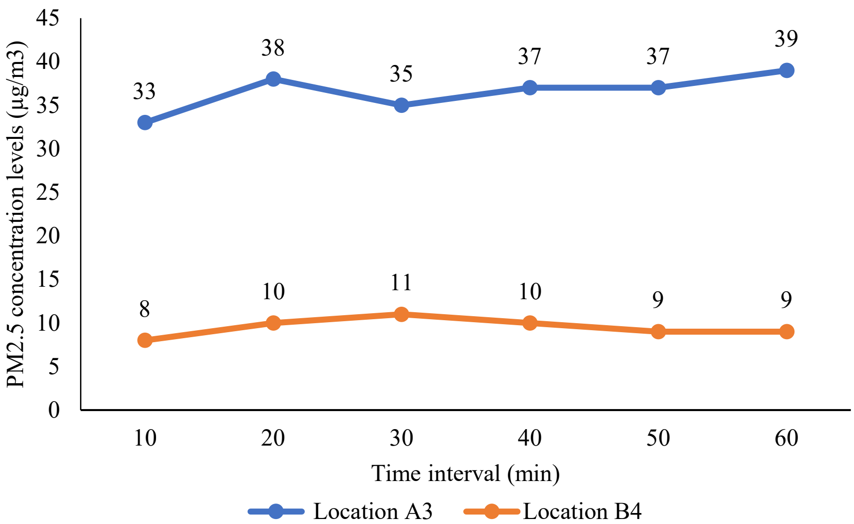

Figure 4. $PM_{2.5}$ Level reading in Week 2 at the location A3 and B4

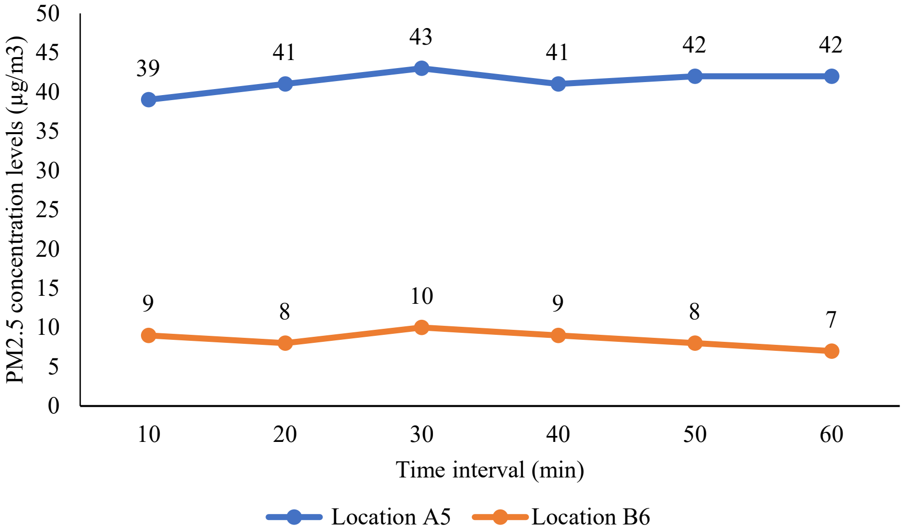

Figure 5. $PM_{2.5}$ Level reading in Week 3 at the location A5 and B6

In conjunction with this, Figure 6 describes the Kuala Kuantan 1 (KK1) map, which comprises the Kuantan City boundary line. The study area consists of 8 sub-areas with boundary lines. Hence, to conduct the IDW interpolation method, the dissolving process was carried out to eliminate the boundaries between the eight sub-areas because it is the main criterion for implementing the IDW process. From the dissolution process, the eight sub-areas have been merged into one boundary, where the result is presented on the map as purple. The purple colour highlighted the study area known as Kuantan City Centre.

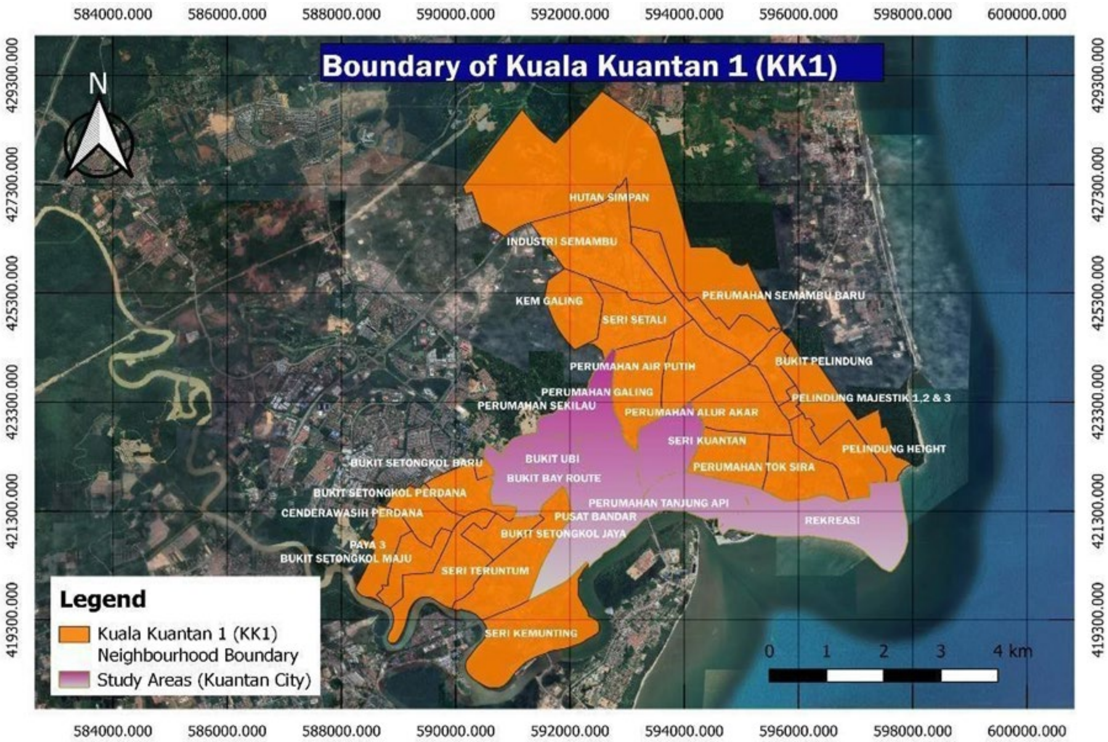

Figure 6. Designated study areas of the Kuantan City (KK1 highlighted in purple)

Figure 7 displays the distribution mapping of the mapping of the building classification linked with air pollution exposure in Kuantan City. This spatial map was developed after conducting the Inverse Distance Weighting (IDW) interpolation method. This is to estimate the value of unknown locations that were not measured and predict that the area of high-rise buildings is affected by $PM_{2.5}$ more than low-rise buildings. In the legend for triangle icons, green colours represent low-rise building locations, while in triangle icons, red colours represent High-rise building locations. This colour band is from Dark Blue colour (Lowest level concentration) to Dark Red colour (Highest level concentration) of $PM_{2.5}$.

Based on the results presented in Figure 7, the spatial mapping using the IDW interpolation method indicates a clear correlation between building classification and air pollution exposure, particularly concerning $PM_{2.5}$ concentrations in

Kuantan City Centre. The analysis shows that high-rise building areas experience higher air pollution than low-rise building areas. This explains that urban building structures, especially high-rise buildings, impact airflow and can accumulate air pollutants, such as $PM_{2.5}$, around those areas [17]. This trend is illustrated through the colour gradient on the map, where areas with high-rise buildings are represented by red triangle icons and are associated with darker red regions on the map. These dark red areas correspond to the highest concentrations of $PM_{2.5}$. In contrast, low-rise building areas, represented by green triangle icons, are predominantly situated in zones shaded with dark blue or lighter colours, indicating lower levels of $PM_{2.5}$ exposure.

The disparity in pollution levels between high-rise and low-rise building areas can be attributed to several factors. High-rise buildings can obstruct airflow and trap pollutants, creating zones of higher pollution concentration around them. Moreover, their height increases the potential for pollutants to be dispersed at higher altitudes, where wind patterns may carry and concentrate them, further exacerbating the exposure in these areas. As a result, the map clearly demonstrates that areas with high-rise buildings face more significant air quality challenges, with higher levels of $PM_{2.5}$, than their low-rise counterparts. Another study from China supports the relationship between urban forms, particularly high-rise building zones, and air pollution dispersion, concluding that these areas often experience elevated pollution levels due to limited ventilation [18].

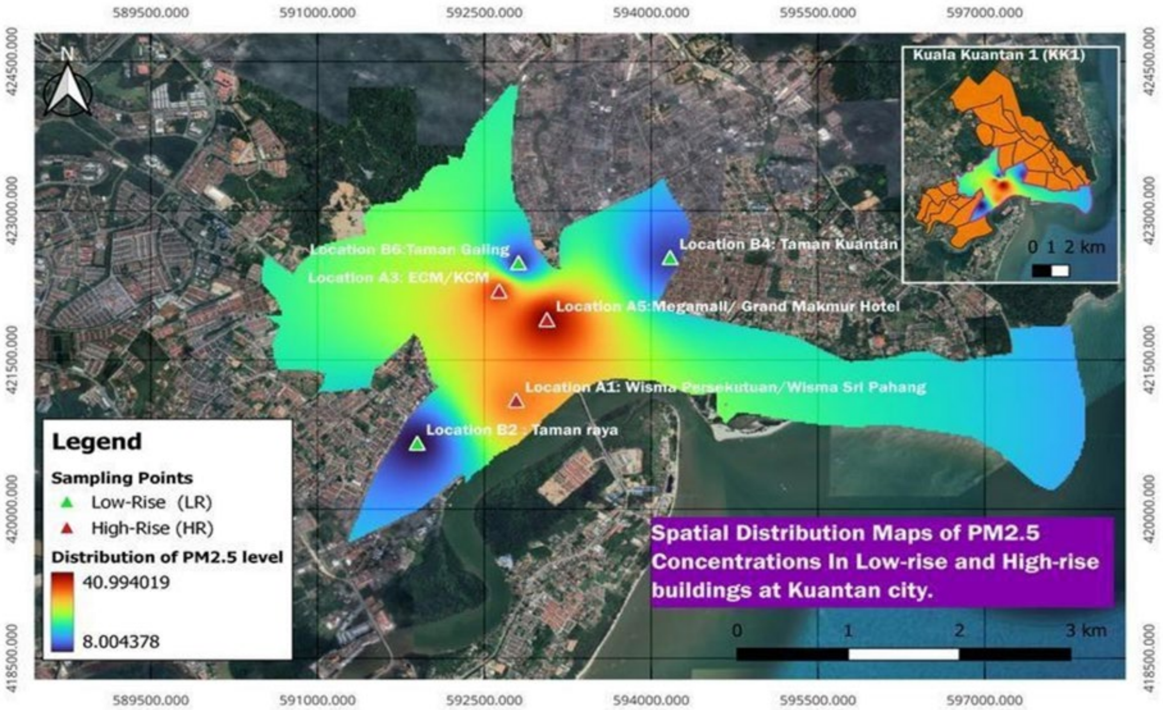

Figure 7. The mapping distribution of building classification (high-rise and low-rise) is linked with air pollution exposure ($PM_{2.5}$) in Kuantan city centre

Tall buildings, especially in densely built urban areas, can block natural wind currents and create disruptions in airflow. Wind is an important factor in dispersing air pollutants and maintaining good air quality [15]. The concentration of wind flow causes a reduction in the dispersion of pollutants because the air can't move as freely or quickly [19]. The canyon effect, in combination with high-rise buildings, can trap pollutants like $PM_{2.5}$ particles, which can come from vehicle emissions, industrial activity, or other sources) get trapped in the air [20, 21]. The absence of strong wind and the narrow channels created by high-rise buildings limit the natural ventilation of the area. Ventilation is key to diluting and removing air pollutants. With restricted ventilation, pollutants accumulate and remain at high levels. Prolonged exposure to elevated levels of pollutants like $PM_{2.5}$ can have serious health impacts, particularly for people living in close proximity to high-rise buildings.

Several strategic approaches can be employed to mitigate $PM_{2.5}$ accumulation in areas with high-rise buildings. Urban planning can be improved by increasing green spaces, enhancing natural ventilation in buildings, reducing traffic congestion with public transport, enforcing stricter air quality regulations, raising public awareness, and using smart technologies for pollution monitoring. Public education and raising awareness about the health risks associated with $PM_{2.5}$ exposure is essential to encourage individuals and businesses to adopt cleaner practices. These measures, combined with community engagement and sustainable construction, can reduce pollutants and create healthier living environments.

This pilot study faces several challenges, including limited monitoring networks, high costs of traditional equipment, and data gaps. This study's findings cannot be generalized to the broader Kuantan area due to its small sample size focusing in KK1 only. However, these preliminary findings can serve as a foundation for future research, which should aim to expand to a larger area providing more comprehensive data. The lack of real-time data, underreporting, and limited public access to information further hinder effective action. Expanding low-cost sensors, integrating satellite data, and improving data transparency are key solutions to enhance air quality monitoring and address these issues. Additionally, pollution variability, non-point sources like open burning, and external factors such as weather can complicate accurate measurements. Incorporating weather conditions, topography, and modeling non-point sources like open burning into GIS models will enhance the accuracy of pollution maps. These efforts, combined with long-term data collection, can lead to more reliable air quality predictions and inform targeted policy interventions.

5. CONCLUSION

In conclusion, outdoor air monitoring shows high-rise buildings area have greater $PM_{2.5}$ concentrations than low-rise buildings areain Kuantan. High-rise structures block wind and delay airflow, accumulating $PM_{2.5}$ particles. Tall structures "canyon effect" traps pollutants. Restricted ventilation and slower airflow keep $PM_{2.5}$ particles suspended for longer, causing health dangers to nearby residents. The study stresses that urban planning should prioritize increased green spaces, optimized building spacing, and mixed-use developments to improve airflow and reduce traffic emissions. Specific air quality management strategies include implementing stricter pollution control measures for construction and transportation, expanding low-emission zones, and investing in real-time air quality monitoring systems. Cities could also encourage sustainable building practices, such as green roofs and energy-efficient designs. These techniques can improve air quality in high-rise buildings and people’s health.

It is essential to carefully select study locations to improve the accuracy and reliability of air quality research in high-rise and low-rise buildings. A diverse range of sites should be included, representing different urban layouts, building heights, and environmental conditions. This will enable more robust data collection and improve the interpolation process in GIS, allowing for better mapping and interpretation of air quality patterns across urban areas. Future studies should focus on creating a comprehensive understanding of specific building height, design, and urban layout impact indoor and outdoor air quality. This includes examining the role of ventilation systems, pollutant dispersion, and building materials in both high-rise and low-rise settings. Additionally, further studies should explore the long-term health impacts of high-rise-induced pollution. Expanding research into these areas could provide deeper insights into the complexities of urban pollution and guide more targeted policy interventions aimed at improving air quality and public health.

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AUTHOR CONTRIBUTIONS

Norsaffarina Aziz: Visualization and investigation.
Navin Kumaran Paramjothy: Writing original draft, preparation and data collection.
Mohammad Adam Adman: Conceptualization, writing and supervision.
Syarifuddin Misbari: GIS validation.
Lim Fang Lee: Reviewing and editing.

DATA AVAILABILITY STATEMENT

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

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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