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HEALTH RISK ASSESSMENT OF AMBIENT AIR BENZENE AMONG PRIMARY SCHOOL CHILDREN IN URBAN AND RURAL AREAS IN JOHOR, MALAYSIA

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Abstract

Introduction: *It is a fact that children are vulnerable, and are at risk from benzene, a volatile, carcinogenic organic compound. The aim of our study is to determine the levels of ambient air benzene and examine the non-carcinogenic and carcinogenic risks involved* ***Methods:*** *A cross-sectional study was conducted in two urban and two rural primary schools in Johor, Malaysia. Benzene concentrations were measured using BUCK Libra L-4 pumps and analyzed in the gas chromatography-mass spectrometry (GC-MS). Data were collected from 334 10-12 year old children, to calculate the exposure levels based on their body weights and heights. The hazard quotient (HQ) served to evaluate the non-carcinogenic risks, whereas the lifetime cancer risk (LCR) was determined with the aid of the United States Environmental Protection Agency (USEPA).* ***Results and Discussion:*** *Benzene concentrations were higher in rural than urban areas, surpassing the European Union (EU) standard of 5 µg/m³. It was also established that the highest average levels recorded were 6.89 ± 6.68 µg/m³. The HQ values, nonetheless, had indicated no immediate non-carcinogenic risk, while LCR estimates were found to be within a tolerable range across all sites. Findings showed that although the immediate risk from benzene exposure is low, long-term exposure still poses a significant cancer risk to children; even low levels of chronic exposure can heighten the likelihood of children to develop cancers.* ***Conclusion:*** *This study has produced a revelation that there are elevated benzene levels in rural areas in Johor. Despite the low, immediate non-carcinogenic risks, further investigation on the potential for long-term cancer risks is warranted. These risks can be addressed by conducting stricter air quality monitoring, enhancing vehicle emission standards, and introducing educational programs that can raise awareness about benzene exposure.*

INTRODUCTION

The surge in harmful air pollutants such as nitrogen dioxide and $PM_{2.5}$ is the flagrant result of industrial growth in developing countries, further causing a grave decline in air quality (1-2). This is the answer to millions of premature deaths all over the world, taking its toll on countries especially Indonesia (3), India (4) and China (5). In Malaysia, the exponential urbanization and industrialization have led to environmental degradation, especially in cities (6-7), where the primary source of air pollution is vehicle emissions. These emissions include volatile organic compounds (VOCs) such as benzene, an established carcinogen (8).

There have been confirmed studies on the linkage between benzene and various serious health problems, especially blood-related disorders and an increased risk of leukemia (9). Long-term or high exposure can certainly lead to severe conditions like bone marrow suppression and various types of cancer, with acute myeloid leukemia (AML) causing a major concern (10-11). People are exposed to benzene in various ways, include workplaces, vehicle emissions, and contact with contaminated water or soil (12–14). It is very common that people inhale benzene from cigarette smoke, gas stations, or car

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exhaust (15-16). People can also be exposed through the consumption of contaminated water or food (17).

It is a global assertion that benzene is recognized as a major pollutant (18-19), intensifying the need for strict monitoring and regulations so that the exposure to humans can be reduced. The WHO sets guidelines for safe benzene levels in the air, where the lifetime exposure limit is 0.17 μg/m³ (20). The USEPA, in its show of dedication to the protection of public health, has also established a reference concentration for chronic inhalation exposure to benzene at 3×10^{-2} mg/m³ (21).

The vulnerability of children to air pollution is acknowledged due to the fact that their bodies are still in progressive development. Compared to adults, their immune, respiratory, and nervous systems are more sensitive to harmful pollutants (22). The fact that children have a larger lung surface area for their body size, suggesting that they inhale more pollutants relative to their weight, is also another factor worth pointing out. Children also have the tendency to breathe through their mouths, so this bypasses the natural filtering mechanisms of the nose (23), and further increases their exposure to airborne contaminants. Anatomically, with their smaller airways, this also means that they are more susceptible to pollutant-oriented inflammations (24). The factor underlying the risk to pollutants is also behavioral. It is common behaviour for children to be more active and spend more time outdoors, taking part in various physical activities that tend to increase their breathing rates (25). One cannot disregard the importance of the fact that if individuals have a longer lifespan, they have more time to develop diseases that may have originated earlier in their lives due to their exposure to pollutants (23,26).

In the local scene, the aggressive urbanization and industrial activities in Malaysia have led to varying benzene concentrations (27). Higher levels of benzene have been reported particularly in urban areas following the increased vehicular emissions, industrial discharges, and other anthropogenic activities (27–29). This current study in the urban schools points to a major source of benzene exposure that elevates benzene levels, which is the nearby highway, with surrounding factories located within a 2 km radius. These sources impose potential health risks for children as they inhale the polluted air during school hours. However, not much detail has been gathered on the exposure among this most vulnerable population. Established scholarly works focused on adult populations or occupational settings (29-30), automatically bringing to our attention that studies that specifically explore benzene exposure in children within non-occupational environments such as schools, where they spend a substantial amount of time, are scarce. This lays bare a wide, critical gap in the literature, as the effect of children's exposure to benzene in these settings is serious and long-term (26). Additionally, non-occupational sources of benzene are more rife in urban areas and are often neglected in current public health strategies (31). This study hopes to fill this gap by looking into ambient benzene levels in both urban and rural school environments in Johor, Malaysia, with children being the target group. By understanding the cancer and non-cancer risks associated with benzene exposure, there is hope that this research can establish important insights that can render effective public health interventions. The findings will certainly advocate the development of targeted strategies and policies to reduce benzene exposure and protect the children's health, contributing to a healthier generation with a better future.

METHODS

Study Location and Population

This cross-sectional study was conducted in Johor, a state in the southernmost part in Peninsular Malaysia. Johor occupies an area of 19,166 square kilometers with a population of approximately 4.1 million. There are ten districts in the state and the closest neighbouring country is Singapore (Figure 1).

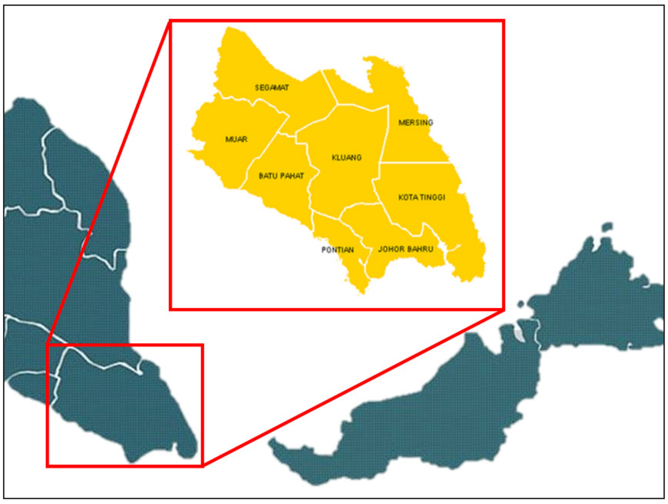
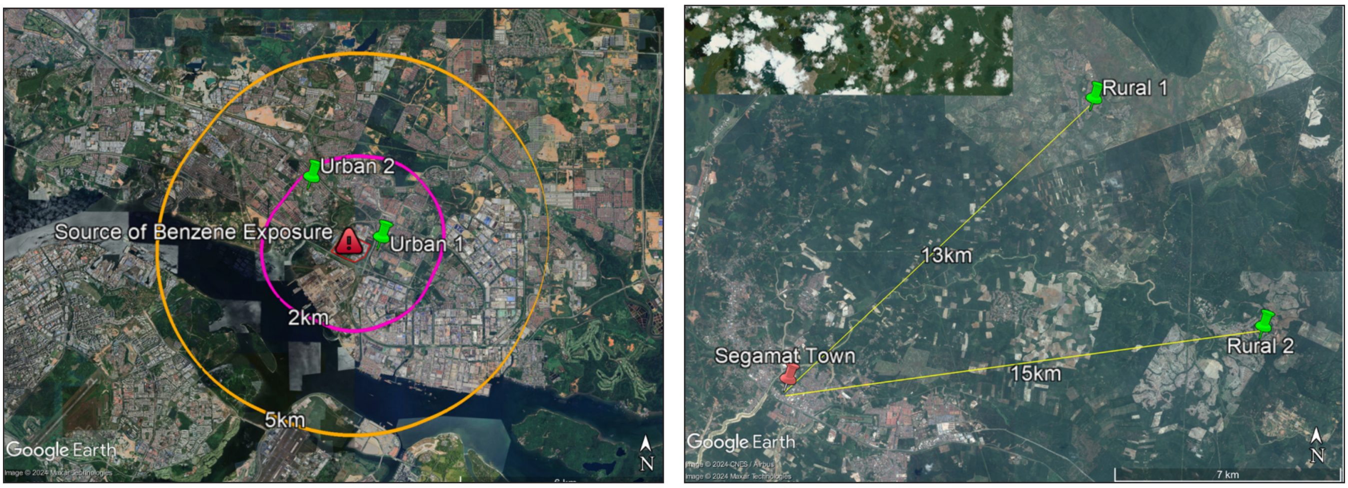


Figure 1. Map of Malaysia Highlighting Johor State and Its Administrative Districts

The primary schools in Pasir Gudang and Segamat were chosen as the research sites in this study. Whether the study areas are urban or rural, was based on definitions of the Department of Statistics Malaysia (32). Two schools in Pasir Gudang, designated as Urban 1 and Urban 2, were selected to represent the urban category. The location of these schools is within a 2 km radius of the known benzene sources and the Pasir Gudang Highway. Next, two schools (Rural 1 and Rural

2) in Segamat were selected for the rural category as they were located approximately 13 km from the city and away from major roads- an indication that the exposure to benzene pollution is lower (Figure 2).



(a) **(b)**

Figure 2. Primary School Locations in Urban (a-Pasir Gudang) and Rural (b-Segamat) Areas

334 primary school children aged 10 to 12 years were involved in this study, with 173 coming from urban areas in Pasir Gudang and 161 from rural areas in Segamat, Johor. The children were the contributor to the key data where their exposure intake to benzene was calculated, using their respective body weights and heights. These measurements were collected using the information kept in SEGAK- National Physical Fitness Standard for Malaysian School Children Assessment program. Ensuring adherence to ethical standards, only data from children whose parents had given their informed consent were included in the analysis. The inclusion criterion was for the children to be between the ages of 10 and 12. This specific age range was selected so that the consistency is maintained between respondents from both urban and rural areas, as rural schools tend to operate within a single school session system. For a more accurate assessment of benzene exposure, these children were required to be students in the study areas who happen to be subjected to the regular and prolonged exposure to the environmental conditions of their respective schools. Absentees, or children not present at school during the study period were excluded from this research.

Sampling Collection and Analysis

Ambient air benzene levels were monitored at the selected primary schools from August to December 2023. A BUCK Libra L-4 Sampling Pump, an active air sampler, was positioned about 1 meter above the ground at a guard post closest to the traffic source. This is to focus on the area of highest potential exposure near traffic, understandably regarded as a reliable and representative measurement of benzene levels the students are most likely to encounter. The sampling was conducted from 7:00 a.m. to 1:00 p.m., or for six hours for two days in a row, with close alignment with the school hours and peak traffic times so that the maximum benzene concentrations can be captured. The calibration of the BUCK Libra L-4 Sampling Pump was set to a flow rate of 0.098 - 0.100 L/min, based on the airflow calibrator guidelines (33) to ensure that the benzene capture is accurate without the sorbent material saturation. The Sorbent tubes were pre-conditioned and packaged within 30 days prior to the sampling. Field blanks were prepared, the process in which the tubes were unsealed and immediately resealed as controls.

The Buck Libra L-4 Pump was operated continuously to keep a consistent flow rate. After six hours, sorbent tubes were analysed after they were collected, sealed, and transported to the laboratory. The analysis of the samples took place in a certified environmental laboratory using Agilent 7890B gas chromatography-mass spectrometer (GC-MS) that complies with the US EPA Compendium Method TO-17 (33).

Risk Assessment of Benzene Exposure

Equation 1 is used to ascertain the chronic daily intake of benzene via inhalation (CDI_{inh}) (34). Inhalation served as the chosen primary exposure pathway as benzene is known to be volatile and its presence is common in ambient air (8,12), emitted from specifically vehicles and industrial sources. Children spend long periods in school environments, so the school is the place where inhalation represents the most relevant route of exposure to pollutants.

$$CDI_{inh} = (C \times R_{inh} \times ET \times EF \times ED)/(BW \times AT)$$

CDI_{inh} is measured in mg/kg/day in this equation. C is the concentration value derived from the average benzene levels found in ambient air samples (mg/m³) (35). R_{inh}, or the inhalation rate, is the volume of air breathed daily (m³/day). As established in this work, the anticipated inhalation rate for children was 5 m³/day (36), which was then divided by 24 hours to convert to m³/hour. ET, or exposure time, refers to the duration of the school hours per 24-hour period, measured in hours (37). The estimated exposure frequency (EF) for school children was 195 days per year, considering the time spent outside of school (37). The exposure duration (ED) indicates the number of years a student spends in primary school, which is six years (38). Each student's body weight (BW) is measured in kilograms, obtained from the established National Physical Fitness Standard for Malaysian School Children Assessment program (39). Trained teachers measured children's weight and height (37) by following a standardized protocol set by the Ministry. Table 1 highlights a list of the input parameters and values used in this investigation, other than provides a thorough overview of the parameters used in calculating the CDI_{inh}.

Table 1. Input Parameters and Specific Values for Exposure Assessment of Benzene Through Inhalation (for children)

Symbol	Parameter	Unit	Value	Reference
C	Average benzene concentration in ambient air	µg/m³		This study
R_{inh}	Inhalation rate	m³/day	5	(36)
ET_{school}	Time exposed at school	hours/24 hours	6	(37)
EF_{school}	Frequency of exposure at school	days/year	195	(37)
ED	Duration of exposure at school	years	6	(38)
BW	Individual body weight	kg		This study
AT_{carc}	Averaging time (carcinogen)	days	70 years x 365 days	(38)
$AT_{non\text{-}carc}$	Averaging time (non-carcinogen)	days	ED x 365 days	(38)

With vulnerable populations in mind, the inhalation reference dose (RfD_{inh}) represents a threshold that estimates the maximum acceptable risk of adverse health effects over a lifetime. This threshold is obtained from the reference concentration (RfC), serving as the grounds for such calculations. For benzene, the RfC is 3×10^{-2} mg/m³, predetermined by Integrated Risk Information System (IRIS) from the USA (21). For the calculation of the hazard quotient (HQ), the RfD_{inh} must be established first . The Risk Screening Environmental Indicator (RSEI) method applies a standard adult exposure factor of 20 m³/day and an average body weight (BW) of 70 kg for the conversion of the RfC (mg/m³) into RfD_{inh} (mg/kg/day). The conversion equation used in this process is given in Equation 2 (40).

$$RfD_{inh} = RfC \times 1/BW \times R_{inh}$$

The inhalation cancer slope factor (CSF_{inh}) represents the increased risk of developing cancer caused by a unit increase in the exposure to a carcinogen via inhalation, expressed in terms of risk per mg/kg/day. This factor is obtained from the inhalation unit risk (IUR), which estimates the highest lifetime cancer risk linked with the ceaseless exposure to a carcinogen at a concentration of 1 mg/m³ in the air. The IUR for benzene was 7.8×10^{-6} $(\mu g/m^3)^{-1}$ obtained from IRIS(21) and it has to be converted from µg/m³ to mg/m³ by multiplying it by 1000. Like RfC, IUR expressed in units of exposure (mg/m³) must be converted to units of dose (mg/kg/day) for toxicity calculations relative to body weight. The conversion used an R_{inh} of 20 m³/day and a BW of 70 kg in Equation 3 (40).

$$CSF_{inh} = IUR \times BW \times (1/R_{inh})$$

Non-cancer Risk Assessment.

The hazard quotient (HQ) sheds light on the risk level of non-carcinogenic effects, and the calculation works by dividing the exposure level by the reference dose (Equation 4). Any HQ of >1 points to a potential health risk (34).

$$HQ = CDI_{inh}/RfD_{inh}$$

Cancer Risk Assessment.

The cancer development risk evaluation based on the long-term exposure to carcinogenic substances was carried out using the Lifetime Cancer Risk (LCR). The CSF_{inh} of 0.0273 $(mg/kg/day)^{-1}$ was utilized for benzene, as benzene is officially found to be carcinogenic to humans (category A) (41). Closely referring to the USEPA, values in the range of 1×10^{-6} - 1×10^{-4} are considered acceptable at the expense of the regulations. To calculate LCR, equation 5 was applied (34):

$$LCR = CDI_{inh} \times CSF_{inh}$$

Ethics and Dissemination

This study closely follows the ethical standards in the Declaration of Helsinki and the guidelines established by the Malaysian Good Clinical Practice.The study was granted the ethical approval by Ministry of Health Malaysia (NMRR ID-23-00807-HRP (IIR)) and Faculty of Medicine and Health Sciences, Universiti Malaysia

Sabah (JKEtika 1/23 (14)). Several other agencies-Ministry of Education Malaysia, Johor State Department of Education, Pasir Gudang and Segamat District Departments of Education had given the permission for the research to be conducted in schools within the locations concerned.

RESULTS

Benzene Levels in Ambient Air

The benzene levels measured on both days did not surpass the European Union (EU) standard for benzene levels (5 μg/m³ per year) except for Rural 1. However, all locations exceeded the WHO's recommended exposure limit of 0.17 μg/m³ per lifetime. The benzene levels in the urban setting ranged from 0.96 to 1.69 μg/m³ with a median of 1.17 (IQR 0.57) μg/m³, suggesting relatively consistent and lower levels. By contrast, the rural areas exhibited a broader range from 0.89 to 15.00 μg/m³, with a significantly higher median of 5.83 (IQR 12.51) μg/m³, suggesting greater variability and the possibility for higher benzene exposure in some rural locations. Table 2 highlights the average ambient air levels of benzene in all the study locations.

Table 2. Ambient Air Levels for Benzene by Study Location

School Location (n=8)	Average Ambient Air Level by Location (mg/m³)	School Name	Average Ambient Air Level by School (mg/m³)
Urban (n=4)	0.1250×10^{-2}	Urban 1	0.1410×10^{-2}
		Urban 2	0.1085×10^{-2}
Rural (n=4)	0.6890×10^{-2}	Rural 1*	0.1235×10^{-1}
		Rural 2	0.1430×10^{-2}

**Highest detected value*
n: number of air samples

Health Risk Assessment

Based on the results from the ambient air sampling, a health risk assessment was performed to evaluate the non-carcinogenic and carcinogenic risks of benzene exposure among the targeted urban and rural primary school children.

Non-cancer Risk Assessment

The calculation for the hazard quotient (HQ) for benzene, for individual schools, is derived from multiple data sources in both urban and rural areas, which is shown in Table 3 and Table 4, respectively. In general, the HQ for benzene in most locations was less than one, which is an indicator that there is an acceptable level of non-cancerous risk for human exposure to benzene. However, rural settings projected higher HQ values, with the highest being 4.1×10^{-2} for an individual weighing 13 kg. The lowest HQ in the urban areas was 1.2×10^{-3} for an individual weighing 81 kg. The highest HQ by school location was noted to be in Rural 1 with an average of 2.3×10^{-2}, while the lowest was in Urban 2, recording an average of 2.1×10^{-3}.

Table 3. Hazard Quotient for Benzene Level in Rural and Urban Areas

School Location (n=334)	Average Benzene Level (μg/m³)	Individual Weight (kg)		CDI (mg/kg/day)	RfD (mg/kg/day)	HQ (unitless)
Urban (n=173)	1.25	Min	19	4.4×10^{-5}	8.6×10^{-3}	5.1×10^{-3}
		Max	81	1.0×10^{-5}	8.6×10^{-3}	1.2×10^{-3}
		Average	40	2.1×10^{-5}	8.6×10^{-3}	2.4×10^{-3}
Rural (n=161)	6.89*	Min	13	3.5×10^{-4}	8.6×10^{-3}	4.1×10^{-2}
		Max	92	5.0×10^{-5}	8.6×10^{-3}	5.8×10^{-3}
		Average	38	1.2×10^{-4}	8.6×10^{-3}	1.4×10^{-2}

**Highest detected value*
n: number of cases; CDI: chronic daily intake; RfD: reference dose; HQ: hazard quotient

Table 4. Hazard Quotient for Benzene Level at Each School

School Name (n=334)	Average Benzene Level (μg/m³)	Individual Weight (kg)		CDI (mg/kg/day)	RfD (mg/kg/day)	HQ (unitless)
Urban 1 (n=99)	1.41	Min	20	4.7×10^{-5}	8.6×10^{-3}	5.5×10^{-3}
		Max	81	1.2×10^{-5}	8.6×10^{-3}	1.4×10^{-3}
		Average	38	2.4×10^{-5}	8.6×10^{-3}	2.9×10^{-3}
Urban 2 (n=74)	1.09	Min	19	3.8×10^{-5}	8.6×10^{-3}	4.4×10^{-3}
		Max	74	9.8×10^{-6}	8.6×10^{-3}	1.1×10^{-3}
		Average	41	1.8×10^{-5}	8.6×10^{-3}	2.1×10^{-3}
Rural 1 (n=68)	12.35*	Min	34	2.4×10^{-4}	8.6×10^{-3}	2.8×10^{-2}
		Max	57	1.4×10^{-4}	8.6×10^{-3}	1.7×10^{-2}
		Average	41	2.0×10^{-4}	8.6×10^{-3}	2.3×10^{-2}
Rural 2 (n=93)	1.43	Min	13	7.3×10^{-5}	8.6×10^{-3}	8.5×10^{-3}
		Max	92	1.0×10^{-5}	8.6×10^{-3}	1.2×10^{-3}
		Average	36	2.6×10^{-5}	8.6×10^{-3}	3.1×10^{-3}

**Highest detected value*
n: number of cases; CDI: chronic daily intake; RfD: reference dose; HQ: hazard quotient

Cancer Risk Assessment

Table 5 presents the LCR for benzene exposure in rural and urban school settings. Next, Table 6 shows variations in terms of the individual weights and environmental concentrations. In general, the LCR for benzene was relatively low, with all values being under the threshold of 1×10^{-6}. The readings further showed that the highest LCR recorded was 8.3×10^{-10} for a child weighing 13 kg in a rural setting, while the lowest was 2.4×10^{-11} for a child weighing 81 kg in an urban setting. Referring to the school location, the highest LCR for benzene exposure was observed at Rural 1, with a value of 5.7×10^{-10} for the lightest individuals, suggesting that there is a higher risk among younger children with lower body weights. On the contrary, the lowest LCR was recorded at Urban 2, with a value of 2.3×10^{-11} for heavier children.

Table 5. Lifetime Cancer Risk for Benzene Level in Rural and Urban Areas

School Location (n=334)	Average Benzene Level (µg/m³)	Individual Weight (kg)		CDI (mg/kg/day)	CSF (mg/kg/day)$^{-1}$	LCR (unitless)
Urban (n=173)	1.25	Min	19	3.8×10^{-6}	2.7×10^{-5}	1.0×10^{-10}
		Max	81	8.8×10^{-7}	2.7×10^{-5}	2.4×10^{-11}
		Average	40	1.8×10^{-6}	2.7×10^{-5}	4.9×10^{-11}
Rural (n=161)	6.89*	Min	13	3.0×10^{-5}	2.7×10^{-5}	8.3×10^{-10}
		Max	92	4.3×10^{-6}	2.7×10^{-5}	1.2×10^{-10}
		Average	38	1.0×10^{-5}	2.7×10^{-5}	2.8×10^{-10}

**Highest detected value*
N: number of cases; CDI: chronic daily intake; CSF: cancer slope factor; LCR: lifetime cancer risk

Table 6. Lifetime Cancer Risk for Benzene Level at Each School

School Location (n=334)	Average Benzene Level (µg/m³)	Individual Weight (kg)		CDI (mg/kg/day)	CSF (mg/kg/day)$^{-1}$	LCR (unitless)
Urban 1 (n=99)	1.41	Min	20	4.0×10^{-6}	2.7×10^{-5}	1.1×10^{-10}
		Max	81	9.9×10^{-7}	2.7×10^{-5}	2.7×10^{-11}
		Average	38	2.1×10^{-6}	2.7×10^{-5}	5.8×10^{-11}
Urban 2 (n=74)	1.09	Min	19	3.3×10^{-6}	2.7×10^{-5}	8.9×10^{-11}
		Max	74	8.4×10^{-7}	2.7×10^{-5}	2.3×10^{-11}
		Average	41	1.5×10^{-6}	2.7×10^{-5}	4.1×10^{-11}
Rural 1 (n=68)	12.35*	Min	34	2.1×10^{-5}	2.7×10^{-5}	5.7×10^{-10}
		Max	57	1.2×10^{-5}	2.7×10^{-5}	3.4×10^{-10}
		Average	41	1.7×10^{-5}	2.7×10^{-5}	4.7×10^{-10}
Rural 2 (n=93)	1.43	Min	13	6.3×10^{-6}	2.7×10^{-5}	1.7×10^{-10}
		Max	92	8.9×10^{-7}	2.7×10^{-5}	2.4×10^{-11}
		Average	36	2.3×10^{-6}	2.7×10^{-5}	6.2×10^{-11}

**Highest detected value*
N: number of cases; CDI: chronic daily intake; CSF: cancer slope factor; LCR: lifetime cancer risk

DISCUSSION

Some key insights have been established from the findings of this study concerning the distribution of benzene concentrations and the associated health risks for children, a vulnerable population group.

Benzene Concentrations and Environmental Factors

The current work exposes that rural schools had higher average ambient air benzene levels (0.6890 x10^{-2} mg/m³) compared to urban schools (0.1250 x 10^{-2} mg/m³), where, "Rural 1" recorded the highest benzene concentration at 0.1235 x 10^{-1} mg/m³. Such discrepancy suggests that rural areas may have distinct or more concentrated sources of benzene pollution. In support of this fact, notable benzene concentrations have been detected in rural regions, such as 0.69 ± 0.45 µg/m³ (min-max: 0.03-3.17 µg/m³) in Fraser Hill, suggesting that rural pollution sources are significant contributors to ambient benzene levels (28,42). The variability in benzene concentrations in rural settings (Rural 1 and Rural 2) further indicates the potential presence of localized pollution sources, stressing on the need to conduct additional investigation (27-28).

The observed disparities in benzene levels also throw some light on the meteorological conditions and its significant role (43). The weather stations near the rural areas studied issue data showing that the rural site with the highest benzene concentration (Rural 1) had the lowest average wind speed (3.5 m/s). Lower wind speeds in rural areas, such as Danum Valley, cause smaller pollutant dispersion and a rise in sustained benzene concentrations (28). This accentuates the critical role of wind speed in spreading airborne pollutants and maintaining air quality. As opposed to this, a rural school with lower benzene levels (Rural 2) tends to face much higher wind speeds (7.1 m/s), which means that the pollutant dispersion is more effective. CFD simulations demonstrated that higher wind speeds improve benzene dispersion significantly, thereby reducing its atmospheric concentration (44).

Moderate wind speeds and higher temperatures were noted in the urban areas, causing more efficient dispersion of air pollutants and lower benzene concentrations. A study focused on how urban-rural breezes and synoptic weather patterns in urban environments significantly enhance pollutant dispersion and this is in tune with these current findings. The moderate wind speeds and elevated temperatures in urban areas lead to better pollutant dispersal which is different from rural regions laden with stagnant air (45). The fundamental interaction of temperature, wind speed, and humidity is crucial in determining the way in which the pollutants are distributed, stressing the need for more focused monitoring in specific seasons to mitigate the exposure risks. Additionally, the UHI effect (Urban Heat Island) is the phenomenon in which the temperatures in urban areas are increased, further causing the volatilization of benzene from various sources (46), and contributing to the observed lower benzene level in urban locations.

The varying fuel quality, transportation modes, and emission standards are contributors to the varying benzene levels between rural and urban areas. In the former, students' main mode of transportation is motorcycles, which may be more than 10 years old. There is a higher likelihood of impairment and failure of emission control devices that become common among these older motorcycles, other than the fact that they exceed the guaranteed manufacturers' durability mileage (47). Thus, increased levels of benzene emissions are expected. Urban students, by contrast, are more likely to travel by car, which typically features more advanced emission control technologies (48). What comes with it is the quality of petrol, as indicated by its Research Octane Number (RON), that influences benzene emissions. RON 95 petrol has a higher benzene content than RON 97 (31).

Health Risk Assessment

The good news is that the HQ values for non-carcinogenic risks were below one at all study sites, indicating no immediate threat to children's health due to benzene exposure. However, LCR estimates suggest a present, yet low, risk of developing benzene-related cancers over a lifetime, albeit within acceptable ranges. The highest LCR recorded was 8.3×10^{-10} in rural areas, which suggests that even long-term exposure to these levels is dangerous to health, particularly with the sensitivity of children to environmental pollutants taken into account. This demands for targeted interventions and enhanced monitoring in rural schools for effective control and mitigation of health risks. Recent literature offers support to these findings, focusing on significant non-carcinogenic health risks in children exposed to benzene, with elevated HQs that frequently exceed the safe limits. The validation of the universal public health concern surrounding benzene exposure is evident, especially for children who are more susceptible to pollutants and have longer life expectancies, and are more likely to develop the cumulative risk of adverse health effects (26).

It has to be added that the cancer risk assessment using the LCR metric is consistent with international standards, and it is verified that the carcinogenic risk from benzene stays low across all locations examined. However, between lighter and heavier individuals particularly in rural schools there is varying levels of risk, and this highlights the importance of individual susceptibility factors in risk evaluations. This differences sets the motion for a refined approach to health risk assessments, to ensure that the varying risks across different population sub-groups are not to be disregarded. It has been acknowledged earlier that children are particularly vulnerable to benzene exposure, mainly through inhalation because of their higher respiratory rates (49), developing respiratory systems (22), and the amount of time spent outdoors near pollution sources (25). Recent research focus on the strong link between benzene exposure and increased cancer risks in which they highlight that current exposure levels, although they are below established regulatory thresholds, may not be adequately protective, so stricter regulations and more effective mitigation strategies are urged (50).

Recommendations for Reducing Benzene Exposure in Primary School Children

Parents, children, and educators are the primary parties who must take several precautions in preventing primary school students from being exposed to benzene. Our observations during sampling were alarming- we noted that a lot of parents had left the engine of their cars running and idle near the place where students arrived and left. Parents should be advised to turn off their vehicle engines while waiting for their children, and they need to be made aware that doing so can substantially reduce the amount of benzene emitted from their idling vehicles, and further improve the air quality around school premises (51). They should also make sure that their vehicles are well-maintained to minimize harmful emissions. Habitually, parents should also avoid smoking near school grounds. In other words, parents should be educated about the sources and risks linked with benzene exposure, helping them to recognize the importance of these preventative actions for safeguarding their children's health and apply them in their daily lives.

Teachers and school administrators need to play a proactive role in lessening benzene exposure among students. It would not be overbearing for schools to strictly implement the no-idling policies for vehicles parked on school grounds (52). In class, teachers can incorporate lessons on air pollution and its health effects to raise better awareness among students. Having outdoor activities in areas away from heavy traffic and planning to do outdoor play during periods of lower traffic can further help children to escape benzene exposure (53). As a school rule, students should be advised to wait for their parents at designated spots away from the school gate during pickup times so that contact with vehicle emissions can further be restricted. There should be concerted efforts between schools, parents, and local health authorities in fostering a healthier environment for children, ultimately safeguarding their long-term health and well-being.

Several potential biases and limitations have been occurring throughout the course of this study. First, the generalizability of the findings might not be achieved considering that only two schools in urban and rural areas were chosen. Thus, this sample might fail to fully capture the broader environmental conditions across Johor. Additionally, the limited number of sampling points within each school could also affect the understanding of the spatial variability of benzene concentrations. Another limitation also lies in the fact that the data collection was conducted over a restricted time frame, which may not account for temporal variations in benzene levels throughout different times of day or seasons.In future, similar studies may need to include more schools, increase the sampling points within each site, and lengthen the monitoring period to offer a more comprehensive evaluation of benzene exposure risks in school settings. Furthermore, future research could consider other contributing factors, such as agricultural activities or smaller-scale industries in order to gain a more comprehensive understanding about these elevated benzene levels in rural environments.

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AUTHORS' CONTRIBUTIONS

NA: gave contribution in the study's conception and design, data acquisition and preparation, data analysis and interpretation, manuscript drafting, and produced the final approval for the version to be submitted. SBS: involved in the study's conception and design, data analysis and interpretation, critical manuscript revision, and provided the final approval for submission. HRT: played a part in the data acquisition and preparation phases, critically revised the manuscript, and approved the final version for submission. All authors have reviewed, and were in agreement with the published version of the manuscript.

CONCLUSION

To conclude, this study has thrown a light on the existence of elevated benzene levels in rural areas of Johor, Malaysia, that poses potential long-term health risks to primary school children. The non-carcinogenic risks are not immediately concerning, but the potential long-term carcinogenic risks that highlight the need for constant monitoring and targeted measures simply cannot be treated lightly. The importance of continuous monitoring, more rigid pollution controls, better vehicle maintenance, and sound educational programs for parents and schools must be highlighted to extenuate these risks. The execution of these strategies will serve as the protection to the vulnerable population and secure a safer environment for future generations.

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