UNIVERSITI PUTRA MALAYSIA

COMPOSITION, CONCENTRATION AND DISTRIBUTION OF LINEAR ALKYLBENZENES IN SURFACE SEDIMENTS FROM SELECTED LOCATIONS IN MALAYSIA

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By

SADEQ ABDULLAH ABDO ALKHADHER

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

January 2017

DEDICATION

For the source of my inspiration all these years

My beloved father

My beloved mother

My beloved wife

My dear kids (Mohammed, Abdullah and Abdulrahman)

All my brothers and sisters

And all other family members and respected friends

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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January 2017

Chairman : Professor Mohamad Pauzi Zakaria, PhD
Faculty : Environmental Studies

Linear alkylbenzenes (LABs) are a group of organic chemical markers that primarily constitute raw materials of linear alkylbenzene sulfonates (LAS) type detergents. LABs are ubiquitous compounds and of high concern due to their intensive usage in detergents around the world. The objective of this study is to investigate the composition, concentration and distribution of LABs in surface sediment samples from selected locations in Malaysia and to identify possible sources and biodegradation of LABs in the sediment samples of the studied areas using the ratio of internal (I) and external (E) isomers of LABs (I/E ratios). The correlation between LABs concentration and total organic carbon (TOC) is also investigated. Thirty two surface sediments were collected from developed and less developed areas around Peninsular Malaysia, that is at Port Dickson, Muar River, Pulau Merambong, the Johor Bahru coast, the Kim Kim River as well as Brunei Bay in Sabah and Brunei waters. The sediment samples were analyzed using gas chromatography-mass spectrometry (GC-MS). The compositional profiles of LABs showed that the long chain alkylbenzenes (C_{13}+C_{14}) were higher than short chain alkylbenzenes (C_{11}+C_{10}). The C_{13} homolog was the most abundant type of LAB found in sediments of the studied areas.The concentrations of LABs found ranged from 7.1 to 255.8 (ng.g^{-1} dw), representing low to moderate levels. The results showed higher levels of LABs in the Muar River and Kim Kim estuary than those investigated in 2004 at the same areas. LABs found in this study are lower than those detected in other places of Southeast Asia such as at Kolkata, India and Jakarta, Indonesia, whereas they are consistent with the levels found in other parts of the world such as Humber, UK, and Santos Bay, Brazil. The results also showed that LABs were strongly correlated with TOC in Port Dickson, Muar River, Merambong and Brunei Bay in Sabah and Brunei waters and weakly correlated in Johor Bahru coast and the Kim Kim River. The I/E ratio of LABs was used as an indicator of LABs biodegradation in the aquatic environment. The results from I/E ratios were from 0.6 to 4.1 and indicate that the LABs come from a range of raw, primary to secondary treated effluents. Based on the results from the

LABs concentrations, it is recommended that different sites of Malaysia should be monitored and managed to reduce the levels of LABs entering the marine environment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KOMPOSISI, TABURAN DAN KEPEKATAN ALKILBENZENA LINEAR DI PERMUKAAN SEDIMEN DARI KAWASAN-KAWASAN TERPILIH DI MALAYSIA

Oleh

SADEQ ABDULLAH ABDO ALKHADHER

Januari 2017

Pengerusi : Profesor Mohamad Pauzi bin Zakaria, PhD
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Alkilbenzena linear (LABs) adalah sekumpulan penanda kimia organik yang kandungan utamanya adalah alkilbenzena sulfonate linear jenis detergen (LAS). LABs adalah sebatian yang mudah didapati dan mendapat perhatian yang serius kerana penggunaannya yang intensif di dalam detergen. Objektif kajian ini adalah untuk mengkaji komposisi, kepekatan dan taburan LABs di permukaan sampel sedimen dari lokasi-lokasi terpilih di Malaysia, dan untuk mengenal pasti berkemungkinan sumber dan biodegradasi LABs di dalam sampel sedimen di kawasan kajian menggunakan nisbah isomer LABs dalaman dan luaran (nisbah I/E). Hubungan antara kepekatan LABs dan jumlah karbon organic (TOC) juga dikaji. Tiga puluh dua sedimen permukaan diambil dari kawasan membangun dan kurang membangun di sekitar Semenanjung Malaysia, iaitu di Port Dickson, Sungai Muar, Pulau Merambong, pantai Johor Bahru, Sungai Kim-Kim, dan juga Teluk Brunei di perairan Sabah dan Brunei. Sampel sedimen dianalisa menggunakan gas kromatografi-spektrometer jisim (GC-MS). Profil komposisi LABs menunjukkan bahawa alkilbenzena rantaian panjang, (C_{13}+C_{14}) adalah lebih tinggi berbanding alkilbenzena rantaian pendek (C_{11}+C_{10}). Homolog C_{13} adalah jenis homolog LAB yang paling banyak ditemui di dalam sedimen kawasan kajian. Kepekatan LABs yang ditemui adalah di antara 7.1 to 255.8 (ng.g^{-1} dw) yang mewakili aras rendah dan sederhana. Keputusan kajian menunjukkan aras LABs yang lebih tinggi di sungai Muar dan muara Kim-Kim daripada kajian 2004 yang dijalankan di kawasan yang sama. Kandungaan LABs yang ditemui di kawasan ini adalah lebih rendah daripada kawasan-kawasan lain di Asia Tenggara seperti Kolkata, India, dan Jakarta, Indonesia, di mana ia adalah konsisten dengan aras yang ditemui di kawasan-kawasan seperti Humber, UK, dan Teluk Santos, Brazil. Keputusan kajian juga menunjukkan LABs mempunyai korelasi yang kuat dengan TOC di Port Dickson, Sungai Muar, Merambong dan Teluk Bay di periaran Sabah dan Brunei dan korelasi yang lemah di periaran Johor Bahru dan Sungai Kim-Kim. Nisbah I/E LABs digunakan sebagai penentu biodegradasi LABs dalam persekitan akuatik. Keputusan pada nisbah adalah dari I/E 0.6 – 4.1 menggambarkan LABs berasal

daripada efluen terawat mentah, primer dan sekunder. Berdasarkan keputusan-keputusan kepekatan-kepekatan LABs, dicadangkan agar beberapa kawasan di Malaysia perlu dipantau dan diuruskan untuk mengurangkan aras LABs yang memasuki persekitaran marin.

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I certify that a Thesis Examination Committee has met on 26 January 2017 to conduct the final examination of Sadeq Abdullah Abdo Al-Khadher on his thesis entitled "Composition, Concentration and Distribution of Linear Alkylbenzenes in Surface Sediments from Selected Locations in Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

LABs	Linear alkyl benzenes
LASs	Linear alkyl benzene sulfonates
TABs	Tetra propylene-based alkylbenzenes
TBS	Tetra propylene benzene sulfonates
K_{WO}	Octanol – water partition coefficient
TOC	Total organic carbon
GC-MS	Gas chromatography-Mass spectrometry
I/E	a ratio of 6-,5-C_{12} LAB relative to 4-,3-,2-C_{12}LAB
L/S	a ratio of 5-C_{13}LAB+5-C_{12}LAB relative to 5-C_{11}LAB+5-C_{10} LAB
C_{13}/C_{12}	a ratio of 6-,5-,4-,3-and 2-C_{13} / 6-, 5-, 4-, 3-, and 2-C_{12}LAB
LC-LABs	Longer chains alkylbenzenes
SC-LABs	Shorter chains alkylbenzenes
WWTP	wastewater treatment plants
SPM	suspended particulate matters
SIS	Surrogate Internal Standard
IIS	Internal Injection Standard
DCM	Dichloromethane
Hex	Hexane
MeOH	Methanol
IWK	Indah Water Konsortium Sdn Bhd
5-C_{10}	5-phenyldecane
4-C_{10}	4-phenyldecane
3-C_{10}	3-phenyldecane
2-C_{10}	2-phenyldecane
6-C_{11}	6-phenylundecane
5-C_{11}	5-phenylundecane
4-C_{11}	4-phenylundecane
3-C_{11}	3-phenylundecane
2-C_{11}	2-phenylundecane
6-C_{12}	6-phenyldodecane
5-C_{12}	5-phenyldodecane

4-C_{12}	4-phenyldodecane
3-C_{12}	3-phenyldodecane
2-C_{12}	2-phenyldodecane
7,6- C_{13}	7, 6-phenyltridecane
5-C_{13}	5-phenyltridecane
4-C_{13}	4-phenyltridecane
3-C_{13}	3-phenyltridecane
2-C_{13}	2-phenyltridecane
7-C_{14}	7-phenyltetradecane
6-C_{14}	6-phenyltetradecane
5-C_{14}	5-phenyltetradecane
4-C_{14}	4-phenyltetradecane
3-C_{14}	3-phenyltetradecane
2-C_{14}	2-phenyltetradecane

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The coastal marine system is one of the most significant habitats for organisms. However, this system is sensitive to disturbance caused by severe anthropogenic activities (Wei *et al.,* 2014a). The importance of coastal waters for recreational and aquaculture uses have been investigated (Law and Azahar, 1990). Moreover, the coastal areas have been used as final disposal places of human wastes (Craig, 2012).

Severe water pollution can be caused by industrial facilities and building metropolitan centers along rivers leading to discharge of industrial and domestic wastewater especially due to improper regulation (Zahang *et al.,* 2012). Generally, the released effluents can be resulted in the contamination of water, sediments, and aquatic species, in addition to detriment human health.

Linear alkylbenzenes (LABs) as one of organic compounds class are successfully applied to trace urban wastes in coastal regions (Venturini *et al.,* 2015; Martins *et al.,* 2012b).

The environment of the world was subject to various threats and risks in the past century and a part of it has already been lost due to increasing pressure from the uncontrolled human use of natural resources (World Bank, 2010). There has been an increasing concern for the environment in recent decades. The pollution of coastal and riverine ecosystem is an important part of these risks resulting from the extensive use of synthetic detergents in domestic life, industries, and in the agricultural field during the past few years. The rising inputs of untreated domestic waste due to rapid population, industrialization, and urbanization has posed high health risk to the people. Thus, it is necessary to determine the amount and kinds of domestic waste released to the aquatic environment. One of the effective waste tracers that can be applied in the aquatic environment is linear alkylbenzenes, (LABs) (Takada *et al.,* 1994; Zeng *et al.,* 1997). Information about distribution and sources of these organic compounds let us evaluating the ecosystem condition in the affected areas by domestic discharge (Wang *et al.,* 2012).

LABs are defined as a set of chemical markers that widely used to assess the source of sewage pollution (Eganhouse, 1997). Owing of their strong attachment to anthropogenic activities, LABs have been applied as indication of human activities on the aquatic environment (Venkatesan *et al.,* 2010; Martins *et al.,* 2012b; Rinawati *et al.,* 2012; Wei *et al.,* 2014a). Because of their superior biodegradability and cost-effectiveness, the older branched alkylbenzene had totally changed by LABs to produce LASs which have been applied in the household laundry detergents and dishwashing uses.

LABs in relation to surfactants (LASs) are currently widely used in developing countries and because of the greater consumption of synthetic detergents, they replaced natural soap and non-biodegradable branched alkylbenzenes and their usage has been rampant, resulting in great release of these compounds into the environment and thus posing a potential threat (Eganhouse *et al*., 1983a; Takad a *et al.*, 1985; Eganhouse *et al.,* 2000). LABs have both aromatic and aliphatic characteristics as a result of their unique structure i.e. LABs have the same physical properties as other hydrocarbon chemicals (Sherblom *et al.,* 1992).

Majority of LABs utilization (~98%) of LABs is as a raw materials in the manufacturing of LASs, despite of many other usage of linear alkyl benzene (Steber and Berger, 1995; Johnson *et al.,* 2007).

The synthesis of alkylbenzene by Friedel-Crafts alkylation using tetra propylene was the earliest utilization of detergent alkylates on a manufacturing level in the 1950s (Eganhouse *et al*.,1983a). The tetra propylene-based alkylbenzenes, (TABs) turned into tetra propylene benzene sulfonates (TBS) as a result of sulfonation of TAB. This kind of alkylate is called a “hard detergent alkylate” owing to biodegradation problems of branched TBS detergents in aquatic environments, followed by stable foaming problems. Hence, the detergent industry turned to enhanced degradable alkylbenzenes compounds i.e. the “soft detergent alkylate”, named LABs (Takada and Eganhouse, 1998). The predominance of LAB compounds in the environment significantly reflects the existence of sewage pollution, regardless of their sources and fate (Tsutsumi *et al*., 2002; Isobe *et al*., 2004; Magam *et al*., 2012). LABs compounds are exposed to numerous processes and changes in regard to their isomer compositions after being discharged from various sources into the marine environment. LABs were widely detected in Southeast Asia due to improper sewage treatment.

Malaysia, which is situated in Southeast Asia, has been rapidly heading towards being a developed and industrialized country since the second half of 20th century (Shahbazi *et al*., 2010; Keshavarzifard *et al*., 2014) (Figure 1.1).

Figure 1.1: Malaysia map in Southeast Asia
(Source: GIS centre, UKM)

While Malaysia is developing rapidly in terms of industrialization, urbanization and motorization, it has also been increasingly experiencing extraordinary economic and population growth in the last few decades. This has led to more risks and possible harmful effects that could affect this country, especially from urbanization and industrialization-related pollutants that are steadily discharged to the aquatic ecosystem.

The concentration and sources of sewage or wastewater pollution in Malaysia differ from one location to the other (Magam *et al*., 2012). Due to the presence a lot of urban development and wastewater treatment plants in the Western coast of Malaysia, , the domestic waste are now being introduced through non-point sources discharge as well as point sources such as factories. Because of less development in the Eastern coast of Malaysia, the majority of pollution comes from urban and industrialized areas (Shahbazi *et al*., 2010).

To understand the LABs contamination level in the riverine and coastal areas, researchers frequently investigate different environmental samples for examples, water, sediments, and particles. In Malaysia, only a few researchers have studied LABs to investigate the sewage pollution condition (Magam *et al*., 2012). However, studies on LAB levels in East Malaysia are rare. No pervious researcher has studied Brunei Bay in Sabah for LABs concentrations. Moreover, most of the rivers studied in this research have not been investigated for LABs levels previously. Therefore, this study fills the data gap in the study area and shows the trends of LABs in other locations.

1.2 Linear alkyl benzenes (LABs)

LABs are defined as a group of secondary phenyl alkanes C_6H_5-C_nH_2n+l, n= 10-14 (Eganhouse *et al*., 1983a). LABs are a group of chemical markers that are manufactured from the interaction of benzene with common mono chloro paraffins or mono alkenes in the presence of proper catalysts. Sulfonation of LABs with SO_3 or H_2SO_4 results in formation of linear alkylbenzene sulfonates (LASs). They have been commonly used for over 50 years with worldwide utilization as high as 18.2 million tons in 2003 (Hauthal and Wagner, 2004).

LABs are hydrophobic chemicals and log octanol-water partition coefficient ~7-9 (Sherblom *et al*., 1992). Therefore, they are preferentially attached to rich organic matters in the sewage (Murray *et al*., 1987; Takada, *et al*., 1994).

Unsulfonated residual LABs moving with LAS during LAS detergent production into the aquatic ecosystem poses serious problems since LABs affect marine/terrestrial ecosystems and result in huge amounts of used synthetic detergents being discharged into the municipal and industrial wastes prior to utilization. Moreover, LABs do not degrade easily and are preserved in the environment for a long time. The fast population growth and development growth around the world has increased water contamination and sped up environmental deterioration. Many previous studies support the above facts (Ishiwatari *et al*., 1983; Takada and Ishiwatari, 1985; Takada and Ishiwatari, 1987; Eganhouse *et al*.,1983a; Eganhouse *et al*., 1983b). LABs distribution at riverine environment (Takada and Ishiwatari, 1987), estuarine sediment (Ishiwatari *et al*., 1983; Takada and Ishiwatari, 1985; Eganhouse *et al*., 1983a; Eganhouse *et al*., 1988; Valls *et al*., 1989), and pelagic fishes (Albaigés *et al*., 1987) proves that they are very persistent in the environment. In this context, LABs suggested as one of useful indicators of industrial and domestic waste (Takada and Ishiwatari, 1987; Eganhouse *et al*., 1983a; Eganhouse *et al*., 1988).

Since the 1960s, LASs as an anionic surfactant group have been largely used to produce synthetic detergents (Eganhouse *et al*., 1983a). Due to small amount of LABs are attached with LAS-type detergents in addition to wide application of detergents and subsequent discharge of LABs to the riverine and coastal areas. Therefore, municipal wastewaters contain high amounts of LABs (Eganhouse, *et al*., 1983a; Takada and Ishiwatari, 1987).

Vivian (1986) also reported the use of LABs as molecular marker for environmental pollution originating from municipal and industrial waste. The external isomers (of which the benzene ring close to the end of the straight alkyl chain) are easier to degrade than internal isomers (of which the benzene ring is near to the centre of the chain). In addition, the LABs concentration and composition reflect its significance as well as indicates the type of wastewater released to the aquatic ecosystem (Tsutsumi, *et al*., 2002). Figure 1.2 shows the structure of LAB and LAS.

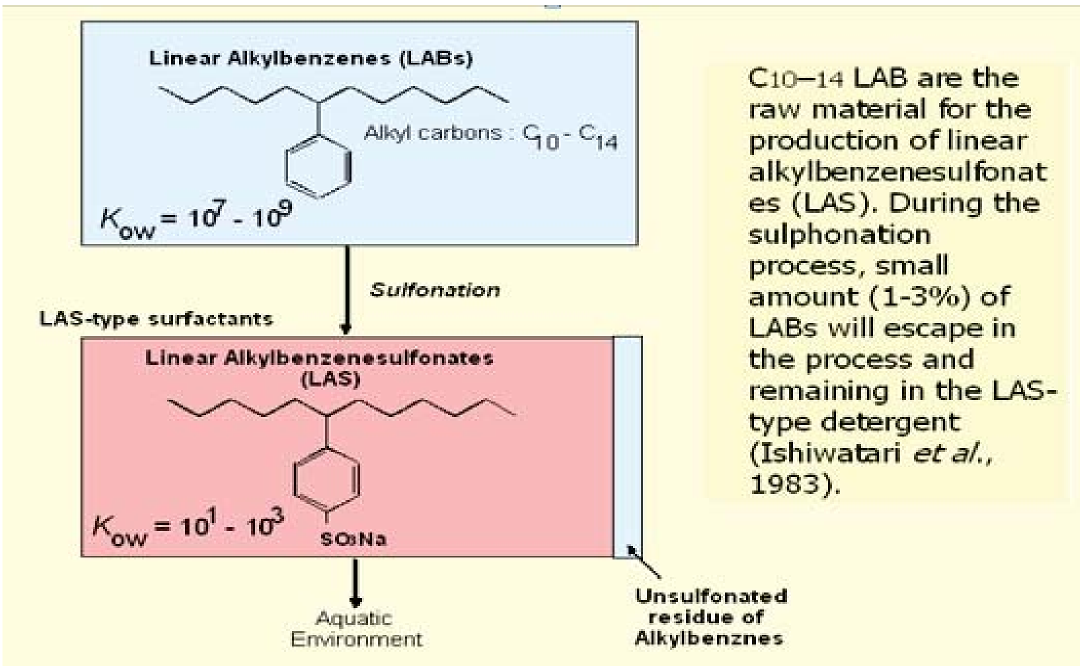

Figure 1.2: Structures and introduction pathways of LABs into aquatic environments (Takada and Eganhouse, 1998)

1.3 Problem Statement

Malaysia has been affected by municipal and industrial waste with land-based pollution due to its rapid population growth and land development (Shahbazi *et al*., 2010), which has caused increasing stresses in the form of accelerating environmental deterioration and water quality pollution. Densely populated cities stretching along the rivers and coastline areas are expected to directly and indirectly release bulky volumes of sewage and domestic wastewater into these rivers and coastal areas. The high discharge of poorly treated sewage to marine environment is one of the main concern (Magam *et al*., 2012). As long as human population grows, the problem with sewage pollution will continue. The amount of sewage discharged into the aquatic environments in Asian countries would expand and add to the previous pollution in the next years. Therefore, the question arises as to what extent Malaysia and specifically the areas in the Western coast that have experienced a boost in population are polluted with LABs.

Some studies also reported the accumulation of LABs in aquatic species (Tsutsumi *et al*., 2002). High LABs concentration in the environment is not only affecting the aquatic ecosystems but also acts as a detriment to human health because human on top of food chain. Besides this, tourism, which is one of the important human activities, can also be a potential source of water pollution in the studied areas. Consequently, sewage contamination poses huge health risks to communities inhabiting along these estuaries and rivers. Indirect or direct release of municipal wastewater, poorly controlled septic tanks, and inefficient management of STPs are likely the main causes of water-borne diseases (Isobe *et al*., 2004). Generally, it can be said that the use of synthetic detergents can negatively affect the environment.

However, synthetic detergents undergo production, formulation, the usage phase, and the discharge phase during their lifecycle. The levels of chemicals released into the environment from production and formulation is generally low (Eganhouse *et al*., 1983a), considering that there are proper installations to reduce pollutants in chemical plants. Nonetheless, when it comes to the usage and discharge phase, the concentrations of pollutants released into the environment can be much higher. The biological and physicochemical properties of the chemical and the way it is used and discharged into the environment can be used to identify the type of chemical discharged into the marine environment. Unsulfonated residual LABs moving with LAS during LAS detergent production into the aquatic ecosystem can pose serious problems because LABs (a) affect marine/terrestrial ecosystem and (b) huge amounts of used synthetic detergents are discharged into municipal and industrial wastes prior to utilization (c) LABs do not degrade easily and are preserved in the environment for a long time and (d) the fast population growth and development growth around the world has increased the chances of water contamination and environmental deterioration (Ishiwatari *et al*., 1983; Takada and Ishiwatari, 1985; Takada and Ishiwatari, 1987; Eganhouse *et al*., 1983a; Eganhouse *et al*., 1983b).

Increasing inputs of untreated sewage especially in slum areas and locations that are overcrowded and limited or those with no sewage treatment systems to rivers and coastal environment will lead to increased health threats to humans and aquatic environment (Isobe *et al*., 2002). The aquatic environment is exposed to the accumulation of LABs in the sediment because of the increasing pollution level along the coastlines and estuaries, which have in turn led to serious pollution in coastal areas. However, there is a lack of studies on LABs distribution and transport pathways in the sedimentary environment in Malaysia. The concentrations of LABs have not been reported from the most of sampling stations of Peninsular Malaysia and Brunei Bay in Sabah and Brunei waters.

1.4 Significance of the Study

Safeguarding water resources and the aquatic ecosystem is one of the most important environmental concerns in the 21st century (World Bank, 2010). Therefore, monitoring the natural waterways and appropriate wastewater management for emerging pollutants has become inevitable to ensure good water quality and a healthy ecosystem. Particulate material for example, sand, silt, clay and shell fragments in the water column may act as sorptive materials for partitioning of organic pollutants (Martins *et al*., 2010).

The concept of molecular marker has been improved and applied by organic geochemists to trace the transport, origins, and fate of hydrophobic compounds (Vivian, 1986). Molecular marker defined as hydrophobic compounds specific to particular pollution sources (Eganhouse *et al*., 1983a). Anthropogenic molecular markers are released to the aquatic ecosystem via human activities. Therefore, the information from anthropogenic markers such as LABs is highly important when it comes to environmental contamination (Takada and Eganhouse, 1998).

LABs species have been found to be high hydrophobicity and have strong affinity to attach to sewage particles. Therefore, the major source of LABs comes from sewage contamination discharge to aquatic environment. Aquatic sediment is a main sink of particulate materials (Abdullah *et al*., 1999). LABs distribution in sediments could be helpful in evaluating the alteration of pollutants derived from sewage through moving to and residing in the sea bottom (Wang *et al*., 2010).

Sedimentary ecosystems are exposed to the accumulation of LABs in the sediments because of the increasing pollution level along the coastlines and rivers (Magam *et al*., 2015). The results of this study will help to identify whether or not the sediment ecosystem in Malaysian waters is affected by sewage pollution using LABs as chemical markers.

Control the sewage pollution in the aquatic ecosystem is carried out by the use of LABs that are utilized as chemical marker of sewage-derived particles (Eganhouse *et al*., 1988) due to octanol – water partition coefficient (K_{WO}) of LABs is close to K_{WO} of sewage particles and they are more persistent in the environment than LAS. Heavy loads of domestic waste are expected to be released to the aquatic ecosystems of Malaysia due to rapid population growth, urbanization, and industrialization in the last decade (Masood *et al*., 2015). Therefore, it is of high priority to monitor wastewater and sewage systems with the help of diagnostic ratios such as internal over external LABs isomers ratio (I/E ratio).

Release of inadequately treated or untreated sewage may cause danger to human health living in the surrounding areas because sewage has various harmful chemicals as well as viruses and pathogenic bacteria (Isobe *et al*., 2002).

This research is expected to gain comprehensive data on the distribution and concentration of sewage molecular markers in the aquatic environment of selected locations of the southern Peninsular of Malaysia (Muar, Merambong, Johor Bahru coast, Kim Kim river and Port Dickson) and Brunei Bay. However, no comprehensive study using LABs as chemical markers has been conducted in the areas chosen so far.

1.5 Research Questions

Sediments are the principal environmental sink for many contaminants, as many organic contaminants introduced into the water column have affinities to sediment particles (Abdullah *et al*., 1999). Because sewage particles also have strong affinity with contaminant concentrations such as LABs.

Contaminants which deposited in sediments are present in an equilibrium state with the water phase which may be altered by anthropogenic environmental disturbances (Wang *et al*., 2010). Therefore, major questions arise i.e. what are the concentration and distribution of LABs in sediments samples? What is compositional profile of LABs in marine environment? What is the correlation between sediment and organic carbons in the sediments of study areas? And finally, to what extent are LABs biodegraded in the aquatic environment?

1.6 Research Objectives

The specific objectives of this research are:

i. To determine the composition, concentration and distribution of LABs in surface sediment samples collected from selected locations in Malaysia along the Port Dickson, Muar River, Merambong Island, the Kim Kim River, the Johor Bahru coast as well as Brunei Bay using GC-MS.
ii. To investigate the correlation between LABs and total organic carbon (TOC) in the surface sediment samples collected.
iii. To evaluate the biodegradation and sources of LABs in the sedimentary environment using I/E ratios.

1.7 Conceptual framework of LABs in Coastal Environment

The conceptual framework of the movement of LABs in the coastal environment is simplified in the form of flow diagram (Figure 1.3). It could be the guide to readers to understand this research related to the goals of the research.

Figure 1.3 illustrates the study process as well as the relationship between these research elements with each other within this study.

The conceptual framework summarizes the distribution, composition and sources of LABs in the aquatic environment. It starts with input stage in which the sources of LABs come from detergents and sewage discharge (Eganhouse *et al,* 1983a).

LABs undergo physio - chemical processes during riverine runoff and accumulation in suspended and sediments particles of receptors (Lue *et al.,* 2008).

Biodegradation is a natural process that control of LABs composition and the high or low of LABs concentration in aquatic ecosystem depends on the proximity or far LABs thon their sources (Takada and Ishiwatari, 1987).

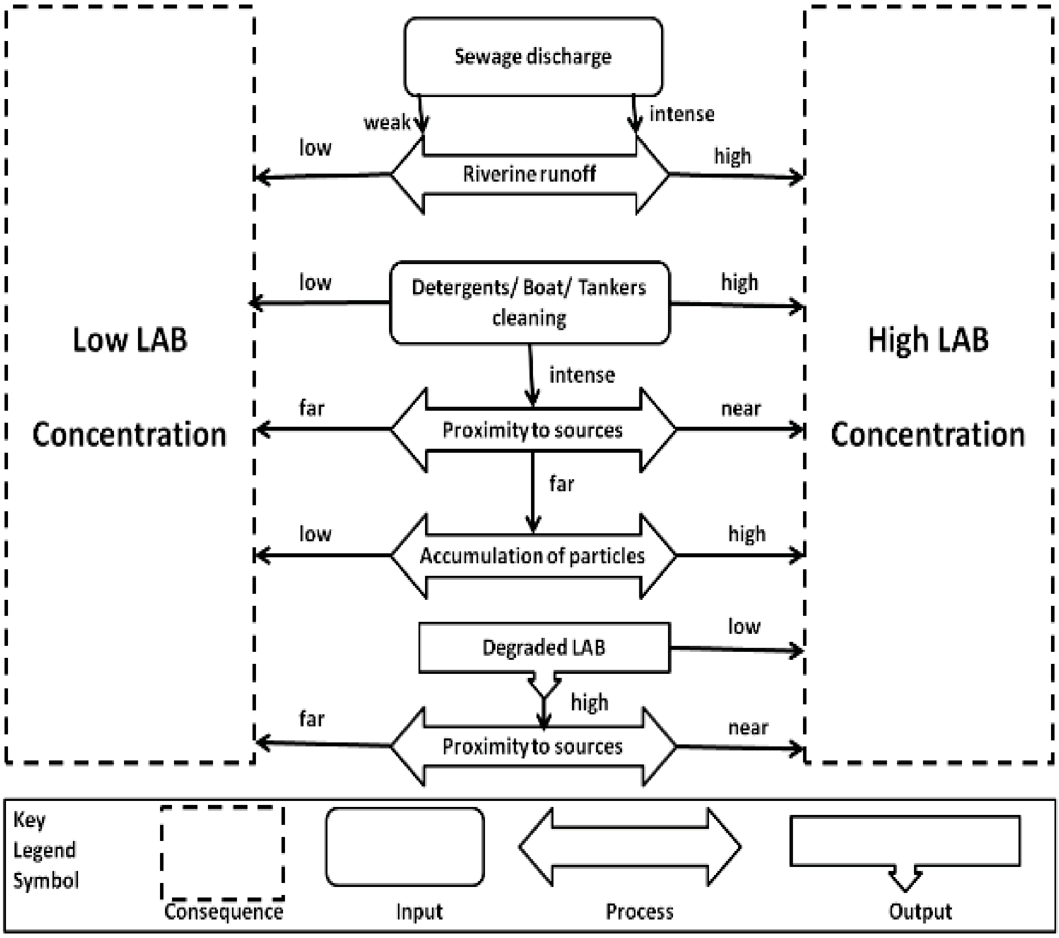

Figure 1.3: Conceptual framework of LABs in coastal environment

1.8 Thesis Structure

The thesis structure is shown in Figure 1.4. The first chapter is an introduction on the background of this study, the linear alkylbenzenes (LABs), problem statement, the significance of this study, the research questions, and the study's objectives.

The second chapter is the literature review. This chapter provides a comprehensive literature review regarding distribution, source, pathways, and the fate of organic contaminants in the environment and ecosystems.

The third chapter presents the Methodology for this study, which touches on sampling, sample preparation, and sample analysis.

The fourth chapter outlines the results and discussion, which talk about the concentration, distribution, and sources of the LABs in this study.

Finally, the fifth chapter presents the conclusion and recommendations for future research.

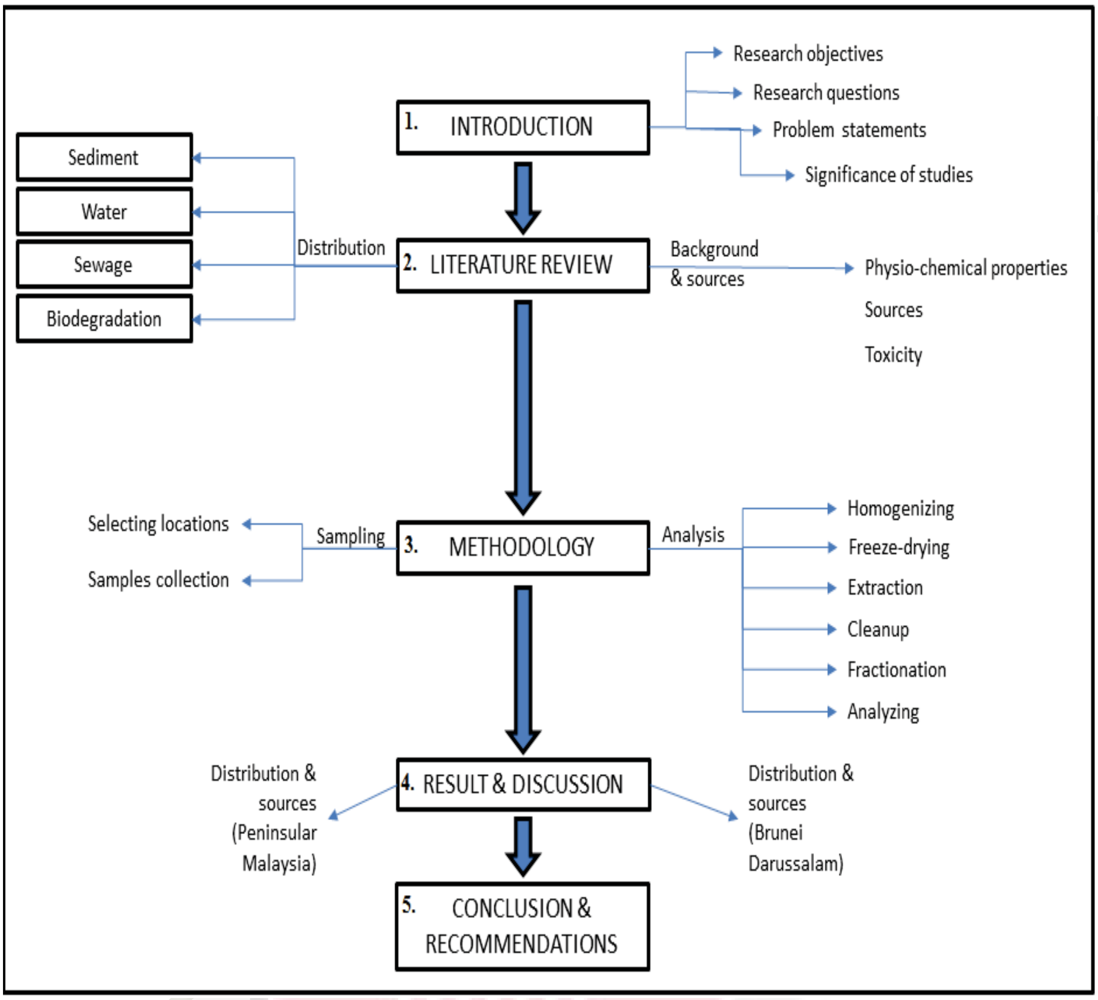

Figure 1.4: Thesis structure

REFERENCES

Abdullah, A. R., Tahir, N. M., Tong, S. L., Hoque, T. M. and Sulaiman, A. H. (1999). The GEF/UNDP/IMO Malacca Straits Demonstration Project: sources of pollution. *Marine Pollution Bulletin* 39: 229–233.

Abu Samah, B., Yassin, S. M., Shaffril, H. A. M., Hassan, M. S., Othman, M. S., Abu Samah, A. and Ramli, S. A. (2011). Relationship to the river: The case of the Muar River community. *American Journal of Environmental Science* 7: 362-369.

Accardi-Dey, A. and Gschwend, P. M. (2002). Assessing the combined roles of natural organic matter and black carbon as sorbents in sediments. *Environmental Science and Technology* 36(1): 21-29.

Achman, D. R., Brownawell, B. J. and Zhang, L. H. (1996). Exchange of polychlorinated biphenyls between sediment and water in the Hudson River Estuary. *Estuaries* 19 (4): 950-965.

Albaigés, J., Farran, A., Soler, M. and Gallifa, A. (1987). Accumulation and distribution of biogenic and pollutant hydrocarbons, PCBs and DDT in tissues of western Mediterranean fishes. *Marine Environmental Research* 22 (1): 1-18.

Alkhadher, S. A. A., Zakaria, M. P., Yusoff, F. M., Kannan, N., Suratman, S., Keshavarzifard, M., Magam, S. M., Masood, N., Vaezzadeh, V. and Sani, M. S. A. (2015a). Baseline distribution and sources of linear alkylbenzenes (LABs) in surface sediments from Brunei Bay, Brunei. *Marine Pollution Bulletin* 101 (1): 397-403.

Alkhadher, S. A. A., Zakaria, M. P., Yusoff F, M., Kannan, N., Suratman, S., Magam, S. M., Masood, N., Keshavarzifard, M., Vaezzadeh, V. and Sani, M.S.A. (2015b). Distribution and sources of linear alkylbenzenes (LABs) in surface sediments from Johor Bahru Coast and the Kim Kim River, Malaysia. *Environmental Forensics* 17 (1): 36-47.

Alsalahi, M. A., Latif, M. T., Ali, M. M., Magam, S. M., Abd Wahid, N. B., Khan, M. F. and Suratman, S. (2014). Distribution of surfactants along the estuarine area of Selangor River, Malaysia. *Marine Pollution Bulletin* 80: 344–350.

Arzayus, K. M., Dickhut, R.M. and Canuel, E. A. (2001). Fate of atmospherically deposited polycyclic aromatic hydrocarbons (PAHs) in Chesapeake Bay. *Environmental Science and Technology* 35 (11): 2178-2183.

Azman, S., Chiang, B. C. W., Ismail, R., Jaafar, J. and Said, M. I. M. (2012). Effect of land use on coastal water and perna viridis at Johor Straits, Malaysia. *International Journal of Environmental Science and Development* 3 (3): 237-239.

Bakhtiari, A. R., Zakaria, M. P., Yaziz, M. I., Lajis, M. N. H and Bi, X. (2011). Variations and origins of aliphatic hydrocarbons in sediment cores from Chini Lake in Peninsular Malaysia. *Environmental Forensics* 12 (1): 79-91.

Bayona, J., Albaigés, J., Solanas, A. M. and Grifoll, M. (1986). Selective aerobic degradation of linear alkylbenzenes by pure microbial cultures. *Chemosphere* 15 (5): 595-598.

Bícego, M. C., Taniguchi, S. Yogui, G.T., Montone, R.C., Silva, D.A.M.D., Lourenço, R.A.,Martins, C.C., Sasaki, S.T., Pellizari, V.H. and Weber, R.R. (2006). Assessment of contamination by polychlorinated biphenyls and aliphatic and aromatic hydrocarbons in sediments of the Santos and São Vicente Estuary System, São Paulo, Brazil. *Marine pollution bulletin* 52 (12): 1804-1816.

Boyes, S. and Elliott, M. (2006). Organic matter and nutrient inputs to the Humber Estuary, England. *Marine Pollution Bulletin* 53: 136–143.

Brusseau, M. L. and Chorover, J. (2006). Environmental and Pollution Science. In L. L. Pepper, C. P. Gerba and M. L. Brusseau, (Eds.) *Chemical Processes Affecting Contaminant Transport and Fate* (pp. 89-104)*,* Oxford: Elsevier.

Chalaux, N., Bayona, J. M., Venkatesan, M. I. and Albaiges, J. (1992). Distribution of surfactant markers in sediments from Santa Monica basin, Southern California. *Marine pollution bulletin* 24 (8): 403-407.

Chalaux, N., Takada, H. and Bayona, J. M. (1995). Molecular markers in Tokyo Bay sediments: sources and distribution. *Marine Environmental Research* 40 (1): 77-92.

Colombo, J. C., Cappelletti, N., Speranza, E., Migoya, M.C., Lasci, J. and Skorupka, C. N. (2007). Vertical fluxes and organic composition of settling material from the sewage impacted Buenos Aires coastal area, Argentina. *Organic geochemistry* 38 (11): 1941-1952.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D. and Savelli, H, *Sick water? The central role of wastewater management in sustainable development. A rapid response assessment.* United Nations Environment Programme, UN-HABITAT, GRID-Arendal. 2010.

Craig, R.K., (2012). Marine biodiversity, climate change, and governance of the oceans. *Diversity* 4: 224- 238.

Crisp, P. T., Brenner, S., Venkatesan, M. I., Ruth, E. and Kaplan, I. R. (1979). Organic chemical characterization of sediment-trap particulates from San Nicolas, Santa Barbara, Santa Monica and San Pedro Basins, California.*Geochimica et Cosmochimica Acta* 43 (11): 1791-1801.

Dauner, A. L. I., Hernández, E. A., MacCormack, W. P. and Martins, C. C. (2015). Molecular characterisation of anthropogenic sources of sedimentary organic matter from Potter Cove, King George Island, Antarctica. *Science of the Total Environment* 502: 408–416.

Delinom, R. M., Assegaf, A., Z. Abidin , H., Taniguchid , M., Suherman , D., Lubis , R. F. and Yulianto, E. (2009). The contribution of human activities to subsurface environment degradation in Greater Jakarta Area, Indonesia. *Science of the Total Environment* 407: 3129 – 3141.

Department of Statistics Malaysia (DOSM). Population and demography report no. 1; intercensal mid-year population estimates, June 2016, www.statistics.gov.my (accessed 8 June /2016).

Díez, S., Jover, E., Albaigés, J. and Bayona, J. M. (2006.). Occurrence and degradation ofbutyltins and wastewater marker compounds in sediments from Barcelona Harbor, Spain. *Environment International Journal 32*: 858–865.

Eganhouse, R. P. and Kaplan, I. R. (1981). Extractable organic matter in urban stormwater runoff. 1. Transport dynamics and mass emission rates. *Environmental Science & Technology* 15 (3): 310-315.

Eganhouse, R. P. and Kaplan, I. R. (1982). Extractable organic matter in municipal wastewaters. 2. Hydrocarbons: Molecular characterization. *Environmental Science and Technology* 16 (9): 541-551.

Eganhouse, R. P., Blumfield, D. L. and Kaplan, I. R. (1983a). Long-chain alkylbenzenes as molecular tracers of domestic wastes in the marine environment. *Environmental Science & Technology* 17 (9): 523-530.

Eganhouse, R. P., Ruth, E. C. and Kaplan, I. R. (1983b). Determination of long-chain alkylbenzenes in environmental samples by argentation thin-layer chromatography/high-resolution gas chromatography and gas chromatography/mass spectrometry. *Analytical Chemistry* 55 (13): 2120-2126.

Eganhouse, R. P., Olaguer, D. P., Gould, B. R. and Phinney, C. S. (1988). Use of molecular markers for the detection of municipal sewage sludge at sea. *Marine Environmental Research* 25 (1): 1-22.

Eganhouse, R. P. (1997). Molecular markers an environmental geochemistry: An overview. In P.R Eganhouse, ed., *Molecular Markers in Environmental Geochemistry* (pp. 1-20). Washington D. C: American Chemical Society.

Eganhouse, R., Pontolillo, J. and Leiker, T.J. (2000). Diagenetic fate of organic contaminants on the Palos Verdes Shelf, California. *Marine Chemistry* 70 (4): 289-315.

Eganhouse, R. and Sherblom, P. M. (2001). Anthropogenic organic contaminants in the effluent of a combined sewer overflow: impact on Boston Harbor. *Marine Environmental Research* 51 (1): 51-74.

Eganhouse, R. P. (2004). Molecular markers and their use in environmental organic geochemistry. *The Geochemical Society Special Publications 9*: 143-158.

Eganhouse, R. P. and Pontolillo, J. (2008). Susceptibility of synthetic long-chain alkylbenzenes to degradation in reducing marine sediments. *Environmental Science and Technology* 42 (17): 6361-6368.

Edser, C. (2012). Feedstock sourcing looks to the emerging markets. *Focus surfactants* 12: 1–2.

Gallagher, E. D. and Keay, K. E. (1998). Organism - sediment- contaminant Interaction in Boston Harbor. In Contaminated sediments in Boston Harbor, In *MIT Sea Grant publication 98-1,* K. D. Stolzenbach, and E. E. Adams, eds, MIT, Cambridge, pp. 89-132.

Gerba, C. P. and Pepper, I. L. (2006). Municipal Wastewater Treatment. In L. L., Pepper, C. P. Gerba and Brusseau, M. L., (Eds), *Environmental and Pollution Science* (pp. 429-450). Oxford: Elsevier.

Gledhill, W. E., Saeger, V. W. and Trehy, M.L. (1991). An aquatic environmental safety assessment of linear alkylbenzene. *Environmental toxicology and chemistry* 10 (2): 169-178.

González, A. G. and Herrador, M. Á. (2007). A practical guide to analytical method validation, including measurement uncertainty and accuracy profiles. *Trends in Analytical Chemistry* 26: 227–238.

Government, M. Tourism Malysia, 2015, http:// corporate. Tourism.gov.my (accessed 8 June 2016).

Grathwohl, P. (1990). Influence or organic matter from soils and sediments from various origins on the sorption of some chlorinate aliphatic hydrocarbons: implications on Koc correlations. *Environmental Science and Technology 24* (11): 1687-1693.

Gustafsson, Ö., Long, C. M., MacFarlane, J. and Gschwend, P. M. (2001). Fate of linear alkylbenzenes released to the coastal environment near Boston Harbor.*Environmental Science & Technology 35* (10): 2040-2048.

Hadibarata, T., Abdullah, F., Yusoff, A. R. M., Ismail, R., Azman, S., and Adnan, N. (2012). Correlation study between land use, water quality, and heavy metals (Cd, Pb and Zn) content in water and green lipped mussels Perna viridis (Linnaeus) at the Johor Strait. *Water Air Soil Pollution* 223: 3125–3136.

Hamzah, A., Kipli, S., Ismail, S.R., Una, R. and Sarmani, S. (2011). Microbiological study in coastal water of Port Dickson, Malaysia. *Sains Malaysiana* 40: 93–99.

Hartmann, P. C., Quinn, J., King, J. W., Tsutsumi, S. and Takada, H. (2000). Intercalibration of LABs in marine sediment SRM1941a and their application as a molecular marker in Narragansett Bay sediments. *Environmental Science and Technology* 34 (5): 900-906.

Hartmann, P. C., Quinn, J. G., Cairns, R.W. and King, J. W. (2005). Depositional history of organic contaminants in Narragansett Bay, Rhode Island, USA. *Marine Pollution Bulletin* 50 (4): 388-395.

Harwood, J.J. (2014). Molecular markers for identifying municipal, domestic and agricultural sources of organic matter in natural waters. *Chemosphere 95* (2014): 3-8.

Hauthal, H. and Wagner, G. (2004). Household Cleaning, Care and Maintenance Products. Augsburg, Germany. *Publishing house for chemical industry* 207-211.

Heim, S., Schwarzbauer, J., Kronimus, A., Littke, R., Woda, C. and Mangini, A. (2004). Geochronology of anthropogenic pollutants in riparian wetland sediments of the Lippe River (Germany). *Organic Geochemistry* 35 (11): 1409-1425.

Hinga, K.R. (2003). Degradation rates of low molecular weight PAH correlate with sediment TOC in marine sub tidal sediments. *Marine Pollution Bulletin* 46 (4): 466-474.

Holt, M. and Bernstein, S. (1992). Linear alkylbenzenes in sewage sludges and sludge amended soils. *Water Research* 26 (5): 613-624.

Hong, H., Xu, L., Zhang, L., Chen, J.C., Wong, Y.S. and TS, M. (1995). Environmental fate and chemistry of organic pollutantsin the sediments Xiamen and Victoria Harbours. *Marine Pollution Bulletin* 31: 229-36.

Indah Water Konsortium Sdn, Bhd. Sustainability report, 2013, https://www.iwk.com.my (accessed 8 June 2016).

Indah Water Konsortium Sdn, Bhd. planning of sewerage system. Kuala Lumpur : Malaysia, 2003, https://www.iwk.com.my/do-you-know/sewage-treatment-plan) (accessed 8 June 2016).

Ishiwatari, R., Takada, H., Yun, S.J. and Matsumoto, E. (1983). Alkylbenzene pollution of Tokyo Bay sediments. *Nature* 301: 599-600.

Iskandar Regional Development Authority (IRDA), Shoreline Management Plan Blueprint for Iskandar Malaysia.Iskandar service centre. 2011 , Johor Bahru, Malaysia. (http://iskandarmalaysia.com.my. Retrieved 18 June 2016.

Isobe, K. O., Tarao, M., Zakaria, M. P., Chiem, N. H., Minh, L. Y. and Takada, H. (2002). Quantitative application of fecal sterols using gas chromatography-mass spectrometry to investigate fecal pollution in tropical waters: Western Malaysia and Mekong Delta, Vietnam. *Environmental Science and Technology* 36 (21): 4497–4507.

Isobe, K. O., Zakaria, M. P., Chiem, N. H., Minh, L. Y., Prudente, M., Boonyatumanond, R., Saha, M., Sarkar, M. and Takada, H. (2004). Distribution of linear alkylbenzenes (LABs) in riverine and coastal environments in South and Southeast Asia. *Water Research* 38 (9): 2449-2459.

Johnson, S., Christofi, N. and Barr, D. A. (2003), Anaerobic Biodegradation of Linear Alkylbenzenes. In European Bioremediation Conference, 2., Chania, Crete, Greece. Proceedings. Chania.

Johnson, S. J., Castan, M. Proudfoot, L., Barry, D. A. and Christofi, N. (2007). Acute toxicity of linear alkylbenzene to Caenorhabditis elegans maupas, 1900 in soil. *Bulletin of Environmental Contamination and Toxicology* 79 (1): 41-44.

Jones, K. C. and de Voogt, P. (1999). Persistent organic pollutants (POPs): state of the science. *Environmental Pollution* 100: 209–221.

Kadaruddin, A. (1997). Penggunaan and pengurusan zon pinggir pantai Negeri Sembilan (Use and management of coastal zones, Negeri Sembilan). *Akademika* 50: 3–23.

Keshavarzifard, M., Zakaria, M. P., Shau Hwai, T., Yusuff, F. F., Mustafa, S., Vaezzadeh,V., Magam, S. M., Masood, N., Alkhadher, S. A. A. and Jahromi, F. A. (2014). Baseline distributions and sources of Polycyclic Aromatic Hydrocarbons (PAHs) in the surface sediments from the Prai and Malacca Rivers, Peninsular Malaysia. *Marine Pollution Bulletin* 88 (1-2): 366-372.

Keshavarzifard, M., Zakaria, M. P., Hwai, T.S., Yusuff, F.M. and Mustafa, S. (2015). Distributions and source apportionment of sediment-associated polycyclic aromatic aromatic hydrocarbons (PAHs) and hopanes in rivers and estuaries of Peninsular Malaysia. *Environmental Science Pollution Research* 22 (12): 9424-9437.

Kowalska, M., Güler, H. and Cocke, D. L. (1994). Interactions of clay minerals with organic pollutants. *Science of the Total Environment 141* (1): 223-240.

Kimerle, R.A. and Swisher, R.D. (1977). Reduction of aquatic toxicity of linear alkylbenzene sulfonates (LASs) by biodegradation. *Water Research* 11: 31-37.

Kong, K. Y., Cheung, K. C.,Wong, C. K. C. and Wong, M.H. (2005). The residual dynamic of polycyclic aromatic hydrocarbons and organochlorine pesticides in fishponds of the Pearl River delta, South China.2005. *Water Research* 39: 1831–1843.

Krumgalz, B.S. (1989). Unusual grain size effect on trace metals and organic matter in contaminated sediments. *Marine Pollution Bulletin* 20 (12): 608-611.

Law, A.T. and Azahar, O. (1990).Sewage pollution in the coastal waters off Port Dickson, Straits of Malacca. *Pertanika 1*3 (3): 375-380.

Lewis, M. A. (1991). Chronic and sublethal toxicities of surfactants to aquatic animals: a review and risk assessment. *Water Research* 25 (1): 101-113.

Lim, H. S., MatJafri, M. Z., Abdullah, K. and Asadpour, R. (2011). TSS Mapping Using THEOS Imagery over Penang Island, Malaysia. *In Proceeding of The First International Conference on Interdisciplinary Research and Development,* Dusit Palace, Sanam Sueapa, Bangkok, Thailand. Special Issue of the International Journal of the Computer, the Internet and Management Vol. 19 No. SP1 31 May–1 June 2011, Assumption University Press, Srisakdi Charonman IT Center, Assumption University of Thailand, Thailand. Volume 17, Number SP1. ISSN: 0858–7027. p.p. 55.1–55.6. Available online: http://www. inrit2011.com/Proceedings/55_01C_H.%20S.%20Lim_ [6].pdf.

Liu, L.Y., Wang, J. Z., Wei, G.L., Guan, Y. F. and Zeng, E.Y. (2012). Polycyclic aromatic hydrocarbons (PAHs) in continental shelf sediment of China: implications for anthropogenic influences on coastal marine environment. *Environmental Pollution* 167: 155-162.

Liu, L.Y., Wang, J.Z., Wong, C. S., Qiu, J.W., & Zeng, E.Y. (2013). Application of multiplegeochemical markers to investigate organic pollution in a dynamic coastal zone. *Environmental Toxicology and Chemistry* 32: 312–319.

Luo, X. J., Chen, S. J. Ni, H. G., Yu, M. and Mai, B. X. (2008). Tracing sewage pollution in the Pearl River Delta and its adjacent coastal area of South China Sea using linear alkylbenzenes (LABs). *Marine pollution bulletin* 56 (1): 158-162.

Macías-Zamora, J.V. and Ramírez-Alvarez, N. (2004). Tracing sewage pollution using Linear alkylbenzenes (LABs) in surface sediments at the south end of the Southern California Bight. *Environmental Pollution* 130: 229–238.

Magam, S. M., Zakaria, M. P., Halimoon,N., Masood, N. and Alsalahi, M. A. (2012). Aliphatic Distribution of Linear Alkylbenzenes (LABs) in Sediments of Sarawak andSembulan Rivers, Malaysia. *Environment Asia* 5 (1): 48-55.

Magam, S. M., Zakaria, M. P., Halimoon, N., Aris, A. Z., Kannan, N., Masood, N., Mustafa, S., Alkhadher, S. A., Keshavarzifard, M., Vaezzadeh, V., and Sani, M.S.A. (2015). Evaluation of distribution and sources of sewage molecular marker (LABs) in selected rivers and estuaries of Peninsular Malaysia. *Environmental Science Pollution research* 23 (6): 5693-5704.

Malaysia Water Industry Guide (MWIG). 2015, http://www.mwa. org. my/publication-guideline.html (accessed 8 June 2016).

Mangas, E., Vaquero, M.T., Comellas, L. and Broto-Puig, F. (1998). Analysis and fate of aliphatic hydrocarbons, linear alkylbenzenes, polychlorinated biphenyls and polycyclic aromatic hydrocarbons in sewage sludge-amended soils. *Chemosphere* 36 (1): 61-72.

Martins, C. C., Ferreira, J. A., Taniguchi, S., Mahiques, M. M., Bícego, M. C. and Montone, R. C. (2008). Spatial distribution of sedimentary linear alkylbenzenesand faecalsteroids of Santos Bay and adjoiningcontinental shelf, SW Atlantic, Brazil: origin and fate of sewage contamination in the shallow coastal environment. *Marine Pollution Bulletin* 56: 1353–1376.

Martins, C. C., Bícego, M. C., Mahiques, M. M., Figueira, R. C., Tessler, M. G. and Montone, R. C. (2010). Depositional history of sedimentary linear alkylbenzenes (LABs) in a large South American industrial coastal area (Santos Estuary, Southeastern Brazil). *Environmental Pollution* 158 (11): 3355-3364.

Martins, C. C., Aguiar, S. N., Bícego, M. C. and Montone, R. C. (2012a). Sewage organicmarkers in surface sedimentsaround the Brazilian Antarctic station: resultsfrom the 2009/10 austral summer and historical tendencies. *Marine Pollution Bulletin* 64: 2867-2870.

Martins, C. C., Bícego, M. C., Figueira, R.C.L., Angelli, J. L. F., Combi, T., Gallice, W. C., Mansur, A.V., Nardes, E., Rocha, M. L., Wisnieski, E., Ceschim, L. M. M. and Ribeiro, A.P., (2012b). Multi-molecular markers and metals as tracers of organic matter inputs and contamination status for an Environmental Protection Area in the SW Atlantic (Laranjeiras Bay, Brazil). *Science Total Environment (*417–418): 158– 168.

Martins, C. C., Cabral, A. C., Barbosa-Cintra, S. C. T., Dauner, A. L. L., and Souza, F. M. (2014). An integrated evaluation of molecular marker indices and linear alkylbenzenes (LABs) to measure sewage input in a subtropical estuary (Babitonga Bay, Brazil). *Environmental Pollution* 188: 71-80.

Masood, N., Zakaria, M. P., Ali, M. M., Magam, S. M., Alkhadher, S., Keshavarzifard, M., Vaezzadeh, V. and Hussein, M. A. (2014). Distribution of petroleum hydrocarbons in surface sediments from selected locations in Kuala Selangor River, Malaysia. In: Aris A. Z. et al. (Eds.), *From Sources to Solution, Proceedings of the International Conference on Environmental Forensics* 2013 (pp. 351-356). Singapore: Springer Science + Business Media.

Masood, N., Zakaria, M. P., Halimoon, N., Aris, A. Z., Magam, S. M., Kannan, N., Mustafa, S., Ali, M. M., Keshavarzifard, M., Vaezzadeh, V., Alkhadher, S. A. A. and Al-Odaini,N.A. (2015). Anthropogenic waste indicators (AWI) particularly PAHs and LABs in Malaysian sediments: application of aquatic environment for identifying anthropogenic pollution. *Marine Pollution Bulletin* 102 (1): 160-175.

Masron, T., Yaakob, U., Mohd Ayob, N. and Mokhtar, A. S. (2012). Population and spatial distribution of urbanisation in Peninsular Malaysia 1957 – 2000. *Malaysia Journal of Society and Space* 2: 20 – 29.

Matsumoto, E. (1983). The sedimentary environment in the Tokyo Bay. *Chikyukagaku (Geochemistry)* 17: 27-32.

Medeiros, P. M. and Caruso Bícego, M. (2004). Investigation of natural and anthropogenic hydrocarbon inputs in sediments using geochemical markers. I. Santos, SP—Brazil. *Marine pollution bulletin* 49 (9): 761-769.

Medeiros, P. M., Bícego, M. C., Castelao, R. M., Del Rosso, C., Fillmann, G., and Zamboni, A. J. (2005). Natural and anthropogenic hydrocarbon inputs to sediments of Patos Lagoon Estuary, Brazil. *Environment International Journal 31* (1): 77-87.

Murray, A. P., Gibbs, C. F. and Kavanagh, P. E. (1987). Linear alkyl benzenes (LABs) in sediments of Port Phillip Bay (Australia). *Marine Environmental Research* 23 (1): 65-76.

Murray, A. P, Richardson, B. J. and Gibbs, C. F. (1991). Bioconcentration factors for petroleum hydrocarbons, PAHs, LABs and biogenic hydrocarbons in the blue mussel. *Marine Pollution Bulletin* 22 (12): 595-603.

Needleman, S. B. and Robert, W. R. (1990). Limits of linearity and detection for some drugs of abuse. *Journal of Analytical Toxicology* 14 (1): 34-38.

Nexant. *Linear Alkylbenzene (LAB)*. ChemSystems Process Evaluation / Research Planning (PERP) Report, California, 2009. Retrieved from http://www.chemsystems.com, 5 February 2016.

Ni, H. G., Lu, F. H., Wang, J. Z., Guan, Y. F., Luo, X. L. and Zeng, E. Y. (2008). Linear alkylbenzenes in riverine runoff of the Pearl River Delta (China) and their application as anthropogenic molecular markers in coastal environments. *Environmental Pollution* 154 (2): 348-355.

Ni, H. G., Shen, R. L., Zeng, H. and Zeng, E. Y. (2009). Fate of linear alkylbenzenes and benzothiazoles of anthropogenic origin and their potential as environmental molecular markers in the Pearl River Delta, South China. *Environmental Pollution* 157 (12): 3502-3507.

Noor wahyu, B. N. *Factors influencing to the selection of sewage treatment plant*. MSc Thesis. Universiti Technology Malaysia. 2010.

Peterman, P. H. and Delfino, J. J. (1990). Identification of isopropylbiphenyl alkyl diphenylmethanes, diisopropylnaphthalene, linear alkyl benzenes and other polychlorinated biphenyl replacement compounds in effluents, sediments and fish in the Fox River system. *Wisconsin Biology Mass Spectrometry* 19: 755–770.

Phillips, C. R., Venkatesan, M. I. and Lin, T. (2001). Linear alkylbenzenes in muscle tissues of white croaker near a large ocean outfall in southern California, USA. *Environmental Toxicology and Chemistry* 20 (2): 231-238.

Pierard, C., Budzinski, H. and Garrigues, P. (1996). Grain-size distribution of polychlorobiphenyls in coastal sediments. *Environmental Science & Technology* 30 (9): 2776-2783.

Praveena, S. M. and Aris, A. Z. (2013). A baseline study of tropical coastal water quality in Port Dickson, Strait of Malacca, Malaysia. *Marine Pollution Bulletin* 67: 196–199.

Praveena, S. M., Shamira, S. S., Ismail, S. N. S. and Aris, A. Z. (2016). Fecal indicator bacteria in tropical beach sand: Baseline findings from Port Dickson coastline, Strait of Malacca (Malaysia). *Marine Pollution Bulletin* 110: 609–612.

Preston, M. R. and Raymundo, C. C. (1993). The associations of linear alkyl benzenes with the bulk properties of sediments from the River Mersey estuary. *Environmental Pollution* 81 (1): 7-13.

Ramli, A. T., Sahrone, S. and Wagiran, H. (2005). Terrestrial gamma radiation dose study to determine the baseline for environmental radiological health practices in Melaka state, Malaysia. *Journal of Radiological Protection* 25: 435–450.

Raymundo, C. C. and Preston, M. R. (1992). The distribution of linear alkylbenzenes in coastal and estuarine sediments of the Western North Sea. *Marine Pollution Bulletin* 24 (3): 138-146.

Raza, M., Zakaria, M. P., Hashim, N. R., Yim, U. H., Kannan, N. and Ha, S. Y. (2013). Composition and source identification of polycyclic aromatic hydrocarbons in mangrove sediments of Peninsular Malaysia: indication of anthropogenic input. *Environmental Earth Sciences* 70 (6): 2425-2436.

Razalli, N. M., Peng, T. C.,Yusof, M. S. M., Juliana Mohamed , J., Hwai, T. S., Yasin, Z. and Abdullah, A. L. (2011). Distribution and Biomass of Halophila ovalis (R. Brown) Hook.. f. at Pulau Gazumbo, Penang, Straits of Malacca. *Publications -Seto Marine Biological Laboratory* 41: 71 -76.

Rinawati., Koike, T., Koike, H., Kurumisawa, R., Ito, M., Sakurai, S., Togo,A., Saha, M., Arifinc,Z., and Takada, H. (2012). Distribution, source identification, and historical trends of organic micro pollutants in coastal sediment in Jakarta Bay, Indonesia. *Journal of Hazardous Materials* (217-218): 208-216.

Rinawati., and Takada, H. (2013). Molecular Marker of Sewage Contamination : Distribution of Linear Alkyl Benzenes (LABs) in Jakarta River. *In Prosiding Semirata FMIPA universitas Lampung (In Proceedings Semirata Science Po university)*, Lampung, Indonesia, 2013.

Robinson, E. C. and Nair, R. S. (1992).The genotoxic potential of linear alkylbenzene mixtures in a short-term test battery. *Fundamental Applied Toxicology* 18: 540–548.

Robinson, E. C. and Schroeder, R. E. (1992). Reproductive and developmental toxicity studies of a linear alkylbenzene mixture in rats. *Fundamental Applied Toxicology* 18: 549–556.

Rosman, P.S. (2015). Water Quality Assessment of Muar River Using Environmetric Techniques and Artificial Neural Networks. *In Proceeding of Engineering Technology International Conference*, Bali, Indonesia, August. 10-11, 2015.

Rosnani, I. (2001). River water quality status in Malaysia. *In Proceedings of national conference on sustainable river basin management in Malaysia*, Kuala Lumpur, Malaysia, November. 13–14, 2000.

Sanagi, M. M., Ling, S. L., Nasir, Z., Hermawan, D., Ibrahim, W. A. and Abu Naim, A. (2009). Comparison of signal-to-noise, blank determination, and linear regression methods for the estimation of detection and quantification limits for volatile organic compounds by gas chromatography. *Journal of AOAC International* 92 (6): 1833–1838.

Sany, S. B. T., Salleh, A., Rezayi, m., Saadati , N., Narimany, L. and Tehrani, G. M. (2013). Distribution and Contamination of Heavy Metal in the Coastal Sediments of Port Klang, Selangor, Malaysia.*Water Air Soil Pollution* (2013) 224: 1476.

Scott, M. J. and Jones, M. N. (2000). The biodegradation of surfactants in the environment. *Biochimica et Biophysica Acta (BBA)-Biomembranes* 1508 (1): 235-251.

Serrazanetti, G. P., Pagnucco, C., Conte, L. S. and Artusi, R. (1994). Aliphatic hydrocarbons and linear alkylbenzenes in zooplankton from the Gulf of Trieste. *Chemosphere* 28 (6): 1119-1126.

Shahbazi, A., Zakaria, M. P., Yap, C. K, Tan, S. G, Surif, S., Mohamed, C. A. R. and Chandru, K. (2010). Use of different tissues of Perna viridis as biomonitors of polycyclic aromatic hydrocarbons (PAHs) in the coastal waters of Peninsular Malaysia. *Environmental Forensics* 11 (3): 248-263.

Sherblom, P. M., Gschwend, P.M. and Eganhouse, R.P. (1992). Aqueous solubility, vaporpressure, and n-octanol-water partition coefficients for C9-C14 linear alkylbenzenes. *Journal of Chemical and Engineering Data* 37: 394–399.

Shea, D. and Kelly, J.R. (1992). Transport and fate of toxic contaminants discharged in MWRA input to the Massachusetts Bay. Massachusetts Water Resources Authority, Boston, MA, Technical Report 92-94.

Simpson, C. D., Mosi, A. A., Cullen, W. R. and Reimer, K. J. (1996). Composition and distribution of polycyclic aromatic hydrocarbon contamination in surficial marine sediments from Kitimat Harbor, Canada. *Science of the Total Environment* 181 (3): 265-278.

Steber, J. and Berger, H. (1995). The Biodegradability of anionic surfactants. IN D.R. Karsa, M.R. Porter (Eds.). *Biodegradability of Surfactants, Blackie Academic and Professional* **(**pp**.**134-182). Netherlands **:**. Springer.

Sung, W. and Higgins, M. (1998). Deer Island Effluent Characterization Studies: January 1997-October 1997. Boston: Massachusetts Water Resources Authority. Report ENQUAD 98-06.77p.

Sur, D., Manna, B., Deb, A. K., Deen, J. L., Holliday, M. C., Seidlein, L. V., Clemens, J. D . and Bhattacharya, S. K. (2004). Factors Associated with Reported

Diarrhoea Episodes and Treatment-seeking in an Urban Slum of Kolkata, India. *Journal of Health, Population and Nutrition* 22 (2): 130-138.

Takada, H. and Eganhouse, R. P. (1998). Molecular markers of anthropogenic waste. In R. A. Meyers. *Encyclopedia of Environmental Analysis and Remediation* (pp. 2883-2940). New York: John Wiley & Sons.

Takada, H., Farrington, J. W., Bothner, M. H., Johnson, C. G. and Tripp, B. W. (1994). Transport of sludge-derived organic pollutants to deep-sea sediments at Deep Water Dump Site 106. *Environmental Science and Technology* 28 (6): 1062-1072.

Takada, H. and Ishiwatari, R. (1985). Quantitation of long-chain alkylbenzenes in environmental samples by silica gel column chromatography and high-resolution gas chromatography. *Journal of Chromatography A* 346: 281-290.

Takada, H. and Ishiwatari, R. (1987). Linear alkylbenzenes in urban riverine environments in Tokyo: distribution, source, and behavior. *Environmental Science & Technology* 21 (9): 875-883.

Takada, H. and Ishiwatari, R. (1990). Biodegradation experiments of linear alkylbenzenes (LABs): isomeric composition of C_{12} LABs as an indicator of the degree of LAB degradation in the aquatic environment. *Environmental Science and Technology* 24 (1): 86-91.

Takada, H. and Ishiwatari, R. (1991). Linear alkylbenzenes (LABs) in urban riverine and coastal sediments and their usefulness as a molecular indicator of domestic wastes. *Water Science & Technology* 23 (1-3): 437-446.

Takada, H., Ishiwatari, R. and Ogura, N. (1992). Distribution of linear alkylbenzenes (LABs) and linear alkylbenzenesulphonates (LAS) in Tokyo Bay sediments. Estuarine, Coastal and Shelf Science 35 (2): 141-156.

Tourism Malaysia, Malaysia travel guide, year of festival 2015, Kuala Lumpur, Malaysia, 2015, http://motac.gov.my/en/media/press-release/815-the-malaysia-year-of-festivals-myfest-2015-a-national-campaign-to-continue-boosting-the-national-tourism-growth (accessed 3 February 2017).

Tsutsumi, S., Yamaguchi, Y., Nishida, I., Akiyama, K. I., Zakaria, M. P. and Takada, H. (2002). Alkylbenzenes in mussels from South and Southeast Asian coasts as a molecular tool to assess sewage impact. *Marine Pollution Bulletin* 45 (1): 325-331.

Valls, M., Bayona, J. M. and Albaiges, J. (1989). Use of trialkylamines as an indicator of urban sewage in sludges, coastal waters and sediments. *Nature* 337 (6209): 722-724.

Vaezzadeh,V., Zakaria, M.P., Mustafa, S., Ibrahim, Z. Z.,Shau-Hwai, A.T., Keshavarzifard, M., Magam, S.M. and Masood, N. (2014). Distribution of polycyclic aromatic hydrocarbons (PAHs) in sediment from Muar River and

Pulau Merambong, Peninsular Malaysia. In: A.Z., Aris et al. (Eds.), *From Sources to Solution*, *Proceedings of the International Conference on Environmental Forensics* 2013 (pp. 351-356). Singapore: Springer Science Business Media.

Vaezzadeh, V., Zakaria, M. P., Shau-Hwai, A.T., Ibrahim, Z. Z., Mustafa, S., Jahromi, F.A., Masood, N., Magam, S.M. and Alkhadher, S.A.A. (2015). Forensic investigation of aliphatic hydrocarbons in the sediments from selected mangrove ecosystems in the west coast of Peninsular Malaysia. *Marine Pollution Bulletin* 100 (1): 311–320.

Venkatesan, M.I., Merino, O., Baek, J., Northrup, T., Sheng, Y. and Shisko, J. (2010). Traceorganic contaminants and their sources in surface sediments of Santa Monica Bay, California, USA. *Marine Environmental Research* 69 (5): 350–362.

Venturini, N., Bícego, M.C., Taniguchi, S., Sasaki, S., García-Rodríguez, F., Brugnoli, E. and Muniz, P. (2015). A multi-molecular marker assessment of organic pollution inshore sediments from the Río de la Plata Estuary, SW Atlantic. *Marine Pollution Bulletin* 91: 461–475.

Verge, C., Bravo, J., Moreno, A. and Berna, J. L. (1999). Acute toxicity of linear alkylbenzene (LAB) to Daphnia magna. *Tenside, Surfactants, Detergents* 36 (2): 127-129.

Vivian, C. (1986). Tracers of sewage sludge in the marine environment: a review. *Science of the Total Environment* 53 (1): 5-40.

Wada, E., Kabaya, Y., Tsuru, K. and Ishiwatari, R. (1990). 13C and 15N abundance of sedimentary organic matter in estuarine areas of Tokyo Bay, Japan. *Mass Spectroscopy* 38 (6): 307-318.

Wang, X.C., Zhang, Y.X. and Chen, R. F. (2001). Distribution and partitioning of polycyclic aromatic hydrocarbons (PAHs) in different size fractions in sediments from Boston Harbor, United States. *Marine Pollution Bulletin* 42 (11): 1139-1149.

Wang, J. Z., Guan, Y. F., Ni, H. G., Liu, G. J., and Zeng, E. Y. (2010). Fecal steroids in riverine run off of the Pearl River Delta, South China: Levels, potential sources and inputs to the coastal ocean. *Journal of Environmental Monitoring* 12: 280–286.

Wang, J.Z., Zhang, K. and Liang, B. (2012). Tracing urban sewage pollution in Chaohu Lake (China) using linear alkylbenzenes (LABs) as a molecular marker. *Science of the Total Environment* 414: 356-363.

Wania, F., Axelman, J. and Broman,D. (1998). A review of processes involved in the exchange of persistent organic pollutants across the air–sea interface. *Environmental Pollution* 10: 3–23.

Wei,G.L.,Liu,L.Y., Bao,L.J. and Zeng,E.Y. (2014a). Tracking anthropogenic influences on the continental shelf of China with sedimentary linear alkylbenzenes(LABs). *Marine Pollution Bulletin* 80: 80-87.

Wei, G. L., Bao, L. J., Guo, L. C., He, Z. C., Wu, F. C. and Zeng, E.Y.(2014b). Utility of soil linear alkylbenzenes to assess regional anthropogenic influences with special reference to atmospheric transport. *Science of the Total Environment* 487: 528-536.

World Bank. (2010). Managing Pollution for Poverty Reduction and Green Development. Available from: http://web.worldbank.org (accessed 27 February 2017).

Zakaria, M. P., Takada, H., Tsutsumi, S., Ohno, K., Yamada, J., Kouno, E. and Kumata, H. (2002). Distribution of polycyclic aromatic hydrocarbons (PAHs) in rivers and estuaries in Malaysia: a widespread input of petrogenic PAHs. *Environmental Science & Technology* 36 (9): 1907-1918.

Zeng, E.Y., Khan, A.R. and Tran, K. (1997). Organic pollutants in the coastal environment Off San Diego, California. 3. Using linear alkylbenzenes to trace sewage-derived organic materials. *Environmental Toxicology and Chemistry* 16 (2): 196–201.

Zeng, E. Y., Cheng, D., Khan, A. R. and Vista, C. L. (1998). Validity of using linear alkylbenzenes as markers of sewage contamination with interference from tetrapropylene-based alkylbenzenes. *Environmental Toxicology and Chemistry* 17 (3): 394-397.

Zhang, K., Wang, J. Z. Liang, B., Shen, R. L. and Zeng, E. Y. (2012). Assessment of aquatic wastewater pollution in a highly industrialized zone with sediment linear alkylbenzenes. Environmental Toxicology and Chemistry 31 (4): 724-730.