



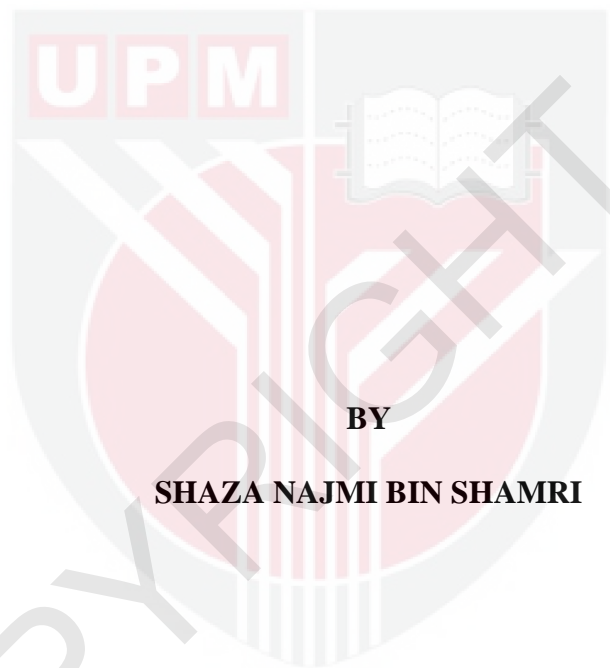
UNIVERSITI PUTRA MALAYSIA

***A REVIEW ON OCCURRENCE OF POLYCYCLIC AROMATIC
HYDROCARBONS (PAHs) IN ROAD DUST SAMPLES IN
SOUTHEAST ASIA AND THEIR POTENTIAL CARCINOGENIC RISK***

SHAZA NAJMI BIN SHAMRI

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**BY
SHAZA NAJMI BIN SHAMRI**

**This thesis submitted in fulfilment of the requirement for the degree of Bachelor
Science (Environmental and Occupational Health) from the Faculty of Medicine
and Health Sciences, Universiti Putra Malaysia**

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ABSTRACT

A REVIEW ON OCCURRENCE OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) IN ROAD DUST SAMPLES IN SOUTHEAST ASIA AND THEIR POTENTIAL CARCINOGENIC RISK

SHAZA NAJMI BIN SHAMRI

Introduction: Polycyclic aromatic hydrocarbons (PAHs) are persistent environmental pollutants that can be generated through petrogenic and pyrogenic sources. Vehicular emissions have been determined as the major source of PAHs, but stricter regulation is yet to be widely established. **Objectives:** Hence, this study aimed to review the occurrence of PAHs in road dust and their potential carcinogenic risk in Southeast Asia. **Methodology:** Scopus database was utilized to search for relevant studies in Southeast Asia from 2011 until 2021. The maximum reported concentrations of PAHs from each study were reviewed and assessed to assimilate the worst-case scenario. Incremental lifetime cancer risk (ILCR) was used to assess the possible carcinogenic health risks caused by PAHs in road dust via inhalation, ingestion, and dermal exposure pathways. **Results and Discussion:** The PAHs concentration in road dust for urban areas ranged from 2800 ng g⁻¹ to 1043245.4 ng g⁻¹ whereas rural areas from 50 ng g⁻¹ to 2900 ng g⁻¹. The highest concentration of PAHs was reported in road dust samples from one residential area in Kuala Lumpur. Meanwhile, the commercial area in was found to constitute highest carcinogenic risk compared to other areas. Urban areas shown higher carcinogenic risk ranging from 10⁻⁷ to 10⁻² that exceed the range of acceptable risk. The cancer risk of ingestion and dermal contact for PAHs in road dust samples were found to be significant in determining the total ILCR values compared to cancer risk from dust inhalation. **Conclusion:** This study between three countries in Southeast Asia namely Vietnam, Myanmar, and Malaysia indicate that the urban area generates relatively high concentration of PAHs in road dust and posed high potential carcinogenic risk to human health compared to rural areas.

Keywords: Polycyclic aromatic hydrocarbons, traffic density, road dust, Southeast Asia, Carcinogenic health risk assessment

ABSTRAK

TINJAUAN TERHADAP KAJIAN POLISIKLIK AROMATIK HIDROKARBON (PAH) DALAM SAMPEL DEBU JALAN RAYA DI ASIA TENGGARA DAN POTENSI RISIKO KARSINOGENIK

SHAZA NAJMI BIN SHAMRI

Pengenalan: Polisiklik Aromatik Hidrokarbon (PAH) adalah pencemar alam sekitar kekal yang terhasil daripada sumber petrogenik dan pirogenik. Pelepasan asap kenderaan telah dikenal pasti sebagai antara sumber utama PAH, tetapi perundangan berkaitan kawalan parameter PAH masih tidak lagi dikuatkuasakan secara meluas. **Objektif:** Oleh itu, kajian ini bertujuan untuk membuat tinjauan kajian mengenai kepekatan PAH dalam debu jalan raya dan potensi risiko karsinogenik yang berfokus di Asia Tenggara. **Metodologi:** Pangkalan data Scopus digunakan untuk melakukan carian kajian-kajian yang berkaitan di Asia Tenggara dari tahun 2011 hingga 2021. Kepekatan PAH tertinggi yang dilaporkan dari kajian tersebut telah dijadualkan untuk mengasimilasikan senario terburuk. Risiko barah seumur hidup kemudian digunakan untuk menganalisis kemungkinan risiko kesihatan karsinogenik yang disebabkan oleh pendedahan PAH dalam debu jalan raya melalui penyedutan, pengambilan, dan sentuhan kulit. **Keputusan dan Perbincangan:** Julat kepekatan PAH dalam debu jalan untuk kawasan bandar adalah dari 2800 ng g⁻¹ hingga 1043245.4 ng g⁻¹ sedangkan julat di kawasan luar bandar dari 50 ng g⁻¹ hingga 2900 ng g⁻¹. Kepekatan PAH tertinggi dilaporkan dalam sampel habuk jalan raya dari salah satu kawasan perumahan di Kuala Lumpur. Sementara itu, kawasan komersial dalam kajian serupa didapati mempunyai risiko karsinogenik tertinggi berbanding dengan kawasan lain. Kawasan bandar secara umum menunjukkan risiko karsinogenik yang lebih tinggi dengan julat yang direkodkan daripada 10⁻⁷ sehingga 10⁻² yang mana telah melebihi julat risiko yang dibenarkan. Risiko kanser daripada pengambilan dan sentuhan kulit telah didapati signifikan dalam menentukan jumlah keseluruhan pengiraan risiko barah seumur hidup berbanding risiko kanser daripada penyedutan debu. **Kesimpulan:** Kajian antara tiga negara dalam Asia Tenggara iaitu Vietnam, Myanmar dan Malaysia ini menunjukkan bahawa kawasan bandar menghasilkan kepekatan PAH yang agak tinggi dalam debu jalan raya dan menimbulkan potensi risiko karsinogenik kepada kesihatan manusia berbanding dengan kawasan luar bandar.

Kata kunci: Polisiklik Aromatik Hidrokarbon, kepadatan trafik, debu jalan raya, Asia Tenggara, penilaian risiko karsinogenik kesihatan,

TABLE OF CONTENTS

	Page
DECLARATION	iii
SIGNATURE OF SUPEVISOR/ INTERNAL EXAMINER	iv
ACKNOWLEDGEMENT	v
ABSTRACT	vi
ABSTRAK	vii
CONTENTS	x
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF ABBREVIATIONS	xiii
CHAPTER 1: INTRODUCTION	
1.1 Background	1
1.2 Problem Statement	2
1.3 Study Justification	4
1.4 Research Question	5
1.5 Objectives	5
1.6 Conceptual Framework	6

CHAPTER 2: LITERATURE REVIEW

2.1	Origin of PAHs in the ambient air	7
2.2	Road dust PAHs and their distributions	9
2.3	Categories of PAHs commonly identified	11
2.4	Health effects from the environmental PAHs exposure	12
2.5	Health risk assessment for PAHs	14
2.6	Legislation related to environmental PAHs exposure control	15

CHAPTER 3: METHODOLOGY

3.1	Data collection for studies on PAHs in road dust	18
3.2	Carcinogenic health risk assessment	20

CHAPTER 4: RESULTS

4.1	PAHs concentration reported from the studies	23
4.2	Carcinogenic health risk assessment	27

CHAPTER 5: DISCUSSION

5.1	Different level of PAHs concentration in road dust samples	30
5.2	Potential carcinogenic health risk of PAHs	31

CHAPTER 6: CONCLUSION

6.1 Conclusion 34

6.2 Future recommendations 35

REFERENCES 36



LIST OF TABLES

		Page
Table 2.1	The 16 PAHs according to U.S Environmental Protection Agency.	8
Table 2.2	Standards and regulations related to PAHs in the environment.	16
Table 3.1	Carcinogenic potencies for related PAHs	21
Table 3.2	Determinants of exposure and variables for carcinogenic health risk assessment.	22
Table 4.1	Occurrence of PAHs in road dust samples and their associated carcinogenic health risk.	24
Table 4.2	Carcinogenic potencies and BAP-EQ calculations for *NR studies.	28
Table 4.3	Estimated ILCR values	29

LIST OF FIGURES

	Page
Figure 1.1 Conceptual Framework	6
Figure 2.1 Diagram of health effects from PAHs exposure	14
Figure 3.1 Flow Diagram of study selection process	19



LIST OF ABBREVIATIONS

PAHs	Polycyclic Aromatic Hydrocarbons
US EPA	United State Environmental Protection Agency
SEA	Southeast Asia
ASEAN	Association of Southeast Asian Nations
ILCR	Incremental Life Cancer Risk
IRIS	Integrated Risk Information System
HMW	High Molecular Weight
MMW	Medium Molecular Weight
LMW	Low Molecular Weight
DOE	Department of Environmental
PM _{2.5}	Particulate Matter 2.5
PM ₁₀	Particulate Matter 10
RTVM	Road Traffic Volume Malaysia
BaP	Benzo[a]pyrene
ATSDR	Agency for Toxic Substances and Disease Registry
IARC	International Agency for Research on Cancer

TLV	Threshold Limit Value
REL	Recommended Exposure Limit
PEL	Permissible Exposure Limit
MCL	Maximum Concentration Level
ACGIH	American Conference of Governmental Industrial Hygienists
CCME	Canadian Council of Ministers of the Environment
NIOSH	The National Institute for Occupational Safety and Health

CHAPTER 1

INTRODUCTION

1.1 Background

Polycyclic Aromatic Hydrocarbons (PAHs) are colourless, white, or pale-yellow organic substances. They are persistent environmental pollutants that are typically produced during the incomplete combustion of organic molecules. They come in a variety of forms and toxicity levels. The rise of anthropogenic activities in today's industrial development era triggers PAHs' accumulation in the environment. Majority of anthropogenic activities involved are aluminium productions, coal-tar pitch and asphalt production, petroleum refineries related activities, and motor vehicle exhaust emissions.

The open atmosphere was a critical mechanism for PAHs to be spread. Due to their physicochemical qualities, they are highly mobile in the environment and can spread through air, soil, and water bodies (Baklanov & Kukkonen, 2007). Although PAHs with low molecular weights are found more commonly in the troposphere in the form of vapour, they may exist in particulate phase as condensation takes places during emission. PAHs with high molecular weights, or HMW PAHS, on the other hand, are shown to be prominent in the particulate phase (Kim et al., 2013).

Since PAHs are primarily generated through incomplete combustion of organic matter, the source can be either natural or anthropogenic. In factual, most of environmental PAHs

being contributed by anthropogenic sources. Therefore, In comparison to rural contexts, PAHs are more frequently reported in urban environments, where the majority of these activities occur and where PAH sources are concentrated. (Z. Wang et al., 2013).

In Malaysia, the most significant PAHs source in cities is expected to come from vehicular emissions as motor vehicles contributed to as much as 95% of air pollutants in Malaysia (Department of Environment Malaysia, 2019). Additionally, PAHs from combustion sources are widespread and typically concentrated in urban centres (Yousef et al., 2002). To back up this argument, the distribution pattern of PAHs in Kuala Lumpur, Malaysia's capital city, demonstrates that vehicular emissions are the primary source of PAHs in the atmosphere (Yousef et al., 2002).

Also, as the PAHs' sources to the terrestrial and water surfaces are relatively unknown, it was higher probability that it comes from atmospheric deposition (US) (Ackermann, 1997). As prolong exposure to PAHs would cause adverse health impact to human, it is necessary to avoid any possibility of having it impacts our quality of life. Even though the emission of PAHs parameters in the air is now monitored in a few countries, one study on PAHs suggested that air quality management must continue to develop over time in order to provide more healthier living conditions (Kim et al., 2013).

1.2 Problem Statement

One of the major sources of PAHs identified comes from the vehicular emissions. Increasing numbers of motor vehicles might contribute to severe air pollution if most

emissions is not effectively being controlled (Department of Environment Malaysia, 2019). Due to the large population, Indonesia has the most registered motor cars among Association of Southeast Asian Nations (ASEAN) member states, with 146.9 million units, or more than 60% of ASEAN's total registered motor vehicles. When population size is factored, however, Brunei Darussalam, Malaysia, and Thailand had the highest total registered motor cars per 1000 people, with 962.9, 925.1, and 598.8 correspondingly. Meanwhile, less than 100 motor vehicles per 1000 persons have been recorded in Cambodia and Vietnam. The total number of registered vehicles in Southeast Asia countries in 2019 was 243.9 million, rising as much as 193.5 percent from 2005 (ASEAN Key Figures, 2020).

In Southeast Asia, air pollution has become a chronic environmental issue that remain untreated. Even if the concentrations of certain air pollutants are small, they can still have considerable health and environmental implications. Nowadays, the air pollution was found heavily contributed by anthropogenic activities. There were few major sources that have been identified to cause air pollution including transportation engines, power and heat generation, industrial processes, and the burning of solid waste. In urban areas, apart from vehicular emission, industrial emission from the burning of burning of materials such as coal, oil, natural gas, and wood can also contributed to released of air contaminants including PAHs to the air. While every industrial process causes air pollution in its own distinctive manner, petroleum refineries was found to be responsible to extensively generate hydrocarbons and particulates to the atmosphere. Initiative action plan should be established with proper enforcement to ensure that the parameters of pollutant were kept in check in tandem with development. Countries will always have to choose between frequently competing ideals between economic drive and environmental sustainability to address the pollution at every

point and at every phase of development in order to provide favourable environmental conditions.

1.3 Study Justification

PAHs are commonly generated to the environment either from natural or anthropogenic sources. The forest fires and volcanic eruptions were examples of natural sources whereas anthropogenic sources of PAHs and their derivatives were from the incomplete burning of fuels, coals, or other organic substances such as tobacco and plant materials. Besides, PAHs are more frequently observed in urban areas than in rural settings, where the majority of these activities occur and where PAH sources are concentrated.(Z. Wang et al., 2013).

The presence of PAHs in the environment is becoming more of a concern because of their potential of cancer risk to human and/or animals. PAHs' carcinogenicity increases as their molecular weight increases, however their acute toxicity decreases. Benzo[a]anthracene, benzo[a]pyrene, and dibenz[ah]anthracene have been reported as the most potent PAH carcinogens (CCME, 2010). This study focuses on PAHs in road dust samples since PAHs may get deposited in road dust depending on their compositions and particle sizes accordingly.

Due to the widespread distribution of PAHs in the environment, the aim of this paper is to provide a general overview to understand the current occurrence of PAHs exposure from

available road dust samples in SEA countries with their potential carcinogenic risk. Considering the advancement of future transportation technology, it is crucial to assess the existing degree of potential health risk linked with PAHs exposure while assisting to provide supporting evidence for determining course of action in national environmental planning programme.

1.4 Research Question

- i. What is the estimated carcinogenic health risk of PAHs that reported in road dust samples in SEA due to inhalation, ingestion, and dermal contact?

1.5 Objectives

- i. To review the literatures related to PAHs in road dust samples in SEA obtained from Scopus database from the year 2011 to 2021.
- ii. To assess the carcinogenic health risk of PAHs reported in road dust samples in SEA due to inhalation, ingestion, and dermal contact.

1.6 Conceptual Framework

This study aimed to review the studies in SEA on the maximum concentration of PAHs in road dust samples to assimilate the worst-case scenario from the environmental exposure. Road dust may disperse in the air depending on their particulate sizes or deposited on the top layer of sediments which can influence the routes of exposure. Referring to the study of road dust samples by Mon et al. (2020), all possible routes of exposure from inhalation, ingestion and dermal contact were considered to assess for this study. Therefore, the carcinogenic health risk assessment via these routes of exposure was calculated to measure the carcinogenic risk of PAHs from dust samples in SEA.

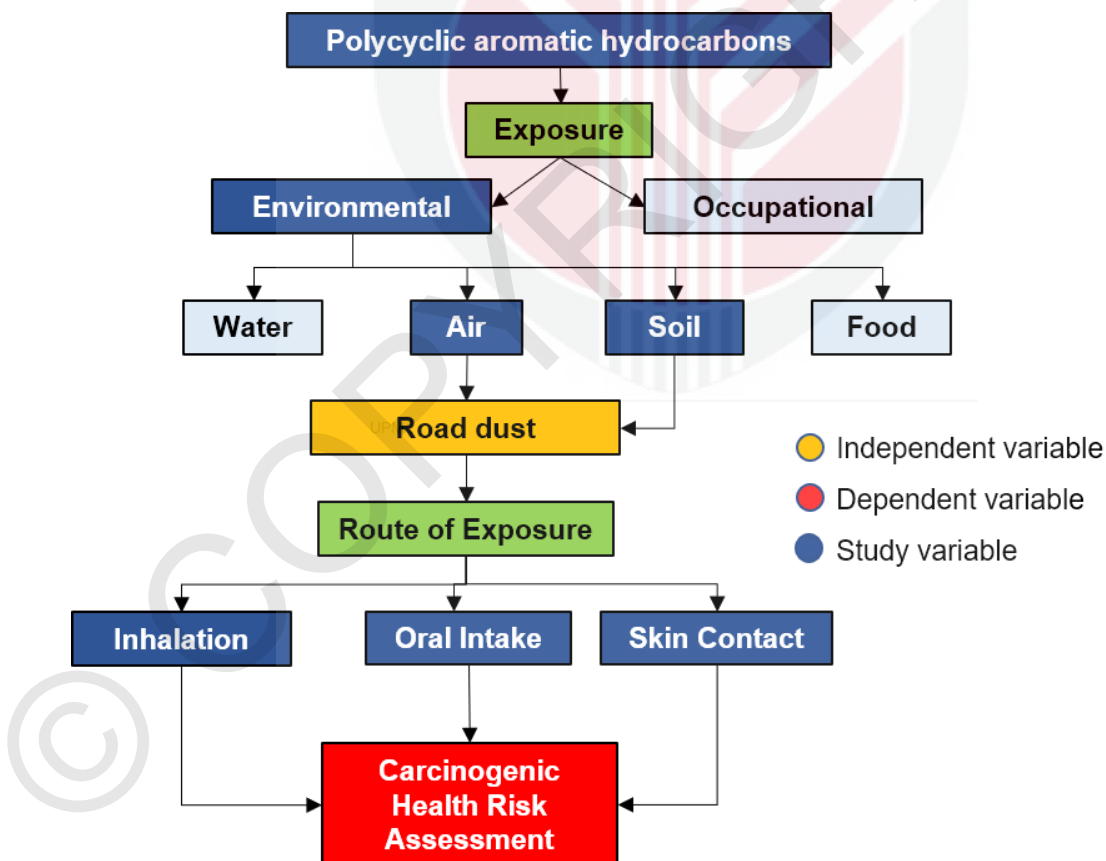


Figure 1.1: Conceptual Framework

CHAPTER 2

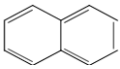
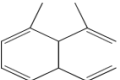
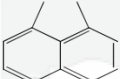
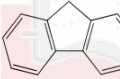
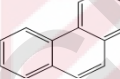


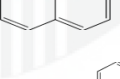
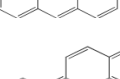
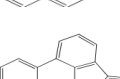
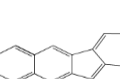
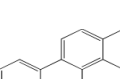
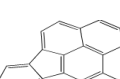
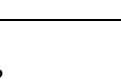
LITERATURE REVIEW

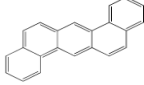
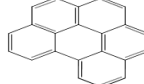
2.1 Origin of PAHs in the ambient air

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous environmental contaminants which primarily originated from the incomplete combustion of carbonaceous materials (Suchanová et al., 2008). Most of them existed in colourless, white, or pale-yellow solids. They are environmentally persistent with various structures and varied in toxicity in which their toxic effects on organisms can causes mutagenic and carcinogenic influences (Abdel-Shafy & Mansour, 2016).

PAHs are mostly formed from combustion of saturated hydrocarbon that being kept under oxygen-deficient condition which defines the incomplete combustion. Pyro-synthesis and pyrolysis are two major mechanisms leading to PAHs formation. The U.S. Environmental Protection Agency (USEPA) has identified 16 PAHs as priority compounds, with the relevant data presented in Table 2.1 (USEPA, 2011). They were been classified based on their distinguished nature and molecular characteristics.

Table 2.1: The 16 PAHs according to U.S Environmental Protection Agency

PAH	CAS No.	No. of Rings	Chemical Formula	Structural Formula	Molecular Weight	Water Solubility (mg L ⁻¹ water)	Melting Point (°C)	Boiling Point (°C)
Naphthalene	91-20-3	2	C ₁₀ H ₁₂		128	3.17	81	218
Acenaphthylene	208-96-8	3	C ₁₂ H ₈		152	3.93	92-93	265-275
Acenaphthene	83-29-9	3	C ₁₂ H ₁₀		154	1.93	95	96.2
Fluorene	86-73-7	4	C ₁₃ H ₁₀		166	1.68-1.98	116-117	295
Phenanthrene	85-01-8	3	C ₁₄ H ₁₀		178	1.20 (at 25°C)	100	340
Anthracene	120-12-7	3	C ₁₄ H ₁₀		178	0.0760	218	342
Fluoranthene	206-44-0	4	C ₁₆ H ₁₀		202	0.20-0.26	111	375
Pyrene	129-00-00	4	C ₁₆ H ₁₀		202	0.077 (at 25°C)	156	393
Benz[a]anthracene	56-55-3	4	C ₁₈ H ₁₂		228	0.010	158-159	400
Chrysene	218-01-9	4	C ₁₈ H ₁₂		228	2.8x10 ⁻³	255-256	448
Benzo[b]fluoranthene	205-99-2	5	C ₂₀ H ₁₂		252	0.0012	168	No Data
Benzo[k]fluoranthene	207-08-9	5	C ₂₀ H ₁₂		252	7.6x10 ⁻⁴ (at 25°C)	216	480
Benzo[a]pyrene	50-32-8	5	C ₂₀ H ₁₂		252	2.3x10 ⁻³	179	495
Indeno[1,2,3-cd]pyrene	193-39-5	6	C ₂₂ H ₁₂		276	0.062	164	530

Dibenz[a,h]anthracene	53-70-3	5	C ₂₂ H ₁₄		278	5x10 ⁻⁴	262°C	No Data
Benzo[g,h,i]perylene	191-24-2	6	C ₂₂ H ₁₂		276	2.6x10 ⁻⁴ (at 25°C)	273	550

The atmosphere is the most important mean of PAHs dispersal; PAHs being pervasive in the environment due to the bulk of PAHs being loaded from multi-sources. PAHs are released to the atmosphere predominantly as a result of incomplete combustion of organic materials, which can be from natural or manmade sources. The natural sources include volcanoes and forest fires while the anthropogenic sources are vehicle exhaust, agricultural fires, power plants, automotive manufacturing plants, and other industrial sources. Also, PAHs tend to be found in greater concentrations in urban environments than in rural environments because most PAHs sources are located in or near urban centres (Z. Wang et al., 2013).

2.2 Road dust PAHs and their distributions

Road dust is a complex mixture of particles of various sizes that contains organic compounds like PAHs as well as inorganic species. It received dust from natural and man-made sources as well as re-entrained materials that have been deposited on the road previously (Majumdar et al., 2017). Environmental PAHs can be generated through natural and manmade sources. However, the major producer of PAHs nowadays come from anthropogenic activities such as emission of vehicle exhaust, wood and fossil fuel combustion, industrial waste discharge, and oil spills (Tham et al., 2008). Airborne particulate matter produced by various fuel combustion operations will absorb PAHs released

into the atmosphere. Then, they will subsequently be carried to varied distances depending on their aerosol sizes. For smaller size particles with $<1\mu\text{m}$ in size, they will travel further from their sources despite the wet and dry deposition processes. Larger airborne aerosols, on the other hand, will be deposited closer to their sources because they have significant gravitational settling velocities and are efficiently removed from the atmosphere by the precipitation process (Sheu et al., 1997). Therefore, it was suggested that the deposition of road dust with larger aerosol particles contain most of pollutant compounds with highest possibilities generated from the vehicular emissions.

There was one location-based study being conducted related to PAHs exposure with the proximity to high traffic volume areas. Based on in-depth study of PAHs build-up on urban roadways, a range of influential criteria were considered including highway distance, volume of traffic, and the roughness degree the road surfaces. The outcome highlights traffic volume as first which is the most influential factors of PAHs build up in urban roads. This study indicate that the traffic vehicles are the main sources of PAHs emission in urban area. They conclude from their study that by using the time variation of PAHs and PM_{10} , they able to reflect the basic operation time for their sampling site, a traffic tunnel. This indicate that the concentration of PAHs measure in the air can be used to estimate the traffic density in an area in correspondence to time basis (Liu et al., 2017). Another study stated that traffic policemen that occasionally working at road intersection being exposed to higher levels of PAHs compared to those on the roadsides and on campus. Vehicle exhaust emissions and road dust should be the major sources of pollution including PAHs at traffic intersections. They concluded that personnel might get exposed to higher concentration of PAHs, the longer they spending their time nearby to high traffic areas (Hu et al., 2007).

2.3 Categories of PAHs commonly identified

PAHs can be divided by referring to their molecular weights which are low, medium, and high. Each category of molecular weights possesses distinguished environmental fates. In general, low molecular weights, LMW PAHs have two to three rings with molecular weight from 152-178 g/mol e.g., fluorene and phenanthrene. Medium molecular weights, MMW PAHs have four rings and with molecular weights of 202 g/mol. This group includes fluoranthene and pyrene. The third category is high molecular weights, HMW PAHs. They contain five or more rings and have molecular weights ranging from 228 – 278 g/mol such as benzo[k]fluoranthene and indeno [1,2,3-c, d] pyrene (ATSDR, 1995). In the surrounding atmosphere, LWM PAHs are more typically detected as vapour in the troposphere, but they also, after the emission due to condensation, remain in the particulate phase in which predominated by the HMW PAHs (Kim et al., 2013).

Khan et al. (2015) carried out a study related to the distribution and origins of 16 PAHs found to be bonded with PM_{2.5} collected in a Malaysian semi-urban area over various seasons (Khan et al., 2015). The results showed that the high molecular weight HMW-PAHs (≥ 5 ring) are significantly prominent ($>70\%$) compared to the low molecular weight LMW-PAHs (≤ 4 ring) in PM_{2.5} (Khan et al., 2015). The diagnostic ratios suggested that the HMW-PAHs originated from fuel combustion sources. The main sources identified were gasoline combustion making up to 65%, diesel and heavy oil combustion at 19% and natural gas and coal burning with 15% (Khan et al., 2015). According to a recent study, the majority of

pyrogenic sources are HMW PAHs, whereas LMW PAHs dominated within petrogenic sources (Marris et al., 2020).

In addition, Jamhari et al. (2014) also carried out a detailed research to find out more about the source of atmospheric PAHs, their concentrations and distribution. The ambient air were determined at two sites within the Klang Valley for urban and industrial areas and one site outside the Klang Valley to represent semi-urban area (Jamhari et al., 2014). The outcomes revealed that 5-ring and 6-ring PAHs accounted for more than 80% of total PAHs (Jamhari et al., 2014). In comparison to LMW and MWH PAHs, these findings suggest that HMW PAHs are more prominent in the atmospheric particle phase.

2.4 Health effects from the environmental PAHs exposure

In environmental toxicology, PAHs are one of the harmful pollutants in the environments due to its possession of genotoxicity characteristic beside being carcinogenic, mutagenic, and teratogenic to multiple life forms. Because of the repeated exposure to PAHs, it might induce chronic and long-term health problems. Long-term exposure to PAHs like BaP has been linked to cancer in the gastrointestinal system (Diggs et al., 2011). PAH exposure can also cause targeted organ diseases such as development of cataracts, deterioration of liver function and kidney disease (ATSDR, 1995). International Agency for Research on Cancer (IARC) has categorised PAHs into four groups depending on their carcinogenicity level to human (Ghosal et al., 2016). Long term exposure to PAHs is found can cause tumour formation to several susceptible organs such as skin, lungs, colon, and women's breast (Rajpara et al., 2017) (Yu, 2002).

PAH exposure from road dust mainly occurs via three possible routes which are inhalation, dermal contact and ingestion (Burchiel, 2005). According to numerous studies, the harmful effects of PAHs on human health are influenced by the route of exposure. Unfortunately, nearly none of these investigations provided detailed information on the effects of oral PAH exposure in humans. Most would be referring to the inhalation exposure where they are occupationally exposed to PAHs, while in few of these studies the mechanism of exposure are through dermal contact (Kim et al., 2013). For most of the people, their own workplace had contribute to the majority of the exposure, i.e., traffic police might get exposed through the inhalation of road dust containing PAHs contaminants (Lee and Vu, 2010). Those with not workplace-based exposure might come from taking grilled and smoked food items on daily basis or a keen smoker for example (Lee and Vu, 2010). As for smoking people, 20–40 ng of BaP is similar to the intake of one cigarette (Skupinska et al., 2004). On the other hand, the diet from non-smoking persons may contributed up to 70% of PAHs exposure (Skupinska et al., 2004).

HMW PAHs commonly contributed to most of adverse health effects from the exposure of PAHs. PAHs with high toxicity characteristic potentially interfering with hormone system as they can cause negative effects on the reproduction and immune function of the body in addition to DNA damage being induced by PAHs exposure (John et al., 2009). The toxic effects of PAHs might also differ depending on factors like pre-existing health and age. Eye discomfort, vomiting, diarrhoea, disorientation, skin irritation, and inflammation are only a few instances of acute health impacts (Abdel-Shafy & Mansour, 2016). The degree for acute effects from PAHs exposure can be influence by the extent of exposure from PAHs

including the route of exposure, concentration, duration and its toxicity (Kim et al., 2013). These acute effects include impaired lung function in asthmatics and thrombotic effects in people affected by coronary heart disease. The most common health issues related to the short-term exposure of PAHs are eyes irritation and nausea while in long term exposure may cause cancer (Kim et al., 2013). Figure 2.0 shows a simple chart listing examples of health effects from PAHs exposure.

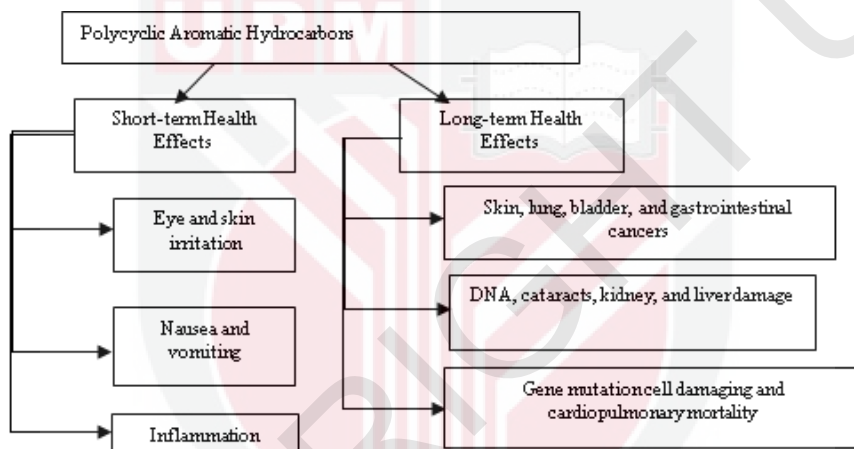


Figure 2.1: Diagram of health effects from PAHs exposure

2.5 Health risk assessment for PAHs

With PAHs known to be ubiquitous in the environment, controlling the level of exposure to PAHs is a concerning matter to public health as few PAHs compound have been classified as carcinogenic to humans (IARC, 2010). There is also evidence that exposure to PAHs would be associated with negative reproductive, neurodevelopmental, and cardiovascular effects (Choi et al., 2008; Edwards et al., 2010; Xu et al., 2010). PAH exposure also can cause development of cataracts in the eyes, liver and kidney deterioration,

reduced immunological function, and asthma-like symptoms (Abdel-Shafy & Mansour, 2016). Some PAHs are also known as mutagens, teratogens, and carcinogens; therefore, they are detrimental to human health and may cause severe complications for long term exposure. BaP as one of the PAH compound which classified as carcinogenic by IRIS USEPA has possibilities to cause direct skin irritants and skin sensitizers if being exposed (Rengarajan et al., 2015). To ensure that the concentration of PAHs in the environment within the permissible limit in which human body would be able to tolerate, the health risk assessment should be conducted. Few previous studies include specified calculations to assess the health risk of pollutants reside in the environment.

2.6 Legislation related to environmental PAHs exposure control

In terms of regulation, since mixture of PAHs in air would cause harmful effects to human health, government agencies should impose and regulating standards to control the emission of PAHs in the environment. In Malaysia, there is absence of specified standards on PAHs concentration in the ambient air. Nevertheless, the emission of PAHs from industrial activity is strictly being monitored to avoid hazardous chemical emission build-up in the environment.

For reference in Europe, due to its highest toxic equivalent factor, BaP as one of the PAHs compounds has become the target of their regulation to regulate detrimental parameters in ambient air. Besides, BaP has often been used as a reference compound that is proportionate to the total amount of PAHs in the environment (Kim *et al.*, 2013). They control the risk from PAHs exposure by regulating permissible annual average concentration

of PAHs which is at 1 ng m^{-3} in PM_{10} medium (Parliament EU Commission, 2005). Table 2.2 lists some of the existing PAH guidelines and regulations established by several international bodies.

Table 2.2 Standards and regulations related to PAHs in the environment.

Agency	Medium	Level	Comments	References
National Institute for Occupational Safety and Health Administration (US)	Air	0.2 mg m^{-3} for benzene-soluble coal tar pitch fraction	Permissible exposure limit (PEL) for benzene soluble fraction of coal tar volatiles.	NIOSH (2010)
National Institute for Occupational Safety and Health (US)	Air	0.1 mg m^{-3}	Recommended exposure limit (REL) for coal tar pitch volatile agents.	NIOSH (2010)
American Conference of Governmental Industrial Hygienists	Air	0.2 mg m^{-3}	Threshold limit value (TLV) for benzene-soluble coal tar pitch fraction.	ACGIH (2005)
Canadian Council of Ministers of the Environment	Soil	0.6 mg m^{-3}	Total potency equivalents for soil contaminated with coal tar volatiles.	CCME (2010)

U.S Environmental Protection Agency	Water	0.0001 mg L ⁻³	Maximum concentration level	USEPA
		0.0002 mg L ⁻³	(MCL) for benz[a]anthracene,	(2000)
		0.0003 mg L ⁻³	MCL for benzo[a]pyrene,	
		0.0004 mg L ⁻³	benzo[b]fluoranthene,	
		0.0002mg L ⁻³	benzo[k]fluoranthene, chrysene	
			MCL dibenz[a,h]anthracene	
			MCL for indenol[1,2,3-c,d]pyrene	
			MCL for benzo[a]pyrene,	
			benzo[b]fluoranthene,	
			benzo[k]fluoranthene, chrysene	

CHAPTER 3

METHODOLOGY

3.1 Data collection for studies on PAHs in road dust

The Scopus database was utilized to obtain previous studies. The search was limited to materials published between 2011 and 2021 that were written in English. To summarise the significant findings, many searches were conducted using the same phrases as those used in the primary literature. The term "PAHs in road dust" followed by 11 countries in SEA was used in the search engine to locate the related research paper. The term is applied to all studies involving road dust sampling and polycyclic aromatic hydrocarbons (PAHs). The studies were selected because they matched the following conditions:

- i. The study took samples of polycyclic aromatic hydrocarbon compounds in road dust and assessed them.
- ii. The research was conducted in countries in Southeast Asia (SEA).

The initial search using the keyword yielded a total of 194 papers spanning the years 2011 to 2021. Majority of the result entries were undertaken by PAHs in PM₁₀ and PM_{2.5} samples which did not fit the inclusion criteria for my review. The number of publications that can be included after screening as per the criteria was 9 papers. One was from Malaysia, one from Myanmar, and the rest were from Vietnam.

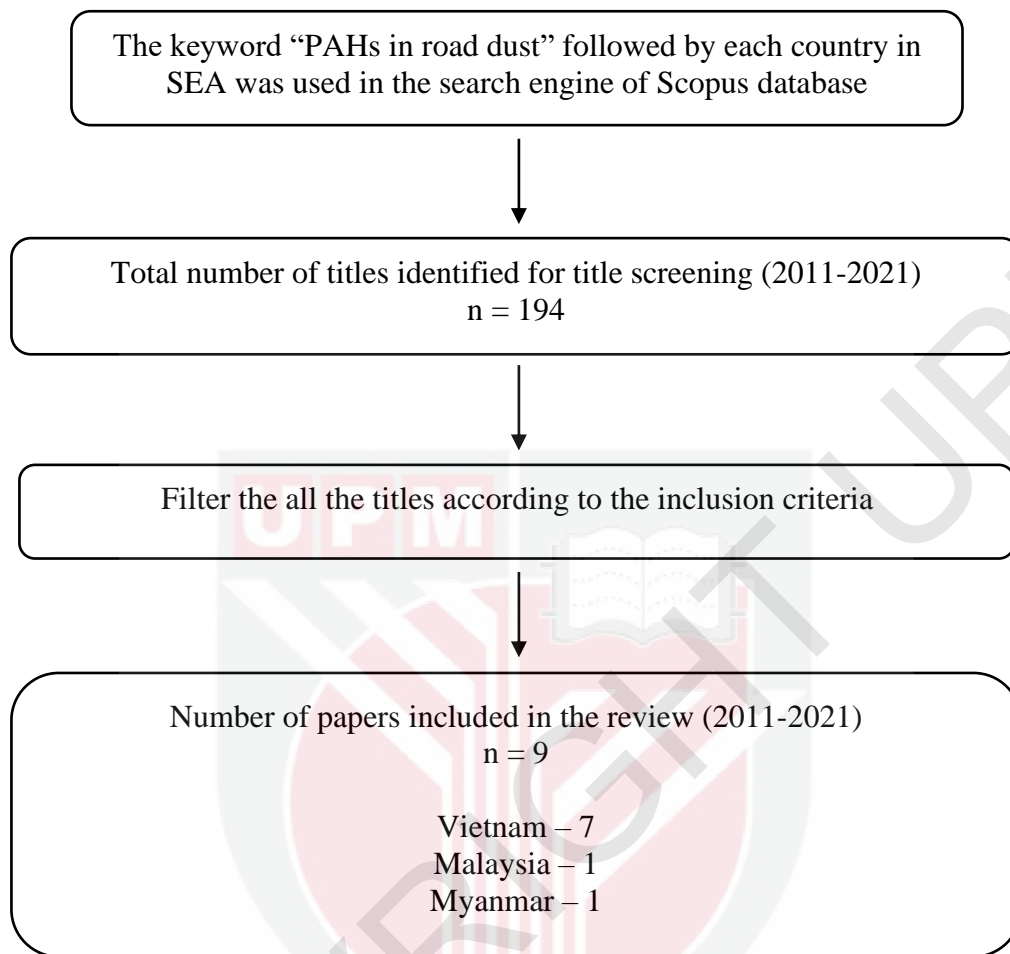


Figure 3.1: Flow Diagram of study selection process

The countries and locations (urban, industrial, sub-urban, and rural) where data collection was done, as well as the maximum PAHs concentrations in road dust, were identified and recorded. The number of PAHs tested in each study, as well as the completion of carcinogenic risk assessment, were also documented. These data were then used to calculate cancer risk that did not have any a complete carcinogenic health risk assessment.

3.2 Carcinogenic health risk assessment

To assimilate worst-case scenario, maximum concentrations were reported in the reviewed studies were used to assess the carcinogenic health risk from inhalation, dermal contact, and ingestion. In this study, the carcinogenic health risk assessment of PAHs in road dust samples will follow the guidance method suggested by Mon et al., (2020). This was done through the health risk assessment suggested by the U.S. Environmental Protection Agency (2011) to assess the Incremental Lifetime Cancer Risk (ILCR). The ILCR values for inhalation, dermal contact, and ingestion were then calculated by using Eq. 3.1, 3.2, and 3.3, respectively.

$$\text{ILCR}_{\text{inhalation}} = \frac{\text{CS} \times (\text{CSF}_{\text{inhalation}} \times \frac{\sqrt[3]{\text{BW}}}{70}) \times \text{IR}_{\text{inhalation}} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times \text{PEF}} \quad \text{Eq. 3.1}$$

$$\text{ILCR}_{\text{dermal}} = \frac{\text{CS} \times (\text{CSF}_{\text{dermal}} \times \frac{\sqrt[3]{\text{BW}}}{70}) \times \text{SA} \times \text{AF} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times 10^6} \quad \text{Eq. 3.2}$$

$$\text{ILCR}_{\text{ingestion}} = \frac{\text{CS} \times (\text{CSF}_{\text{ingestion}} \times \frac{\sqrt[3]{\text{BW}}}{70}) \times \text{IR}_{\text{ingestion}} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT} \times 10^6} \quad \text{Eq. 3.3}$$

In the equations, CS is the concentration of each PAHs compound equivalent to BaP in road dust (g/kg) from the preceding equations. This value was obtained by using carcinogenic potencies in relative to BaP; detail in Table 3.1 (Hester et al., 1998). $\text{CSF}_{\text{Inhalation}}$, $\text{CSF}_{\text{Dermal}}$, and $\text{CSF}_{\text{Ingestion}}$ are carcinogenic slope factors base on the carcinogenicity of BaP. Body weight and exposure frequency are abbreviated as BW and EF, respectively. The exposure duration is denoted by the character ED. The rate of inhalation is referred to as $\text{IR}_{\text{inhalation}}$. $\text{IR}_{\text{ingestion}}$ is the dust ingestion rate. The exposed skin area is referred to as SA. The dermal

adherence factor is abbreviated as AF. ABS stands for absorption fraction of the dermis. PEF stands for particle emission factor, while AT stands for average lifetime. Table 3.2 shows the values utilised for the parameters. The sum of the ILCRs associated with all exposure pathways was used to calculate the total risk.

Table 3.1 Carcinogenic potencies for related PAHs (Mon et al., 2020)

PAHs compound	Carcinogenic potencies
Phenantrene (PHE)	0.0005
Pyrene (PYR)	0.001
Fluorene (FLU)	0.05
Benzo[a]anthracene (BaA)	0.005
Benzo[b]fluoranthene (BbF)	0.15
Benzo[k]fluoranthene (BkF)	0.15
Benzo[a]pyrene (BaP)	1
Benzo[e]pyrene (BeP)	0.002
Benzo[ghi]perylene (BghiP)	0.02
Dibenzo[a,h]anthracene (DahA)	1.1
Indeno[1,2,3-cd]pyrene (IcdP)	0.1

Table 3.2 Determinants of exposure and variables for carcinogenic health risk assessment.

Exposure factors	Parameters (adults)	References
Carcinogenic Slope Factor, CSF inhalation (mg/kg/day)	3.85	Peng et al. (2011)
Carcinogenic Slope Factor, CSF dermal (mg/kg/day)	25	Peng et al. (2011)
Carcinogenic Slope Factor, CSF ingestion (mg/kg/day)	7.3	Peng et al. (2011)
Exposure frequency, EF (days/year)	365	Ferreira-Baptista & De Miguel (2005)
Exposure duration, ED (year)	24	USEPA (2011)
Body weight, BW (kg)	80	USEPA (2011)
Averaging time, AT (days)-(70 years×365 days/year)	25550	Ferreira-Baptista & De Miguel (2005)
Inhalation ratio, IR inhalation (m ³ /day)	20	W.Wang et al. (2011)
Particulate emission factor, PEF (m ³ /kg)	1.36x10 ⁹	USEPA (2011)
Exposed skin area, SA (cm ²)	5700	USEPA (2011)
Skin adherence factor, AF soil (mg/cm ²)	0.07	USEPA (2011)
Dermal adsorption fraction (ABS)	0.13	USEPA (2011)
Ingestion rate, IR ingestion (mg/day)	100	USEPA (2011)

CHAPTER 4

RESULTS

4.1 PAHs concentration reported from the studies

We found a total of 9 studies from Scopus database that reported the concentration of PAHs related to road dust samples in SEA countries. Out of 11 countries in SEA, only 3 countries had studies that fulfilled the reviewed criteria which were from Malaysia, Vietnam, and Myanmar. The number of PAHs in these studies examined, as well as any carcinogenic risk assessments given in these studies, were all scrutinised (Details in Table 4.1). The number of PAHs discovered in each investigation varied, although the majority were those specified by the USEPA. In general, PAH concentrations were found to be greater in urban road dust samples than in rural road dust samples. The concentration of PAHs in road dust samples for urban areas were generally in the range of 2800 ng g⁻¹ to 1043245.4 ng g⁻¹. Meanwhile, the concentration of PAHs in road dust samples in rural areas ranged from 650 ng g⁻¹ to 2900 ng g⁻¹. The highest concentration of PAHs in road dust samples in SEA was reported at 1043245.4 ng g⁻¹, that was collected from one residential area in Kuala Lumpur, Malaysia (Mohd Radzi et al., 2016). Whereas, the lowest concentration of PAHs was reported in Hai Phong, a sub-urban area in Vietnam with the maximum concentration of 520 ng g⁻¹ (Anh, Tran, et al., 2019).

Table 4.1 Occurrence of PAHs in road dust samples and their associated carcinogenic health risk.

Countries	Areas	PAHs Compounds	Maximum reported concentration, ng g ⁻¹	Carcinogenic health risk assessment, **ILCR values	References
Malaysia*	Industrial,	^a 16 PAHs	13581.1,	<u>Industrial</u> = 1.99×10^{-4}	Mohd Radzi et al. (2016)
	Commercial,		329299.1,	<u>Commercial</u> = 4.67×10^{-2}	
	Residential		1043245.4	<u>Residential</u> = 1.56×10^{-2}	
Myanmar	Urban,	^b 19 PAHs	4100,	<u>Urban</u> = 2.4×10^{-4}	Mon et al. (2020)
	Rural		1010	<u>Rural</u> = 5.4×10^{-5}	
Vietnam*	Urban,	^b 19 PAHs	7200,	<u>Urban</u> = 3.04×10^{-4}	Anh, Tran, et al. (2019)
	Industrial,		5800,	<u>Industrial</u> = 3.35×10^{-4}	
	Sub-urban,		520,	<u>Sub-urban</u> = 3.02×10^{-5}	
	Rural		1800.	<u>Rural</u> = 1.65×10^{-4}	

Vietnam	Urban,	^c 24 PAHs	5500,	<u>Urban</u> = 6.7×10^{-4}	Ball & Truskewycz, (2013)
	Rural		1400	<u>Rural</u> = 2.31×10^{-4}	
Vietnam	Urban,	^b 19 PAHs	3900,	<u>Urban</u> = 9.2×10^{-4}	Mon et al. (2020)
	Rural		800	<u>Rural</u> = 1.7×10^{-4}	
Vietnam	Urban	^a 16 PAHs	7500	1.0×10^{-4}	Trung et al. (2021)
Vietnam	Urban,	^b 19 PAHs,	5000,	<u>Urban</u> = 3.1×10^{-7}	Anh, Minh, et al. (2019)
	Industrial		9300,	<u>Industrial</u> = 3.2×10^{-7}	
	Sub-urban		1100,	<u>Sub-Urban</u> = 8.1×10^{-8}	
	Rural		2200	<u>Rural</u> = 6.0×10^{-8}	
Vietnam	Urban,	^b 19 PAHs	2800, 5700	<u>Urban</u> = 3.8×10^{-6}	Anh, Tue, et al. (2019)
	Rural			<u>Rural</u> = 8.8×10^{-6}	

Vietnam	Urban	^c 24 PAHs	4700	2.8×10^{-3}	Tuyen, Tue, Takahashi, et al. (2014)
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(*) : no carcinogenic health risk reported in the study.

(**) : Sum of ILCR via inhalation, ingestion, and dermal contact routes of exposure.

^a : Naphthalene, Acenaphthylene, Acenaphthene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benz[a]anthracene, Chrysene, Fluorene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenz[a,h]anthracene, and indeno[1,2,3- cd]pyrene. Benzo[g,h,i]perylene.

^b : ^a with additional compounds of benzo[c]phenanthrene, benzo[e]pyrene, benzo[j]fluoranthene.

^c : ^a with additional compounds of benzo[c]phenanthrene, 7,12-dimethylbenz[a]anthracene, 3-methylcholanthrene, dibenzo[a,h]pyrene, dibenzo[a,i]pyrene, dibenzo[a,l]pyrene, cyclopenta[c,d]pyrene, benzo[c]phenanthrene.

4.2 Carcinogenic health risk assessment

Carcinogenic risk due to inhalation, ingestion, and skin contact of PAHs in road dust samples are summarised in Table 4.2. Most of the papers had reported the carcinogenic health risk except two, one from Malaysia and one from Vietnam (Anh, Tran, et al., 2019; Mohd Radzi et al., 2016). Subsequently, total ILCR was calculated based on the exposure of PAHs in road dust samples via inhalation, dermal contact, and ingestion from these two papers. The carcinogenic health risk was assessed using method suggested by Mon et al. (2020). The total ILCR values for inhalation, dermal and ingestion exposure routes in urban areas from these studies ranged from 3.1×10^{-7} to 4.67×10^{-2} . In rural areas, the carcinogenic risk ranged from 6.0×10^{-8} to 1.7×10^{-4} . The highest potential of carcinogenic risk from PAHs in road dust exposure was observed in one of the study by Mohd Radzi et al. (2016) in a commercial area near the city of Kuala Lumpur with an estimated total ILCR of 4.67×10^{-2} .

Table 4.2 Carcinogenic potencies and BAP-EQ calculations for *NR studies.

PAHs compound	Carcinogenic potencies	Malaysia Mohd Radzi et al. (2016)			Vietnam Anh, Tran, et al. (2019)			
		Kuala Lumpur (Urban)			Urban (Hanoi)	Industrial (Thai Nguyen)	Sub-urban (Hai Phong)	Rural (Bac Giang)
		Industrial	Commercial	Residential				
Phenantrene (PHE)	0.0005	0.6257	0.9506	0.73905	0.115	0.12	0.0095	0.0275
Fluorene (FLU)	0.05	26.375	8.59	7.33	1.25	0.9	0	0.265
Pyrene (PYR)	0.001	0.9165	6.6844	6.5605	0.56	0.43	0.034	0.11
Benzo[a]anthracene (BaA)	0.005	0.8755	21.143	21.5055	1.4	0.95	0	0.48
Chrysene (CHR)	0.03	31.398	594.615	533.466	15.3	8.4	0	3.3
Benzo[b]fluoranthene (BbF)	0.15	70.14	3149.805	2542.425	90	61.5	5.4	30
Benzo[k]fluoranthene (BkF)	0.15	38.175	1200.615	1270.515	94.5	64.5	5.7	31.5
Benzo[e]pyrene (BeP)	0.002	N/A	N/A	N/A	2.2	1.26	0.28	0.44
Benzo[a]pyrene (BaP)	1	151.8	29023.3	8234.4	360	480	43	240
Indeno[1,2,3-cd]pyrene	0.1	136.05	19085.16	8950.31	0	7	1.8	0

(IcdP)								
Dibenzo[a,h]anthracene								
(DahA)	1.1	124.3	34117.27	7412.68	N/A	N/A	N/A	1.1
Benzo[ghi]perylene (BghiP)	0.02	0.71	222.552	118.942	4	2.4	0.3	0.98
Value of BAP-EQ (unitless)		581.3657	87430.685	29098.87305	569.325	627.46	56.5235	308.2025

Table 4.3 Estimated ILCR values

Conc. (BaP-EQ)	Malaysia Mohd Radzi et al. (2016)			Vietnam Anh, Tran, et al. (2019)			
	Kuala Lumpur (Urban)			Urban (Hanoi)	Industrial	Sub-urban	Rural (Bac Giang)
	Industrial	Commercial	Residential		(Thai Nguyen)	(Hai Phong)	
	581.3657	87430.685	29098.87305	569.325	627.46	56.5235	308.2025
ILCRs - Inhalation	8.6810-09	1.31E-06	4.35E-07	8.05E-09	9.37E-09	8.44E-10	4.60E-09
ILCRs - Dermal	1.99E-04	2.99E-02	9.95E-03	1.95E-04	2.15E-04	1.93E-05	1.05E-04
ILCRs - Ingestion	1.12E-04	1.68E-02	5.60E-03	1.10E-04	1.21E-04	1.09E-05	5.94E-05
ILCRs - Total	1.99E-04	4.67E-02	1.56E-02	3.04E-04	3.35E-04	3.02E-05	1.65E-04

CHAPTER 5

DISCUSSION

5.1 Concentration of PAHs in road dust samples

The study by Mohd Radzi et al. (2016) indicated that the highest concentration of PAHs in road dust samples was obtained from a residential area in Kuala Lumpur, Malaysia. The possible reason was due to the selected residential area were located near many major roads and highways which occasionally have heavy daily traffic. The researchers did mention that the major source of PAHs in road dust samples collected was from vehicular emissions by using diagnostic ratio. Meanwhile, the lowest concentration of PAHs was found in Hai Phong, a sub-urban area of Hanoi, the capital of Vietnam, due to having low traffic density which similar to those seen in rural areas (Anh, Tran, et al., 2019). The concentration of PAHs in road dust samples in SEA countries were found to be higher in urban areas which commonly associated with high traffic density compared to sub-urban and rural areas.

The difference for the observed PAHs in road dust samples from cities may also be influenced by other factors depending on the sampling locations. In Yangon, the largest city in Myanmar, apart from heavy traffic on the roads, the commercial activities of burning dried vegetation and various type of food using charcoal or

wood stoves also contributed to generation of PAHs in road dust (Mon et al., 2020). Besides, in city of Kuala Lumpur, the main source of PAHs in road dust sample comes from vehicular emission as the roads in Kuala Lumpur is commonly preoccupied with heavy traffic congestion every day especially during peak hours where lots of vehicles moving to and from this capital city of Malaysia. As some of industrial areas had been built closer to the main roads in Kuala Lumpur, their emissions also might contribute to PAHs build in road dust samples collected. On the other hand, in Hanoi, the capital city of Vietnam, the PAHs in road dust also mainly contributed from vehicular emission in common traffic congestion. The key difference shows that their ongoing research on PAHs in road dust significantly helps to improve the condition in a way that it influence the authorities' activities to perform critical selection in determining the substance used to improve road surface quality, revising road sweeping method used and prevention of harmful activities that may lead to the increase of PAHs emission such as open burning in roadside communities (Hwang et al., 2019). As all these sampling sites in determined in this study review located near to main roads, it was indicated that the important source of PAHs from road dust comes from the pyrogenic emissions of diesel vehicles.

5.2 Potential carcinogenic health risk of PAHs

In conducting carcinogenic risk assessment, an ILCR value between 10^{-6} and 10^{-4} indicates potential cancer risk, while ILCR value greater than 10^{-4} indicates high potential health risk and ILCR value 10^{-6} or smaller indicates acceptable degree for

carcinogenic risk (U.S EPA, 2005). In this study, total ILCR value means sum of ILCR from inhalation, dermal and ingestion whereas ILCR value for single route of exposure was described accordingly.

Cancer risk from dermal contact and ingestion were found to be significant in estimated ILCR calculations with values ranging from 10^{-2} to 10^{-5} which lie within high potential cancer risk. While ILCR values from inhalation ranged from 10^{-6} until 10^{-10} indicating an acceptable cancer risk. These results were found to be similar with other reviewed studies (Huu Tuyen et al., 2014; Anh, Minh, et al., 2019; Trung et al., 2021), the range of values for dermal and ingestion were found to be higher than the ILCR values from inhalation. In a study by Mon et al. (2020), dermal exposure was found to contribute the most in the sum of ILCR value (inhalation, dermal, and ingestion) followed by ingestion pathway and the rest was inhalation exposure route at 1% or less. The contribution of both dermal and ingestion pathways certainly play an important role compared to road dust inhalation as reported elsewhere (Chiang et al., 2009; Peng et al., 2011; Trung et al., 2021). Therefore, the carcinogenic risk determined from PAHs exposure in road dust samples from inhalation pathway were found to be almost negligible compared to other two pathways.

In addition, the commercial area located in Kuala Lumpur, Malaysia was reported to have the highest total ILCR value from all exposure pathways at 4.67×10^{-2} . This indicate that the concentration of PAHs exposure from road dust in the selected area has exceeded the acceptable cancer risk level and may initiate

substantial carcinogenic health risk. The researchers did mention that the sampling location for that particular study site within major roads with occasional traffic congestions, where it can contribute to continuous build-up of PAHs pollutants in the air and road dust. Besides the total ILCR values in the current study was calculated by using maximum reported concentration of PAHs to generate worst case scenario, therefore actions must be taken beforehand to mitigate the adverse health impacts expected from higher PAHs exposure.

Based on the ILCR calculations from these studies, it is indicated that the communities in urban areas are most likely to be exposed to high potential carcinogenic risk from PAHs in road dust especially via ingestion and dermal contact pathways. The occurrence of PAHs in SEA indicates that there is significant potential hazard from the exposure of PAHs in road dust. Nevertheless, the chronic adverse health effects from PAHs exposure will only start to develop through prolonged exposure. It should be noted that this potential carcinogenic risk is estimated in a condition where the absorption rate was assumed to be at 100% via all possible routes of exposure. In addition, results on carcinogenic risk assessment in one of the studies reported that the exposure to smaller dust particles in road dust was found to generate higher potential carcinogenic risk compared to the exposure to the larger size particles. (Tuyen et al., 2014). Therefore, the health impact from road dust exposure varies depending on their particle size and distributions.

CHAPTER 6

CONCLUSION

6.1 Conclusion

PAHs concentration in road dust were limited to these three Southeast Asian's countries; Malaysia, Vietnam, and Myanmar reported from 2011 up to 2021. Maximum concentration of PAHs was considered to generate worst case scenario in order to gauge the level of highest potential risk that would incur to human health. It was found that the PAHs concentration in road dust from urban areas were higher than from the rural areas due to the different level of traffic density in both places. In addition, the carcinogenic health risk assessment of PAHs from road dust in SEA also has been determined. The ILCR values indicate that exposure to PAHs from road dust posed low carcinogenic risk to people living in rural areas but high levels of carcinogenic risk to people living in urban areas for these three countries in Southeast Asia, according to the evaluated carcinogenic health risk estimates. Nevertheless, the exposure of PAHs in road dust samples from ingestion and dermal contact were found to have significant cancer risk compared to inhalation.

6.2 Future recommendations

As we find occurrence of PAHs in road dust may pose certain risk to human health, hazard warning on its potential adverse effects to communities and initiating any possible preventive measures are necessary. The existence of PAHs in air needs more attention by increasing the awareness on the pollutants' existence and spread the knowledge on potential health impacts from long-term exposure of PAHs. Although several past environmental monitoring studies have been conducted in SEA regions, studies on PAH levels in road dust samples remain limited and insufficient evidence to prove that PAHs can directly incur harm despite being persistent in the environment. Database on road dust PAHs should not be exhaustive and there are more possible locations in SEA that need attention to conduct the study on road dust PAHs for us to keep improving the management of air quality.

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