

# Landfill leachate as a source of polycyclic aromatic hydrocarbons (PAHs) to Malaysian waters

Mohamad Pauzi ZAKARIA\*, Kho Hiaw GEIK, Wong Yoon LEE and Razahidi HAYET

*Department of Environmental Sciences, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor*

*\*E-mail: mpauzi@fsas.upm.edu.my*

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**Abstract**—Organic chemicals of environmental concern are those with known or potentially deleterious effects on natural resources and humans. These compounds are referred to as micro-organic pollutants. Polycyclic aromatic hydrocarbons (PAHs) are one of the most important classes of anthropogenic micro-organic pollutants that have long been the interest of environmental chemists. This concern arises primarily from the fact that a small fraction of the PAHs generated and released to environment has been shown to be carcinogenic and mutagenic to mammals. PAHs have also been reported to disrupt endocrine system in humans. Landfilling and disposing of wastes in open dumpsites have been and is expected to remain the most common method for the disposal of municipal solid wastes in Malaysia. In 1990, there were about 230 official municipal dump sites in Malaysia. In 1994, the amount of wastes generated and collected in Kuala Lumpur was around 3 million kg/day. In the year 2000, the amount of wastes generated has increased to about 7.9 million kg/day and is expected to increase to more than 11 million kg/day in 2010. This study focused on 2 landfill sites in Malaysia: Taman Beringin and Ulu Maasop landfills. The Taman Beringin landfill is located in the city of Kuala Lumpur (representing an urban area) while the Ulu Maasop landfill is located in Negeri Sembilan (representing a rural area). Taman Beringin landfill receives a mixture of municipal, commercial, agricultural, recreational, domestic and mixed industrial wastes originating from households and industrial premises while the Ulu Maasop landfill receives mostly domestic waste. Leachate from both landfills are directly discharged into the adjacent rivers. The objective of this study is to understand the composition and sources of compound-specific PAHs in the landfill leachates and to understand their transport pathways. Leachate, river water and sediment samples were collected at the landfill sites in 2003. The leachate samples were subjected to liquid-liquid extraction using a mixture of 1:1 toluene:methanol and re-extracted twice with hexane. Water samples were filtered and the filtrate containing particulate matter were freeze-dried and soxhlet-extracted. Sediment samples were freeze-dried and soxhlet-extracted with dichloromethane. All the extracts were purified and fractionated by a method described by Zakaria et al., 2002. PAHs were analyzed by gas chromatography mass spectrometry (GC-MS). This is the first report of compound-specific PAHs in landfill leachates in Malaysia. High concentrations of PAHs were detected in the leachate, river particulate and sediment samples for both landfills sites. Total PAHs concentrations in the Taman Beringin leachate, river particulates and sediments ranged from 9.9–575.6 ng/g dry wt, 3.9–5.0 ng/g, and  $1.5 \times 10^5$  ng/g, respectively while PAHs concentrations for the Ulu Maasop leachate, river particulates and sediments range from 11.8–2836 ng/g dry wt., 3783–5904 ng/g, and  $1.31 \times 10^4$ – $3.06 \times 10^5$  ng/g, respectively. River-borne particulate matter is an important carrier of land-based contaminants to the ocean. Particulate matter adsorbs various organic and inorganic pollutants such as PAHs and heavy metals and carries these contaminants along with them and are finally deposited in coastal and open oceans. Landfill sites in Malaysia are normally situated near major towns and rivers. Direct discharge of leachates to these rivers will enhance the transport of organic contaminants such as PAHs to the coastal environments and open oceans. The study has demonstrated that PAHs in leachate pose potential PAH pollution in Malaysian waters. Additional inputs of PAHs from landfill leachate must therefore be controlled to preserve the coastal ecosystems in Malaysia.

**Key words:** landfill, leachates, polycyclic aromatic hydrocarbons, transport pathway, coastal pollution

## Introduction

Organic chemicals of environmental concern are those with known or potentially deleterious effects on natural resources population and on human beings. These compounds are referred to micro-organic pollutants. Many processes and conditions of modern societies introduce micro-organic pollutants to aquatic ecosystems such as production, use and

disposal of synthetic organic chemicals. Many of these chemicals are anthropogenic in that prior to synthesis by humans, these chemicals were not present; these are often termed xenobiotic compounds. Examples of some of these commonly cited xenobiotics are polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides such as DDT or chlordane, tetrachloroethylene, phenols and xylenes. Characteristics of these micro-organic pollutants of environmental concern are persistence, high mobility and possess short-

term and long-term adverse biological impact. These compounds enter the aquatic ecosystems by various means: accidental spill, effluents releases, natural release (e.g. environmental seeps), release to atmosphere and subsequent direct deposition to bodies of surface water, and runoff of dispersed releases (e.g. pesticides sprayed on crops, or road washing of oil from automobiles crankcase dripping).

Polycyclic aromatic hydrocarbons (PAHs) are a class of micro-organic pollutants that has long been of interest in the fields of organic chemistry. PAHs are composed of two or more fused aromatic (benzene) rings and primary environmental concern are mobile compounds ranging in molecular weight from naphthalene ( $C_{10}H_8$ , M.W. 128.16) to coronene ( $C_{24}H_{12}$ , M.W. 300.36). Within this range is an extremely large number of PAHs differing in the number and positions of aromatic rings and in the number, chemistry and position of substituents on the basic ring system (Neff 1979).

There has been a growing concern in recent years regarding possible harmful effects to man and other living organisms of PAHs released into the environment as a consequence of man's activities. This concern arises primarily from the fact that a small fraction of the PAHs generated and released to environment by human activities has been shown to be carcinogenic, mutagenic and tumorigenic to mammals. The presence of PAHs in water, aquatic sediments and organisms has been recognized for more than 20 years. Recently, PAHs have been reported to disrupt endocrine system (Clemons et al. 1998).

Physical and chemical characteristics of PAHs vary in a more or less regular fashion with molecular weight. Resistance to oxidation and reduction tends to decrease with increasing molecular weight. Vapor pressure and aqueous solubility decrease almost logarithmically with increasing molecular weight. As a consequence of this difference, PAHs of different molecular weight vary substantially in their behavior and distribution in the environment and their effects on biological systems. Two molecular weight classes of PAHs can be distinguished on the basis of physical, chemical and biological properties. These are the lower molecular weight 2–3 ring aromatics (naphthalenes, fluorenes, phenanthrenes and anthracenes) and the higher molecular weight 4–7 ring aromatics (chrysene and coronene). The higher molecular weight PAHs has significant acute toxicity to aquatic organisms, whereas the lower molecular weight PAHs do not. On the other hand, all of the 20–30 proven PAHs carcinogens are in the high molecular weight PAHs group (Neff 1979).

There are two types of anthropogenic sources of PAHs: petrogenic and pyrogenic sources. Petrogenic PAHs are derived from petrol and petroleum products such as crude oil, crankcase oil and grease. Pyrogenic PAHs are byproducts of incomplete combustion or pyrolysis of organic materials during both natural events and human activities. These include forest and grass fires, burning of fossil fuels and petroleum

products during industrial production and operations of machinery.

Landfilling and depositing of solid wastes in open dumps have been the most common methods for the disposal of municipal solid wastes in Malaysia. In 1990, there were about 230 official municipal dumping sites in Malaysia. 82% of the landfill sites were categorized as controlled tipping, 14% as crude open dumps and only 4% have been categorized as sanitary landfill. In 1994, the amount of waste generated and collected in Kuala Lumpur was around 3 million kg/day. In 1998, the amount of waste generated has increased to about 3.5 million kg/day and is expected to be around 7.9 million kg/day by the year 2000, 9 million kg/day in 2005, 11 million kg/day in 2010 and by 2015, the amount of solid waste generated in the city would be around 14.3 million kg/day (Department of Environment, Malaysia 1999).

Volume of leachates generated in a landfill site depend on many factors such as the amount of solid waste generated, availability of water, landfill surface condition, refuse condition and underlying soil condition. The migration of leachates in soil and water system are influenced by many physical, chemical and biological mechanisms such as diffusion and dispersion, dilution, straining, precipitation and dissolution, adsorption and desorption, complexation, ion exchange, redox and microbial activity (James Lu et al. 1985). Leachates pollution from landfills is the result of a mass transfer process. Waste entering the landfill reactor undergoes physical, chemical and biological transformations which are controlled by such factors as water input fluxes. If we assume that landfill leachate as a reactor, three physical phases are present: the solid phase (waste), the liquid phase (leachates) and the gas phase. The liquid phase is enriched by solubilized or suspended organic matter and inorganic ions from the solid phase. The gas phase consists of carbon, which prevalently in the form of  $CO_2$  and  $CH_4$  (Christensen et al., 1994).

The objective of this study is to understand the composition and sources of compound-specific PAHs in the landfill leachates and the transport pathways of landfill leachates to receiving water. The determinations of PAHs in landfill leachates are necessary due to increasing importance of landfills as waste repository to Malaysian society. This study will give an initial indication of types and concentration of compound-specific PAHs in landfill leachates and understand their transport pathways that contribute to environmental contamination.

## Materials and Methods

Sampling locations for this study is shown in Fig. 1. Leachates samples as source material were obtained from 2 landfill sites in Peninsular Malaysia: Ulu Maasop landfill,

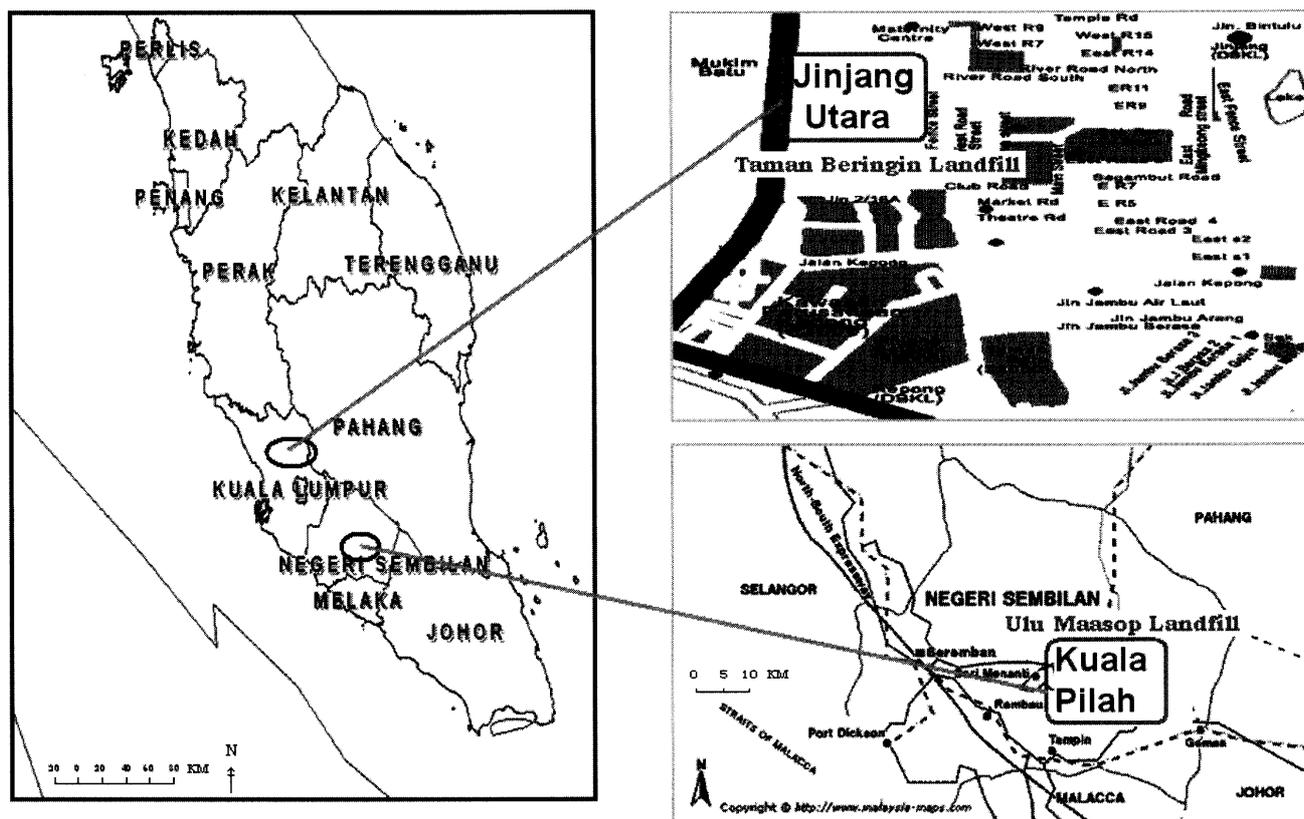


Fig. 1. Sampling locations for the study.

Kuala Pilah, Negeri Sembilan (rural area) and Taman Beringin landfill, Selangor (urban area). Water samples were taken from rivers or streams close to landfill sites. Groundwater samples were taken from as boreholes located in the perimeter of the landfill site. The river water and groundwater samples were collected using a pre-cleaned stainless steel bucket and place in previously cleaned 4-L amber bottles. Leachates samples were collected with a stainless steel bucket and stored in 500 mL amber bottles. The samples were transported to the laboratory in ice and immediately filtered through prebaked glass fiber filters (47 mm Ø Whatman GF/F) (pore size, 0.7  $\mu\text{m}$ ) within 18 hours. Glass fiber filters containing particles and filtrates are stored in a refrigerator ( $-18^{\circ}\text{C}$ ) until further analysis.

The samples were purified and fractionated similar to the method described by Zakaria et al. (2000). Briefly, organic solvents were distilled in glass before use and glassware was rinsed successively with methanol, acetone and n-hexane and muffled at  $380\text{--}400^{\circ}\text{C}$  for 4 hours to get rid of organic contaminants. A 60–200 mesh silica gel (lot no. 06016PS) was purchased from Aldrich Chemical Company, Milwaukee, Wisconsin, USA and baked at  $380^{\circ}\text{C}$  for 3 hours, cooled and activated at  $200^{\circ}\text{C}$  overnight, and deactivated with 5% (w/w) of distilled water.

Leachates and water samples were filtered within 18 hours. The filtered particulates were Soxhlet extracted for 10

hours and the filtrate was extracted with liquid-liquid extraction. Elemental sulfur in the extract was removed with activated copper. An appropriate volume (100  $\mu\text{L}$ ) of PAH surrogate internal standard (1,4-dichlorobenzenes- $\text{d}_4$ , naphthalene- $\text{d}_8$ , acenaphthene- $\text{d}_{10}$ , phenanthrene- $\text{d}_{10}$ , chrysene- $\text{d}_{12}$ , perylene- $\text{d}_{12}$ ) was added to the sample extracts. Each sample was roto-evaporated to near dryness (2–4 mL) using Buchi RE111 Rotary Evaporator, Switzerland. The extracts were eluted with 20 mL of 3:1 hexane/DCM through a 5%  $\text{H}_2\text{O}$ -deactivated silica gel column chromatography to get the hydrocarbons fraction as well as to remove other polar components. The hydrocarbon fraction was further fractionated using a fully activated silica gel column chromatography. PAHs with 3–7 benzene rings were eluted with 14 mL of 3:1 hexane/DCM. PAHs fraction was evaporated to approximately 1 mL, transferred to 1.5 mL amber ampoule and evaporated to near dryness under a gentle stream of nitrogen and re-dissolved into an appropriate volume (100  $\mu\text{L}$ ) of iso-octane containing p-terphenyl- $\text{d}_{14}$  as an internal injection standard (IISTD). PAHs was analyzed by GC-MS using a 30 m fused silica column (HP-5MS) install in a gas chromatograph (HP6890) interfaced with Hewlett Packard 5973A quadrupole mass selective detector (SIM mode), using helium as the carrier gas on a constant pressure at 60 kg/cm<sup>2</sup>.

PAHs were monitored for dibenzothiophene ( $m/z=180$ ), phenanthrene ( $m/z=178$ ), anthracene ( $m/z=178$ ), 2-methyl-

anthracene ( $m/z=192$ ), 2-methylphenanthrene ( $m/z=192$ ), fluoranthene ( $m/z=202$ ), pyrene ( $m/z=202$ ), 1-methylpyrene ( $m/z=216$ ), benz(a)anthracene ( $m/z=278$ ), chrysene ( $m/z=228$ ), benzo(k)fluoranthene ( $m/z=252$ ), benzo(e)pyrene ( $m/z=252$ ), benzo(a)pyrene ( $m/z=252$ ), benzo(e)acephenanthrylene ( $m/z=252$ ) and dibenz(a,h)anthracene ( $m/z=278$ ). Individual PAHs was quantified by comparing the peak area of the selected ion with the peak area of the IISTD.

## Results and Discussion

Table 1 shows the PAHs concentrations of leachates, groundwater and river water samples in this study. As a comparison, Table 1 also includes PAHs concentrations from source materials and environmental samples from the previous studies (Zakaria et al. 2000 and 2002, Wong et al. 2004). The results for the Table 1 are expressed graphically in Fig. 2. From Fig. 2(a), it can be seen that PAHs in leachates are distributed in all molecular weight range (i.e. low and high molecular weight PAHs). Phenanthrene is the most abundant (575.6 ng/g dry wt.) relative to other PAHs compounds in the samples. This could be attributed to the fresh input of PAHs to the landfills such as illegal dumping of waste petroleum products. Lower molecular weight PAHs are more volatile and more bioavailability than the higher molecular weight PAHs. Therefore, the presence of phenanthrene in high concentration was an indicative of the fresh input. The same situation is true for the groundwater and river water samples in that phenanthrene are the abundant. Fresh input of a single diffuse source could have attributed to the high abundance of phenanthrene.

However, the presence of higher molecular weight PAHs indicative the high persistence nature of the PAHs to evaporation and biodegradation within the landfills. High molecular weight PAHs are less volatile and less bioavailability. Of particular concern are their toxicological characteristics and their ability to accumulate in organic-rich particulate matter and biological tissues, such as fish and other organisms by direct uptake from the water or through the food chain. It is because higher molecular weight PAHs are less solubility and hard to biodegrade once enter the biological tissues. All samples (Fig. 2(a) to 2(d)) show the presence of benzo(k)fluoranthene, benzo(e)pyrene and benzo(a)pyrene in relatively high concentrations. These compounds are known carcinogen and mutagen that can disrupt the endocrine system in human body.

As we can see from the Fig. 2(a) to 2(d), the PAHs profile of the leachates as source material resembled those of the groundwater, upstream and downstream river water. Therefore, the PAHs could have been attributed to the landfill leachates. Additional evidence that the rivers and groundwater may have received the leachates from the landfills is the

similarities in the L/H and MP/P ratios. For instance, MP/P ratios for leachates, groundwater, upstream and downstream river waters are 0.29, 0.15, 0.14 and 0.13 respectively (Fig. 3) (s.d.=0.08). Meanwhile, the L/H ratio are 2.71, 2.11, 1.96 and 1.64 respectively (s.d.=0.45). In addition, Fig. 2(a) to 2(d) shows that the PAHs profiles in groundwater, upstream and downstream river water are very similar to the PAHs profiles in landfill leachates. This provides the best evidence that landfill leachates could be directly transported to the adjacent receiving waters.

Furthermore, PAHs profiles in this study are very different than the PAHs profiles in the previous studies (Fig. 2). This indicate that PAHs sources for landfill leachates do not receive the input from fresh and used 2T oil, used crankcase oil, asphalt and street dust. In other words, PAHs signature for landfill leachates in this study is very unique. The question is where the origin of PAHs in the landfill leachates does. We have postulated that the source of PAHs in landfill leachates might have been attributed to the incomplete combustion or pyrolysis of solid wastes and organic materials and incorporated into the landfill leachates by rainwater. In addition, atmospheric deposition of combustion derived PAHs through long-range atmospheric transport of soot particles can contribute to the pyrogenic origin of PAHs in landfill leachates. This evidence is clearly shown in the very low MP/P value, 0.29 of the landfill leachates (Table 1 and Fig. 3). The relative abundance of methylphenanthrene/phenanthrene (MP/P) ratio has been used to distinguish petrogenic and pyrogenic sources of PAHs. MP/P ratios measured in combustion mixture are generally  $<1$ , whereas unburned fossil PAHs mixtures typically display a range of value from 2 to 6 (Youngblood and Blumer 1975, Garrigues et al. 1995).

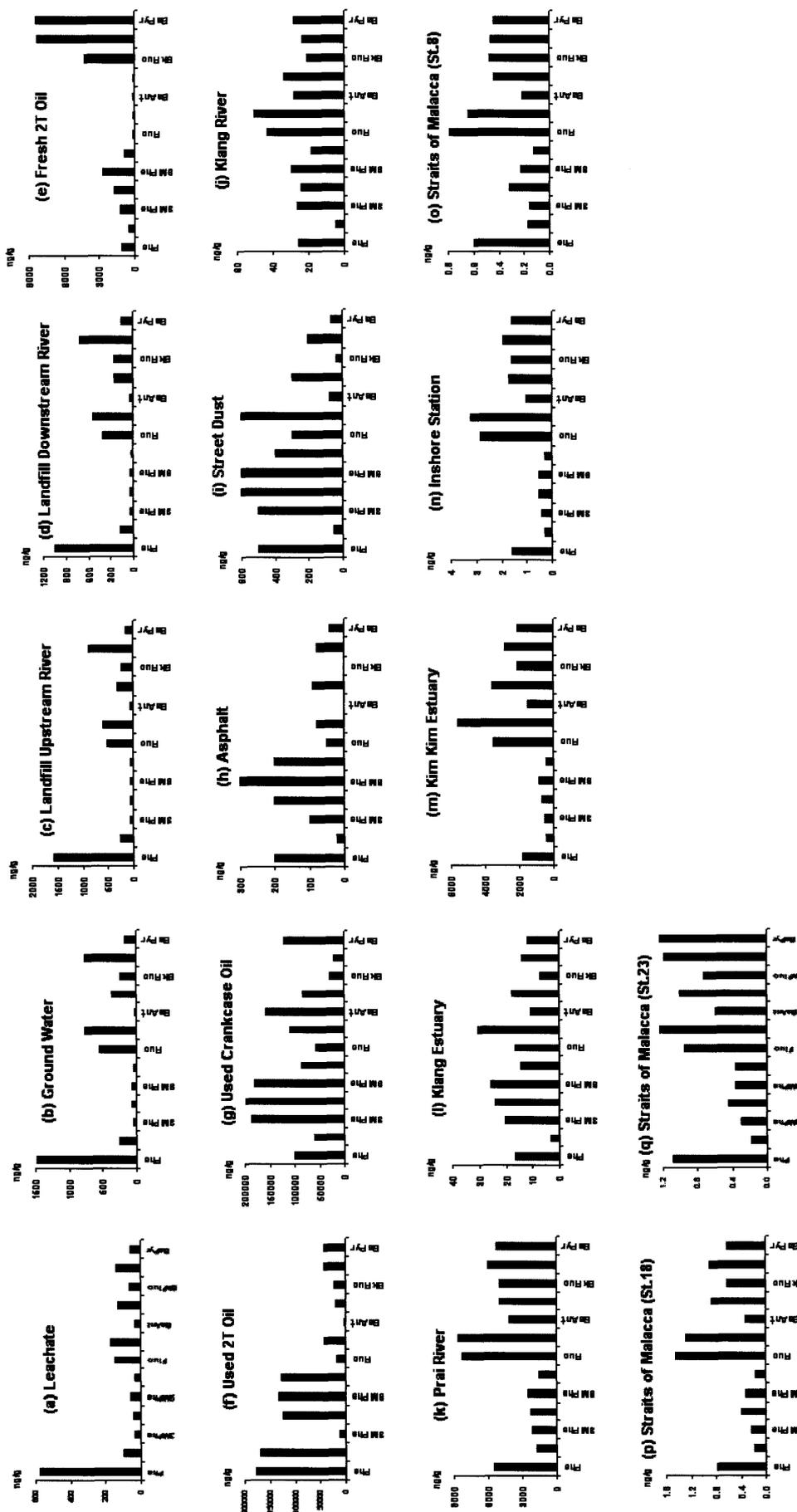
The impact of the leachates to receiving waters outside the area far away from landfills is minimum. This is clearly shown in the PAHs composition, PAHs profiles and MP/P ratios of the samples taken outside the vicinity of the landfills (Table 1 and Fig. 3). Nevertheless, the most landfill leachates as source material be released to the immediate water bodies, care has to be taken in that many human populations use the river water for their living. Also, pyrogenic PAHs in the leachates consists of higher molecular weight PAHs which are more persistent. Long-term chronic effect of using such waters for humans needs pose a significance health risk.

Another striking feature occurred from this study is that, river water samples which was taken from upstream of the landfills shows the similar PAHs profile with the leachates (Fig. 2). We postulated that the upstream river might have been contaminating with illegal dumping of waste by human populations along the river. In this situation, we assumed that the leachates from the upstream locations have similar characteristics with the leachates in this study. We recommended that more studies of the characteristics of the landfill leachates for various locations in Malaysia should be exten-

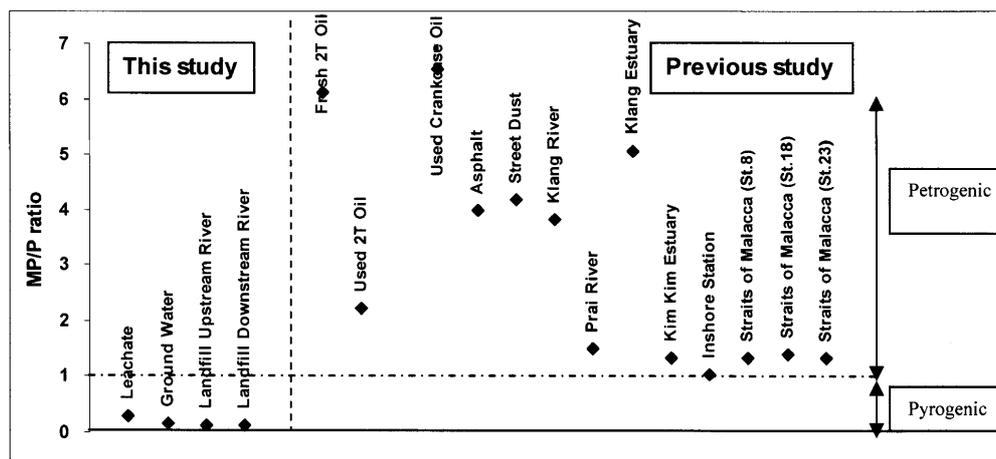
**Table 1.** Comparison of PAHs Concentration in Leachate, River Water, Ground Water, 2T Oil, Crankcase Oil, Asphalt, Street Dust with Sediment in Estuary, Inshore Station, River and Straits of Malacca.

Abbreviation	This Study			Wong et al. (unpublished)			Zakaria et al. (2000, 2001, 2002, 2003)									
	Leachate	Ground Water	Landfill Upstream River	Landfill Downstream River	Fresh 2T Oil	Used 2T Oil	Used Crankcase Oil	Street Dust	Klang River	Prai River	Klang Estuary	Kim Kim Estuary	Inshore Station	Straits of Malacca (St. 8)	Straits of Malacca (St. 18)	Straits of Malacca (St. 23)
Dibenzothiophene	17.0	1.0	16.6	7.7	15418.0	11235.0	na <sup>a</sup>	na	na	na	na	na	na	na	na	na
Phenanthrene	575.6	1478.3	1566.2	1043.4	1058.0	177450.0	98600.0	500.0	25.9	5500.0	16.6	1800.0	1.6	0.6	0.8	1.1
Anthracene	95.2	244.9	252.1	170.3	462.0	170325.0	60200.0	50.0	4.7	1800.0	3.0	400.0	0.3	0.2	0.2	0.2
3-methylphenanthrene	35.9	49.2	52.5	31.0	122.0	10363.0	185400.0	500.0	26.6	2100.0	20.3	500.0	0.4	0.2	0.2	0.3
2-methylphenanthrene	42.9	62.0	58.5	33.7	1710.0	123392.0	195800.0	600.0	24.1	2200.0	24.0	700.0	0.5	0.3	0.4	0.5
2-methylanthracene	9.9	14.8	13.4	8.4	5530.0	164364.0	na	na	na	na	na	na	na	na	na	na
9-methylphenanthrene	53.8	61.9	65.4	40.2	2699.0	131777.0	178800.0	600.0	29.6	2500.0	25.4	800.0	0.5	0.2	0.3	0.4
1-methylphenanthrene	35.4	45.1	47.3	28.5	831.0	127049.0	85100.0	400.0	18.7	1500.0	14.6	400.0	0.3	0.1	0.2	0.4
Fluoranthene	145.6	550.4	502.8	399.5	101.0	15965.0	56700.0	300.0	43.4	8300.0	16.3	3500.0	2.8	0.8	1.5	1.0
Pyrene	169.3	750.1	584.2	524.4	169.0	42575.0	109600.0	600.0	50.3	8600.0	30.5	5600.0	3.2	0.6	1.3	1.2
1-methylpyrene	10.2	35.9	31.8	22.6	151.0	9181.0	na	na	na	na	na	na	na	na	na	na
Benzol(a)anthracene	31.5	31.4	45.5	31.3	163.0	3496.0	157700.0	0.0	28.1	4100.0	10.9	1500.0	1.0	0.2	0.3	0.6
Chrysene	132.8	358.5	306.5	254.8	182.0	18651.0	84200.0	300.0	33.6	5000.0	17.8	3600.0	1.7	0.4	0.9	1.0
Benzol(k)fluoranthene	66.3	22.53	228.1	240.7	4198.0	21371.0	29800.0	0.0	21.0	5000.0	7.0	2100.0	1.6	0.5	0.6	0.7
Benzol(e)acephenanthrylene	63.5	215.5	166.2	198.6	6428.0	8639.0	na	na	na	na	na	na	na	na	na	na
Benzol(e)pyrene	141.5	762.5	862.0	713.5	8243.0	42090.0	20000.0	200.0	23.0	6000.0	13.8	2800.0	1.9	0.5	0.9	1.2
Benzol(a)pyrene	53.2	162.3	152.3	148.1	8449.0	43073.0	120500.0	40.0	70.0	5300.0	11.6	2100.0	1.6	0.4	0.6	1.2
Dibenzol(a,h)anthracene	36.2	76.5	44.4	28.5	15719.0	2051.0	na	na	na	na	na	na	na	na	na	na
Total PAHs <sup>b</sup> (ng/g)	1579.0	4781.9	4723.4	3659.4	29486.0	927579.0	1382400.0	4230.0	356.8	57900.0	211.8	25800.0	17.4	5.0	8.1	9.7
MP/P ratio <sup>c</sup>	0.29	0.15	0.14	0.13	6.11	2.21	6.54	4.00	3.82	1.51	5.08	1.33	1.06	1.35	1.42	1.35
LMW PAHs <sup>d</sup> (ng/g)	1153.7	3241.9	3129.0	2271.0	8251.0	798896.0	970200.0	1150.0	223.3	32500.0	150.7	13700.0	9.6	3.0	4.8	4.9
HMW PAHs <sup>e</sup> (ng/g)	425.3	1540.0	1594.4	1388.4	21235.0	128683.0	412200.0	210.0	680.0	133.5	25400.0	61.1	12100.0	7.8	2.0	3.3
L/H ratio <sup>f</sup>	2.71	2.11	1.96	1.64	0.39	6.21	2.35	5.48	1.67	1.28	2.47	1.13	1.23	1.49	1.44	1.04

<sup>a</sup> Abbreviation for PAHs compounds in this study.<sup>b</sup> Total PAHs = sum of concentration of phenanthrene + anthracene + 3-methylphenanthrene + 2-methylphenanthrene + 9-methylphenanthrene + 1-methylphenanthrene + fluoranthene + pyrene + benzo(a)anthracene + chrysene + benzo(k)fluoranthene + benzo(e)pyrene + benzo(a)pyrene.<sup>c</sup> MP/P ratio = a ratio of the sum of 3-methylphenanthrene, 2-methylphenanthrene, 9-methylphenanthrene, 1-methylphenanthrene to phenanthrene.<sup>d</sup> LMW PAHs = sum of concentration of phenanthrene + anthracene + 3-methylphenanthrene + 2-methylphenanthrene + 9-methylphenanthrene + fluoranthene + pyrene.<sup>e</sup> HMW PAHs = sum of concentration of benzo(a)anthracene + chrysene + benzo(k)fluoranthene + benzo(e)pyrene + benzo(a)pyrene.<sup>f</sup> L/H ratio = a ratio of the sum of phenanthrene + anthracene + 3-methylphenanthrene + 2-methylphenanthrene + 9-methylphenanthrene + 1-methylphenanthrene + fluoranthene + pyrene relative to sum of benzo(a)anthracene + chrysene + benzo(k)fluoranthene + benzo(e)pyrene + benzo(a)pyrene.<sup>g</sup> na = not analyzed.



**Fig. 2.** PAHs concentration in source material, leachate (a), groundwater (b), landfill upstream river (c) and landfill downstream river (d), panel (e) to panel (q) are taken from previous studies (Table 1). See legend of Table 1 for PAHs compound abbreviations.



**Fig. 3.** MP/P ratios of the leachates, groundwater, upstream and downstream river water relative to MP/P ratios of source materials, rivers, inshore and offshore waters derived from previous studies.

sively conducted in order to prove this hypothesis.

## Conclusions

This study shows that PAHs profiles in groundwater, upstream and downstream river water are very similar to the PAHs profiles in landfill leachates. This provides the best evidence that landfill leachates could be directly transported to the adjacent receiving waters. This study also shows that PAHs profile from leachates different from the PAHs profiles of fresh and used 2T oil, used crankcase oil, asphalt and street dust indicating that PAHs sources from the landfill leachates do not receive the input from those source materials. In other words, PAHs signature for landfill leachates in this study is very unique. This study had shown that MP/P ratios of the leachates are below unity and of pyrogenic sources. Hence, we postulate that the source of PAHs in landfill leachates might have been attributed to the incomplete combustion or pyrolysis of solid waste or organic material in the landfill. The pyrolytic materials which carry pyrogenic source PAHs are then carried into the leachates and percolated down into the groundwater by rain. We postulated that the upstream river might have been contaminating with illegal dumping of waste by human populations along the river. In this situation, we assumed that the leachates from the upstream locations have similar characteristics with the leachates in this study. We recommended that more studies of the characteristics of the landfill leachates for various locations in Malaysia should be extensively conducted in order to prove this hypothesis.

The deposition of huge volume of “material” in dumping site conveys with it an inherent potential for pollution of indigenous water resources, surface and groundwater resources, the atmosphere, flora and fauna and these would eventually cause direct and indirect impacts on human life.

The protection of these resources from the impacts posed by municipal solid waste disposal is imperative due to the increasing demands on our land and water resources. The release of leachates to the water bodies (i.e. rivers, water-channels and oceans) will have to be minimized in order to protect the health of our environments.

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