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Characterization and Health Risk Assessment of Particulate Matter and Heavy Metals Generated by Traffic in Urban Areas of Nakhon Ratchasima, Thailand

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Abstract

Traffic-generated particles pose significant health risks, especially to workers and residents who live near traffic-dense in urban areas of Nakhon Ratchasima, Thailand. The particulate matter concentration and their composition of hazardous heavy metals. This study aimed to characterize these particles and assess health risks from inhalation exposure to PM-bound heavy metals. Airborne particles were conducted using a Portable Aerosol Spectrometer (PAS). Heavy metals were collected onto an IOM sampler and analyzed by a Field Emission Scanning Electron Microscope with Energy Dispersive X-Ray Spectrometer (FESEM-EDS). Health risk assessment were following by the standard methodology of the US EPA. Results showed that most particles ranged from 0.25 – 1 µm, often aggregating into larger particles. PM_{10} and inhalable dust had the highest mass concentrations at 71.84 µg/m³ and 139.53 µg/m³, respectively. Heavy metals detected included Al, Fe, Ti, Cu, Zn, Cr, and As. Health risk assessments reveal non-carcinogenic risks (hazard quotient and hazard index > 1) and carcinogenic risks (cancer risk > 1×10^{-6}) for exposed populations, particularly occupational groups like motorcycle drivers and street vendors. The findings underscore the urgent need for stricter emission controls, promotion of green-energy vehicles, and protective measures such as N95 masks for high-risk individuals.

Keywords: Health risk assessment; Particulate matter (PM); Heavy metals; Traffic pollution

1. Introduction

Particulate matter (PM) is a type of air pollution that is the leading environmental threat to human health in many countries, with particulate matter ($PM_{2.5}$ and PM_{10}) being particularly hazardous. The health risks are largely determined by pollutant concentration levels, and an estimated 90% of the global population resides in areas exceeding the World Health Organization's air quality guidelines (WHO, 2021).

Urban growth significantly impacts air pollution due to activities associated with urbanization, which often generate pollution sources. These include the increase in construction activities, industrial operations, factories, and particularly vehicles and dense traffic (Ren *et al.,* 2022). Urban traffic is a major source, accounting for approximately 50% of $PM_{2.5}$ emissions (Timmermans et al., 2017; Frey *et al.,* 2022). The concentration of PM emitted from vehicles is influenced by various factors, including brake and tire wear, engine operation, and fuel combustion (Abu-Allaban *et al.,* 2003; Thorpe *et al.,* 2007; Kam *et al.,* 2012).

In 2019, member countries of the European Union (EU) reported annual average $PM_{2.5}$ levels in urban areas exceeding the WHO recommended annual limit of 10 µg/m³. The highest levels were recorded in urban areas of Bulgaria (19.6 µg/m³) and Poland (19.3 µg/m³) (European Union, 2021). Similarly, Thailand experienced severe air pollution from PM_{10} and $PM_{2.5}$ in early 2019, which directly impacted the environment, economy, and public health (Pollution Control Department, Thailand, 2019). In 2023, air quality monitoring stations along roadside areas in Bangkok recorded average PM10 and $PM_{2.5}$ levels of 59.67 µg/m³ and 29.8 µg/m³, respectively, exceeding the Pollution Control Department's standards of 50 µg/m³ for PM_{10} and 15 µg/m³ for $PM_{2.5}$ (Pollution Control Department, Thailand, 2023). Urban areas in Thailand, such as Bangkok and Nakhon Ratchasima, face critical air pollution challenges, largely driven by rapid urbanization, industrial expansion, and increasing vehicular emissions. These factors have resulted in consistently high levels of $PM_{2.5}$ and PM_{10}, which pose significant risks to public health and the environment.

Particulate matter emitted from vehicles contains various elemental components, particularly heavy metals such as aluminum (Al), chromium (Cr), copper (Cu), iron (Fe), and zinc (Zn). These heavy metals are present in vehicle exhaust and originate from fuels, lubricants, and the wear and tear of engine components (Wang *et al.,* 2003; Hao *et al.,* 2019). These toxic heavy metals can attach to $PM_{2.5}$ particles and enter the human body through inhalation, leading to adverse effects on the respiratory, cardiovascular, nervous systems and also classified as Group 1 carcinogens, indicating it is carcinogenic to humans (IARC, 2024). For example, aluminum (Al), copper (Cu) and iron (Fe) have been associated with respiratory issues such as lung fibrosis and reduced lung function, neurodegenerative diseases (e.g., Alzheimer's) (Brewer, 2010; Pohanka, 2019). Additionally, Al has been linked to kidney damage, bone disorders, and hormonal imbalances (Bonfiglio *et al.,* 2023), while Fe has been implicated in age-related diseases such as arteriosclerosis and diabetes (Brewer, 2010).

Chromium (Cr), exists in various oxidation states, with trivalent chromium (Cr(III)) and hexavalent chromium (Cr(VI)) being the most stable forms. Cr(III) has low bioavailability, while Cr(VI) is highly toxic, reactive, and carcinogenic. Inhalation is the most hazardous exposure route to Cr, linked to lung cancer, respiratory issues (e.g., bronchial asthma), and nasal septum damage (Chatterjee, 2015).

Zinc (Zn), has been associated with respiratory distress, including symptoms such as fatigue, cough, and fever, commonly referred to as metal fume fever. Inhalation of zinc compounds, such as zinc oxide (ZnO) and zinc chloride ($ZnCl_2$), can lead to severe conditions, including acute respiratory distress syndrome and pulmonary inflammation, by inducing oxidative stress (Adamson *et al.,* 2000; Cooper, 2008).

Nakhon Ratchasima Province has undergone significant growth in industrialization, construction, and population, leading to high traffic density in urban areas. This has contributed to elevated PM concentrations, particularly $PM_{2.5}$, with annual averages from 2020 to 2023 exceeding permissible limits (Pollution Control Department, Thailand, 2023). Traffic-related PM emissions have significant health impacts, especially on high-risk groups such as workers and residents in traffic-congested areas. These groups include motorcycle and delivery drivers, street vendors, security guards, and local residents.

This study aims to examine the characteristics of traffic-generated PM and its associated heavy metals. Additionally, it seeks to evaluate the health risks of exposure to PM-bound heavy metals among workers and residents living near urban traffic areas in Nakhon Ratchasima Province. The findings are intended to serve as foundational data for developing strategies to manage air pollution, implement health surveillance programs, and promote the quality of life for the affected population.

2. Methodology

The measurement and sampling processes were conducted in March 2024, during the summer season, which is characterized by the highest PM concentrations in Thailand (Pollution Control Department, Thailand, 2023). This is due to meteorological factors such as low rainfall, low humidity, and low wind speed, which are associated with increased PM concentrations (Das *et al.,* 2021). These processes included: (1) measuring PM to determine particle size distribution and number concentration, and mass concentration; (2) collecting PM samples for analysis of elemental composition and morphology; and (3) conducting a survey to gather exposure-related information through questionnaire.

2.1 Research area

The study was conducted in the urban areas of Nakhon Ratchasima Province, located in Northeastern Thailand. This province is characterized by a large urban center and ranks as the second most populous in Thailand (Department of Provincial Administration, Thailand, 2024). It also has the highest number of registered vehicles in the Northeastern region (Department of Land Transport, Thailand, 2024).

Preliminary measurements of particle measurement in urban areas of Nakhon Ratchasima Province revealed that the intersection roadway near an urban shopping mall exhibited the highest average 8-hour concentration (worst-case scenario). Consequently, this location was selected as the site for particle measurement and sampling in this study, identified as Intersection 2 in Figure 1. Additionally, due to its proximity to the shopping mall, this intersection experiences significantly heavier traffic congestion compared to other intersections with the average of 19,652 vehicles/day, as showed in Figure 2.

The target population included workers and residents living within 5 kilometers of traffic-related PM emission sources (Thunis *et al.,* 2016; de Hoogh *et al.,* 2016). Data collection focused on road intersections near an urban shopping mall, considered a worst-case scenario, covering eight traffic intersections (Figure 1). A purposive sampling method was used to select 100 participants based on specific criteria aligned with the study's objectives. Participants retained the right to withdraw from the study at any time.

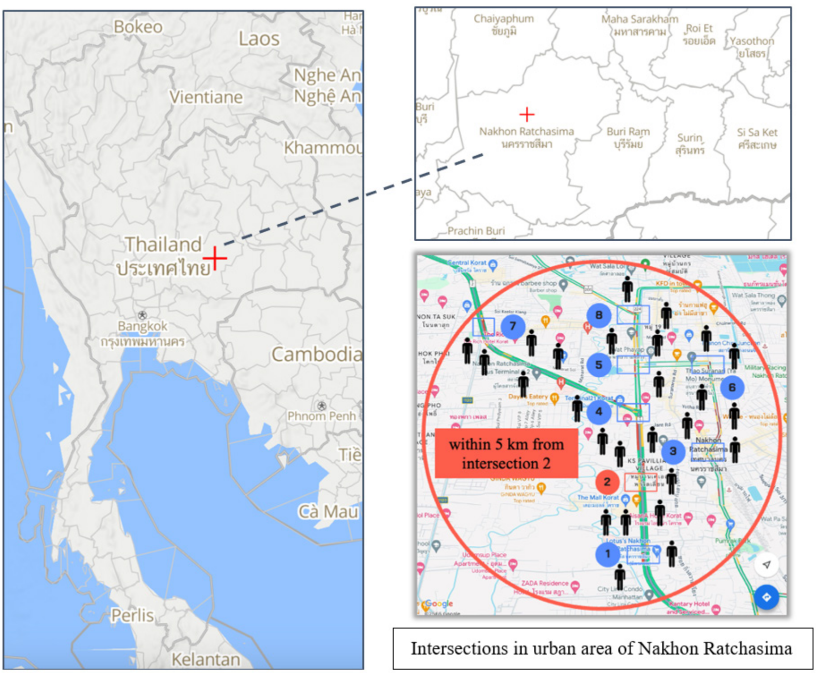

Figure 1. Traffic intersections in the urban areas of Nakhon Ratchasima Province, which experience severe congestion during rush hours

2.2 Questionnaire

The questionnaire, adapted from the OSHA Respirator Medical Evaluation Questionnaire (OSHA, 2001), was modified for the study's specific activities and validated by three experts via an Item-Objective Congruence (IOC) assessment. It includes three sections:

Part 1: Demographic data (gender, age, weight, occupation).

Part 2: $PM_{2.5}$ exposure (work hours, annual duration, experience).

Part 3: Respiratory protection use and symptoms in high-traffic areas.

2.3 Particulate matter (PM) measurement

The measurement of traffic-related PM in this study was conducted over a 7-day period (Monday-Sunday) in March 2024. Measurements were performed daily during peak traffic congestion periods: 06:00–09:00 A.M. (3 hours), 11:00 A.M. – 01:00 P.M. (2 hours), and 03:00 – 06:00 P.M. (3 hours). The Portable Aerosol Spectrometer Dust Detector (PAS), model GRIMM 11D, was employed for the measurement. This instrument is capable of measuring various particle characteristics, including particle size distribution, number concentration, and mass concentration, in accordance with EN 481 standards. The instrument was positioned at the breathing zone level (150 cm) within 2 meters from the traffic intersections, as shown as Figure 3.

2.4 PM-bound heavy metals sampling and analysis

The sampling of PM-bound heavy metals was conducted following the same procedure as particle measurement (section 2.3), over a 7-day period (Monday-Sunday) in March 2024. Samples were collected daily during three time periods with heavy traffic congestion (Figure 4). An IOM sampler equipped with a 25 mm, 0.4 µm polycarbonate membrane filter was used in conjunction with a GilAir Plus Personal Air Sampling Pump at a flow rate of 2 L/min, following the HSE Method MDHS 14/4 (HSE, 2014).

The concentration of PM-bound heavy metals was analyzed using a Field Emission Scanning Electron Microscope (FESEM), model JSM-7001F, combined with an Energy Dispersive X-Ray Spectrometer (EDS). The analysis results were reported in %Atomic. To obtain the concentration of heavy metals in mass-based units (mg/m³), calculations were performed using the particle concentration on the filter, determined by pre- and post-weighing,

Figure 2. Traffic congestion at the intersection roadway near an urban shopping mall

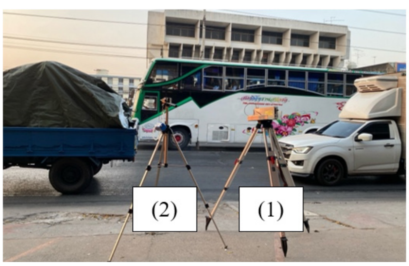

Figure 3. Position of particle measurement instruments included: (1) PAS, (2) IOM sampler (for particle sampling)

following the guidelines of the National Institute for Occupational Safety and Health (NIOSH) Method No. 0600 (NIOSH, 1998), as outlined in Equation 1.

$$C_{PM} = \frac{[(W_2 - W_1) - (B_2 - B_1)]}{V} \times 10^3 \quad (Eq.\ 1)$$

Where C_{PM} is the concentration of particulate matter, W_1 is the tare weight of the filter before sampling (g), W_2 is the post-sampling weight of the sample-containing filter (g), B_1 is the mean tare weight of the blank filters (g), B_2 is the mean post-sampling weight of the blank filters (g), and V is the sampled air volume at the nominal flow rate (m^3).

After determining the particulate weight on the filter, the data are combined with the heavy metal analysis results, expressed in %Atomic, to calculate the mass concentration of each heavy metal (Batsungnoen et al., 2020), as described in Equation 2.

$$C_{HM} = \frac{C_{PM} \times \%\text{Atomic of Heavy Metals}}{100} \quad (Eq.\ 2)$$

Where C_{HM} is the concentration of heavy metals (mg/m^3), CPM is derived from Equation 1, and %Atomic of heavy metals represents the results from the FESEM-EDS analysis (%).

2.5 Health risk assessment

The health risk assessment for inhalation exposure to PM-bound heavy metals were conducted based on the standard methodology of the United States Environmental Protection Agency (US EPA). The assessment consists of four steps (US EPA, 2014), as follows:

Step 1: Hazard identification – This step involves identifying and assessing potential hazards or threats to health. In this study, the hazard is particulate matter generated by traffic in urban areas.

Step 2: Dose-Response Assessment – This step involves evaluating the relationship between the amount of exposure to PM-bound heavy metals and the likelihood of health effects. It includes consideration of the reference dose (RfD) for non-carcinogenic effects and the cancer slope factor (CSF) for carcinogenic effects, as presented in Table 1.

Step 3: Exposure Assessment – This step involves combining the heavy metal concentration analysis results with the exposure characteristics of the participants. Calculations are performed using the average daily dose (ADD) (mg/kg-day) or non-carcinogenic effects and the lifetime average daily dose (LADD) (mg/kg-day) for carcinogenic effects, as shown in Equation 3. Details are provided in Table 2.

$$ADD, LADD = \frac{C_{HM} \times InhR \times ET \times EF \times ED}{BW \times AT} \quad (Eq.\ 3)$$

Step 4: Risk Characterization – This step involves utilizing data and results from the previous three steps to calculate the risk or likelihood of adverse effects on the paricipants due to exposure to PM-bound heavy metals. The heavy metals analyzed include Al, Fe, Ti, Cu, Zn, Cr, and As. The calculations are conducted as follows:

1. Non-carcinogenic effects: These are calculated using the hazard quotient (HQ), which is determined by dividing the average

Table 1. Reference dose (RfD) and cancer slope factor (CSF) of PM-bound heavy metal for health risk assessment

Heavy metals	RfD (mg/kg-day)	CSF (kg-day/mg)	References
Aluminum (Al)	4.00×10^{-4}	-	(US. EPA, 1987)
Iron (Fe)	7.00×10^{-1}	-	(Lu et al., 2014)
Titanium (Ti)	8.60×10^{-3}	-	(EPA Region 9, 2008)
Copper (Cu)	1.00×10^{-3}	-	(ATSDR, 2004)
Zinc (Zn)	3.00×10^{-1}	-	(US. EPA, 2005)
Chromium (Cr)	3.00×10^{-5}	2.70×10^{-1}	(US. EPA, 2024)
Arsenic (As)	3.00×10^{-4}	1.5	(US. EPA, 1995)

daily dose (ADD) obtained from Equation 3 by the reference dose (RfD) for each heavy metal (Table 1), as shown in Equations 4.

Additionally, the hazard index (HI), representing the cumulative risk from exposure to multiple heavy metals, is calculated by summing the HQ values of each heavy metals, as shown in Equations 5.

If the HQ or HI exceeds 1, it is expected that exposure to PM-bound heavy metals may pose a health risk.

$$\text{Hazard Quotient (HQ)} = \frac{\text{ADD}}{\text{RfD}} \quad \textit{(Eq. 4)}$$

$$\text{Hazard Index (HI)} = \Sigma\ \text{HQ} \quad \textit{(Eq. 5)}$$

2. Carcinogenic Effects: These are assessed using the cancer risk (CR), calculated by multiplying the lifetime average daily dose (LADD) obtained from Equation 3 by the cancer slope factor (CSF) for each heavy metal (Table 1), as shown in Equation 6.

The total cancer risk (TCR), representing the cumulative risk from exposure to multiple heavy metals, is calculated by summing the CR values of each heavy metal (Demissie *et al.,* 2024; Evans *et al.,* 2019), as shown in Equation 7.

If the CR or TCR exceeds 1×10^{-6}, it is considered indicative of a carcinogenic health risk from exposure to PM-bound heavy metals.

$$\text{Cancer Risk (CR)} = \text{LADD} \times \text{CSF} \quad \textit{(Eq. 6)}$$

$$\text{Total Cancer Risk (TCR)} = \Sigma\ \text{CR} \quad \textit{(Eq. 7)}$$

3. Results and Discussion

3.1 Particulate matter concentration

The results revealed that most particles were distributed within the size range of 0.25 – 1 µm (250 – 1000 nm), with a gradual decrease up to 10 µm (Zhong *et al.,* 2024). Particles with a size of 0.253 µm exhibited the highest distribution (Zhang *et al.,* 2022), measured at 258,703 particles/L, as shown in Figure 4.

Additionally, particles smaller than 1 µm (1000 nm) can accumulate in the respiratory system, where some may remain trapped and cannot be eliminated through the body's mechanisms. Others may translocated to other target organs, such as the brain, heart, and immune system (Oberdörster *et al.,* 2005).

For the mass concentration results, the measurements were categorized into occupational parameters, including PM_{10}, PM_4, $PM_{2.5}$, and PM_1, and environmental parameters, including inhalable dust, thoracic dust, and respirable dust. The results indicated that PM_{10} and inhalable dust had the highest average concentrations, measuring 71.84 µg/m³ and 139.53 µg/m³, respectively, as shown in Figure 5.

The results of the particle size distribution and number concentration measurements show that the majority of particles generated from traffic are fine particles, within the range of 0.25 – 1 µm. However, when considering the mass concentration results, it is evident that larger particles have the highest concentration (PM_{10}, inhalable dust). This is attributed to the aggregation of fine particles (accumulation mode; < 1 µm) into larger particles (coarse mode; 1 – 10 µm) (Baalbaki *et al.,* 2013; Sánchez *et al.,* 2021).

Table 2. Parameters and values of relevant parameters for health risk assessment

Parameters	Values (P95)	Unit	References
C_{HM} (PM-bound heavy metals concentration)	Show in Figure 7	mg/m³	Sampling in this study
InhR (Inhalation rate)	0.83	m³/hours	(US EPA, 2011)
ET (Exposure time)	12	hours/day	Questionnaire
EF (Exposure frequency)	365	days/year	Questionnaire
ED (Exposure duration)	30	years	Questionnaire
BW (Body weight)	90	kg	Questionnaire
AT (Averaging Time) - Non-carcinogenic - Carcinogenic	 10,950 25,550	days	-

3.2 Particulate matter sample analysis

3.2.1 PM-bound heavy metals

The analysis of traffic-generated particle samples using FESEM-EDS revealed the presence of various heavy metals, including Al, Fe, Ti, Cu, Zn, Cr, and As (Wang *et al.,* 2003; Hao *et al.,* 2019). By combining the weighing of filter before and after sampling, as calculated using Equations 1 and 2, the average concentrations of each heavy metal were determined as follows: Al at 3.70 x 10^{-3} mg/m³, Fe at 7.30 x 10^{-3} mg/m³, Ti and Cu at 2.00 x 10^{-4} mg/m³, Zn and As at 1.00 x 10^{-4} mg/m³, and Cr at 3.00 x 10^{-4} mg/m³ (Figure 6).

3.2.2 Morphology

The analysis of the morphology of traffic-generated particles revealed that, under low magnification at 500x (Figure 7(a)), the particles were observed to be relatively large, ranging in size from 5 to 30 µm. When magnification was increased to 1000x (Figure 7(b)) and 30,000x (Figure 7(c-d)), it was observed that these larger particles were formed by the aggregation of smaller nanoparticles (Wang *et al.,* 2019).

Figures 7(c-d) showed the characteristics of smaller particles and their aggregated formations. The observed particles exhibit various shapes, including ellipsoidal, irregular, fluffy soot aggregates, and spherical shape (Al-Shidi *et al.,* 2020; Labrada-Delgado *et al.,* 2012; Xue *et al.,* 2019).

3.3 Health risk assessment associated with PM-bound heavy metals

The health risk assessment for exposure to PM-bound heavy metals was calculated using exposure data from the study participants and the 95th percentile concentrations of each heavy metal. For non-carcinogenic effect resulted in the average daily dose (ADD), which was subsequently used to compute risk levels in terms of hazard quotient (HQ) and hazard index (HI), as shown in Table 3. Both Al and Cr exhibited HQ values exceeding the threshold of 1 at 1.29 and 1.30, respectively. Additionally, the HI, derived from the combined HQ values of all heavy metals, was 2.65, which is also greater than 1.

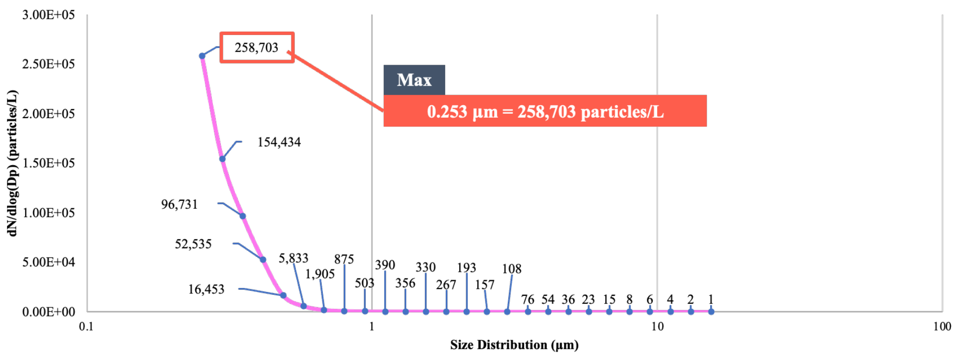

Figure 4. Particle size distribution and number concentration from traffic in urban area results

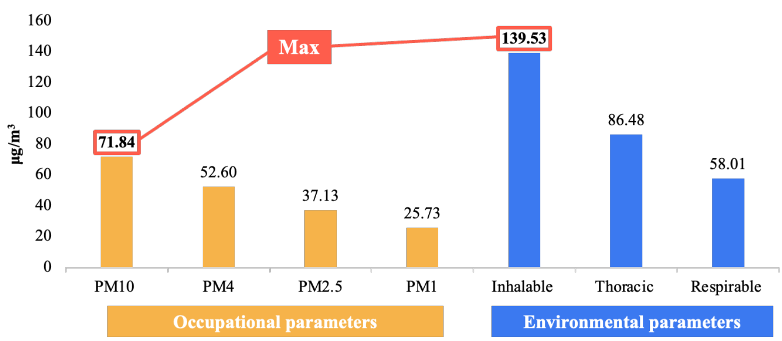

Figure 5. Particle mass concentration results from traffic in urban area

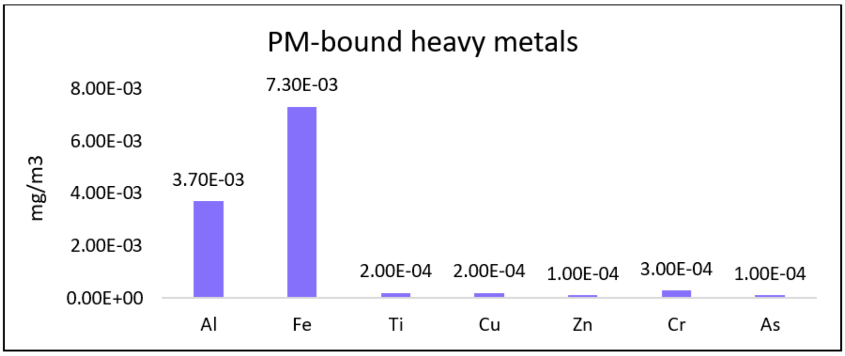

Figure 6. PM-bound heavy metals concentration.

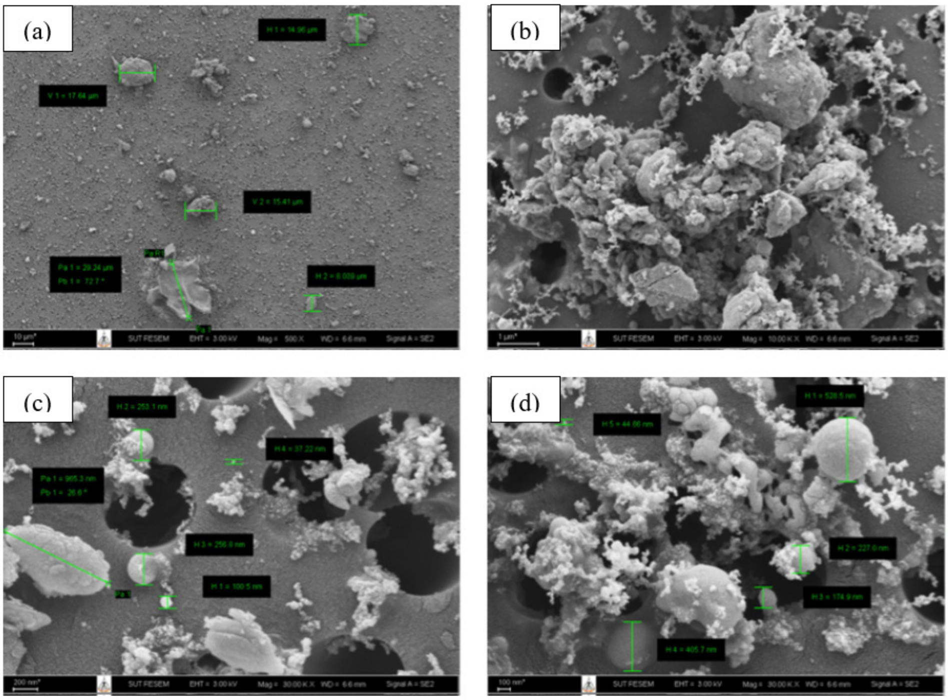

Figure 7. (a) Particle morphology at 500x magnification, (b) Particle morphology at 1000x magnification, (c-d) Particle morphology at 30,000x magnification

Table 3. Exposure assessment and risk characterization to 95th percentile of ADD, HQ and HI

Heavy metals	P95 of ADD (mg/kg-day)	P95 of HQ	HI
Aluminum (Al)	5.17×10^{-4}	1.29	
Iron (Fe)	1.02×10^{-3}	0.0015	
Titanium (Ti)	2.80×10^{-5}	0.0033	
Copper (Cu)	2.80×10^{-5}	0.0280	2.65
Zinc (Zn)	6.99×10^{-6}	0.00002	
Chromium (Cr)	3.91×10^{-5}	1.30	
Arsenic (As)	6.99×10^{-6}	0.023	

For carcinogenic effect, the cancer risk (CR) is calculated using the lifetime average daily dose (LADD). Heavy metals identified as carcinogen and with available cancer slope factors (CSF) include Cr and As, as shown in Table 4. Both Cr and As exhibited CR values exceeding the threshold of 1×10^{-6} at 3.71×10^{-6} and 3.68×10^{-6}, respectively. Additionally, the TCR, derived from the combined CR values of all heavy metals, was 7.40×10^{-6}, which is also greater than 1×10^{-6}.

Among the study participants, motorcycle/delivery drivers had the highest HQ values, followed by street vendors and residents as shown in Figure 8(a). Conversely, street vendors had the highest CR values, followed by motorcycle/delivery drivers and residents, as shown in Figure 8(b) (Abidin *et al.,* 2023, 2024; Sepadi & Nkosi, 2023). Considering the exposure characteristics of the high-risk groups, it was found that they spent more than 10 hours per day, 6 days per week, in close proximity to traffic for over 15 years. The calculated risk values indicate that these participants face both non-carcinogenic and carcinogenic health risks. This finding aligns with previous studies by Awang *et al.* (2019) and Guha & Gokhale (2022), which reported that occupational groups or residents working or living near urban traffic are at an increased health risk due to particle exposure.

A limitation of this study is that data were collected from only one site, selected based on preliminary measurements indicating the highest concentration of particulate matter. Therefore, further research in additional areas is necessary to obtain a more comprehensive dataset on particulate samples and facilitate comparisons between urban sites in Nakhon Ratchasima, Thailand.

Table 4. The exposure assessment and risk characterization to 95th percentile of LADD and CR

Heavy metals	P95 of LADD (mg/kg-day)	P95 of CR	TCR
Chromium (Cr)	1.38×10^{-5}	3.71×10^{-6}	7.40×10^{-6}
Arsenic (As)	2.46×10^{-6}	3.68×10^{-6}	

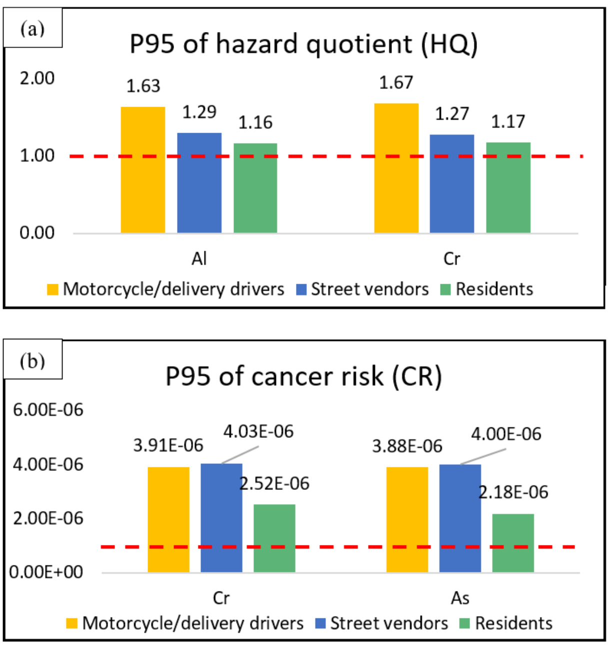

Figure 8. P95 of (a) the hazard quotient (HQ) and (b) the cancer risk (CR) for the top three highest-ranking participants

4. Conclusion

This study investigated the characteristics of particles and assessed the health risks associated with exposure to PM-bound heavy metals from traffic emissions through inhalation in urban areas of Nakhon Ratchasima Province. The particle measurements included particle size distribution, number concentration, and mass concentration. The results indicated that most particles were distributed within the size range of 0.25 – 1 µm (250 – 1000 nm) and tended to aggregate into larger particles. This finding is consistent with the mass concentration analysis, which revealed that PM_{10} and inhalable particles had the highest mass concentrations. Furthermore, the morphology analysis demonstrated the shapes and aggregation patterns of smaller particles as they combined to form larger particles.

The analysis of PM-bound heavy metals revealed that traffic-generated particles contain several hazardous heavy metals, including Al, Fe, Ti, Cu, Zn, Cr, and As. Among these, Cr and As are well-documented as carcinogenic. Health risk assessments based on the 95th percentile concentrations showed that for non-carcinogenic effects, the hazard quotient (HQ) values for Al and Cr exceeded the threshold of 1. Additionally, the hazard index (HI), representing the sum of HQ values for all heavy metals, also exceeded the acceptable level. For carcinogenic effects, Cr and As exhibited cancer risk (CR) values exceeding the threshold of 1×10^{-6}. Additionally, the total cancer risk (TCR), derived from the summation of CR values for each heavy metal, also exceeded the acceptable level, indicating a significant health risk from exposure to these heavy metals.The highest risk group comprised motorcycle/delivery drivers, followed by street vendors and residents for HQ. Conversely, street vendors had the highest CR, followed by motorcycle/delivery drivers and residents.

To mitigate these health risks, stricter regulations should be implemented to reduce vehicle emissions, and the use of green-energy vehicles should be promoted. Incorporating green spaces into urban landscapes can help absorb pollutants while reducing heat islands that exacerbate smog formation. Additionally, redesigning traffic systems to alleviate congestion can further improve air quality over time.

Public awareness campaigns are vital in empowering communities to take preventive measures against air pollution exposure. Tools like Thailand's "Air4Thai" mobile application provide real-time air quality data, enabling individuals to make informed decisions about their activities during high-pollution periods. Encouraging the use of protective equipment such as N95 masks among high-risk groups like street vendors and motorcycle drivers can also reduce health risks associated with PM exposure.

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Ethic Reference

The study was approved by the Human Research Ethics Committee, Suranaree University of Technology, Nakhon Ratchasima, Thailand (Project code: EC-65-138). All participants provided written informed consent.

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