UNIVERSITI PUTRA MALAYSIA

DISTRIBUTION AND CONCENTRATION OF LINEAR ALKYLBENZENES IN RIVER SEDIMENTS AND SHORT-NECK CLAMS (Paphia Undulata) IN PENINSULAR MALAYSIA

SAMI MUHSEN SLEMAN MAGAM

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By

SAMI MUHSEN SLEMAN MAGAM

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

March 2018

DEDICATION

To the sources of my inspiration:

The memory of my beloved mother;

My beloved father;

My beloved wife;

My lovely daughters (Malak and Farah);

All my brothers and sisters;

All other family members and respected friends

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

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Chairperson: Normala bt. Halimoon, PhD
Faculty: Environmental Studies

Due to population growth and extensive urbanization in recent years, urban wastewater has entered to the rivers and coastal environment in Peninsular Malaysia, causing risks to human health and posing threats to other organisms. Therefore, tracing regional anthropogenic influences is important for assessing the magnitude of pollution caused by human activities and its consequences to the environment, especially aquatic ecosystems. In the present study, the presence of linear alkylbenzenes (LABs) that can be used as sawage indicator in equatic enviroment was examined in sediments and short-neck clams (*Paphia Undulata*) tissue. This study aimed to investigate the distribution, concentration and composition of LABs, and also degradation of LABs with the emphasis on the role of bioavailability of LABs to *P. undulata* from sediments and dissipating LABs from input sources to remote areas. Sediment samples were collected from selected rivers and estuaries from the Kedah, Merbok, Prai, Perak, Klang Melaka, Segget, Kuantan, Terengganu, and Kelantan, while *P. undulata* samples were taken from the Kedah, Merbok, Prai, Perak, Klang and Melaka Estuaries in Peninsular Malaysia from January 2013 to February 2014. The sediments and *P. undulata* samples were homogenized, freeze-dried, extracted, cleanup, fractionated and analyzed using gas chromatography mass spectrometry (GC-MS). The concentrations of total LABs in sediments varied from 55.22 to 3117.16 ng g^{-1} dry weight (dw) and *P. undulata* varied from 21.09 to 861.65 ng g^{-1} dw. LABs in sediments can be classified as low to moderate (55.22 to 313.69 ng g^{-1}) contamination in the Kedah, Kuantan, Perlis, Merbok, Kelantan, Terengganu and Perak, moderate to high (977.81 to 1,427.37 ng g^{-1}) in the Segget, and Melaka and high to very high (2,909.59 to 3,117.16 ng g^{-1}) in the Prai and Klang Rivers and Estuaries. LABs in the soft tissues of *P. undulata* can be classified as moderate contamination in the Kedah and Melaka, low contamination in the Perak and Merbok and high contamination in the Prai and Klang. The compositional profiles of LABs in sediments and *P. undulata* of the studied areas demonstrated that the levels of long chain alkylbenzenes (C13; 33 %) were higher than short chain alkylbenzenes (C10; 11 %). The results from the ratio of internal (I) and external (E) isomers of LABs (I/E ratios), in the surface sediments were from 0.56

to 3.18, while the results from I/E ratios in *P. undulata* were from 0.70 to 3.21 indicating a range of raw, primary to secondary treated sewage effluents. The values of the ratio of 5-C_{13}LAB+5-C_{12}LAB relative to 5-C_{11}LAB+5-C_{10} LAB (L/S ratio) ranged from 1.04 to 4.03 in the sediments and from 0.87 to 4.87 in (*P. undulata*). Meanwhile, the values of the ratio of 6-,5-,4-,3-and 2-C_{13}/6-, 5-, 4-, 3-, and 2-C_{12}LAB (C_{13}/C_{12} ratio) ranged from 1.14 to 3.54 in the sediments and from 2.23 to 4.78 in *P. undulata* in the coastal areas of Peninsular Malaysia. These values are slightly higher than those of the commercial detergents. There was significant correlation (r = 94, $p < 0.05$) between total parent LABs in sediments and in *P. undulata* which indicated the ability of *P. undulata* to accumulate the LABs. Therefore, *P. undulata* can be considered as a good biomonitor of LABs in the aquatic environment. 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 aquatic environment.

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

TABURAN DAN KEPEKATAN ALKILBENZENA LURUS DI DALAM SEDIMENT SUNGAI DAN KERANG BERLEHER PENDEK (*Paphia Undulata*) DI PENINSULAR MALAYSIA

Oleh

SAMI MUHSEN SLEMAN MAGAM

March 2018

Pengerusi: Normala bt. Halimoon, PhD
Fakulti: Pengajian Alam Sekitar

Disebabkan pertumbuhan populasi dan perbandaran yang meluas, air sisa perbandaran telah mengalir ke sungai dan pantai di Semenanjung Malaysia menyebabkan risiko kepada kesihatan manusia dan ancaman kepada organisma-organisma lain. Oleh itu, pengesanan pengaruh antropogenik serantau juga adalah penting untuk menilai tahap pencemaran yang disebabkan oleh aktiviti-aktiviti manusia dan kesan-kesannya terhadap alam sekitar terutamanya ekosistem akuatik. Dalam kajian ini, penggunaan alkilbenzena lurus (LABs) yang boleh digunakan sebagai penunjuk kumbahan di persekitaran akuatik diperiksa di sedimen dan tisu leher pendek (*Paphia Undulata*). Kajian ini bertujuan untuk untuk menyiasat taburan, kepekatan dan komposisi LABs, dan juga degradasi LABs dengan penekanan terhadap peranan keupayaan biologi LABs ke atas (*P. undulata*) dari sedimen-sedimen dan pengaliran LABs dari sumber masuk ke kawasan terpencil. Sampel-sampel sedimen diambil dari sungai-sungai dan muara-muara terpilih di Kedah, Merbok, Prai, Perak, Klang Melaka, Segget, Kuantan, Terengganu, dan Kelantan, manakala kerang berleher pendek (*P. undulata*) telah diambil dari Kedah, Merbok, Prai, Perak, Klang dan muara Melaka di Semenanjung Malaysia dari Januari 2013 hingga Februari 2014. Sampel-sampel sedimen dan *P. undulata* telah dihomogen, dibekukering, diekstrak, dibersihkan, difraksinasi dan dianalisa menggunakan kromatografi gas spektrometri jisim (GC-MS). Jumlah kepekatan LAB dalam sedimen adalah dari 55.22 hingga 3,117.16 ng g^{-1} berat kering (dw) dan dalam *P. undulata* adalah dari 21.09 ke 861.65 ng g^{-1} dw. LAB dalam sedimen-sedimen boleh diklasifikasikan berpencemaran rendah ke sederhana (55.22 hingga 313.69 ng g^{-1}) di Kedah, Kuantan, Perlis, Merbok, Kelantan, Terengganu dan Perak, sederhana ke tinggi (977.81 hingga 1,427.37 ng g^{-1}) di Segget dan Melaka dan tinggi ke sangat tinggi (2,909.59 hingga 3,117.16 ng g^{-1}) di sungai dan muara Prai dan Klang. LABs di dalam tisu lembut *P. Undulata* boleh dikelaskan sebagai berpencemaran sederhana di Kedah dan Melaka, berpencemaran rendah di Perak dan Merbok serta berpencemaran tinggi di Prai dan Klang. Profil komposisi LABs dalam sedimen-sedimen dan *P. undulata* di kawasan kajian menunjukkan bahawa alkilbenzena rantai panjang (C13; 33%) adalah lebih tinggi daripada alkilbenzena rantai pendek (C10; 11%). Keputusan daripada nisbah dalaman per

luaran (I/E) di permukaan sedimen adalah dari 0.56 ke 3.18, manakala keputusan daripada nisbah I/E dalam *P. undulata* adalah dari 0.70 ke 3.21 menunjukkan suatu julat efluen kumbahan mentah, efluen kumbahan terawat primer ke sekunder. Nilai nisbah 5-C_{13}LAB+5-C_{12}LAB terhadap 5-C_{11}LAB+5-C_{10}LAB (nisbah L/S) adalah berjulat anatara 1.04 hingga 4.03 di dalam sedimen-sedimen dan antara 0.87 to 4.87 di dalam *P. undulata*. Sementara itu, nilai nisbah 6-,5-,4-,3-dan 2-C_{13} / 6-, 5-, 4-, 3-, dan 2-C_{12}LAB (nisbah C_{13}/C_{12}) adalah berjulat antara 1.14 hingga 3.54 di dalam sedimen-sedimen dan antara 2.23 hingga 4.78 di dalam *P. undulata* di kawasan pantai Semenanjung Malaysia. Nilai-nilai ini adalah sedikit tinggi daripada nilai yang terdapat di dalam detergen-detergen komersial. Terdapat korelasi yang signifikan ($r = 94$, $p < 0.05$) antara jumlah LABs induk di dalam sedimen-sedimen dan di dalam *P. undulata* ($p < 0.05$) yang menunjukkan keupayaan *P. undulata* mengumpul LABs di persekitaran akuatik. Oleh itu, *P. undulata* boleh dijadikan sebagai biomonitor LABs yang baik dalam persekitaran akuatik. Berdasarkan keputusan dari kepekatan-kepekatan LABs, adalah disyorkan agar kawasan-kawasan berlainan di Malaysia harus dipantau dan diuruskan untuk mengurangkan paras kemasukan LABs ke persekitaran akuatik.

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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
TAMs	Trialkylamines
LOD	Limit of detection
LOQ	Limit of quantification
PAHs	Polycyclic Aromatic Hydrocarbons
POPs	Persistent organic pollutant
PCBs	Polychlorinated biphenyls
ABS	Alkybenzene sulfonates
a-TA	a-Tocopheryl acetate
APR	Aminopropanone
BASs	Branched alkylbenzene sulphonates
Biphe-d10	Biphenyl-deuterated -10
DATs	Dialkyltetralinsulfonates
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
UKM	Universiti Kebangsaan Malaysia
SCS	South China Sea
Silicones	Polyorganosiloxanes
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 study

In the last few decades, the rapidly-growing population, industrialization, and urbanization in the world have been accompanied by growing health risks due to the increasing inputs of wastes, including untreated domestic wastewater, into the environment, especially the aquatic environments (UN, 2003). As a matter of fact, most of the environmental degradation issues are attributed to human activities such as lodging, industrial activities, and waste disposal (Shahbazi et al., 2010). Specifically, the lack of precautionary steps taken by humans when engaged in such activities is the main reason behind these environmental problems. Efficiency of the municipal sewage treatment systems can decrease the load of pollutants in the sewage discharged directly into the aquatic environment. However, in most of the rural areas the sewage treatment service is not available and inefficient if available (Alkhadher et al., 2016). Subsequently, organic wastes associated with the untreated sewage effluents are discharged into the aquatic environment in many developing countries where the proper facilities for collection and treatment of sewage are still lacking (Takada et al., 1992; Martins et al., 2008).

Malaysia is situated in Southeast Asia, surrounded by the South China Sea and the Strait of Melaka. Its land area borders with Thailand in the north while its maritime areas border with Indonesia, Singapore, and Vietnam. The population of Malaysia was estimated at 30 million in the year of 2014 (Department of Statistics Malaysia, 2014). The climate of Peninsular Malaysia is characterized by heavy rainfall as is common for a tropical rainforest climate.

Rapid urbanization and industrialization in Malaysia over the recent decades have resulted in an increase in the use of the household detergents and the release of municipal and industrial effluents and domestic wastes, which are reasons for serious concern about safety and health of the Malaysian aquatic environment (Alkhadher et al., 2015). These detergents and wastes led to an increase in the levels of the linear alkylbenzens (LABs) in the local environment. In recent years, urban and industrial development also increased in line with the increase in the population of Malaysia (Masood et al., 2016). Consequently, the environment of Malaysia is nowadays receiving a multitude of hazardous compounds from various anthropogenic sources (Tsutsumi et al., 2002; Isobe et al., 2004). The different wastes have industrial pollutants, which is a factor that contributed to an increase in the industrial pollution, including the release of surfactants such as the LABs into the aquatic environment (Rinawati et al. (2013). These compounds are released from anthropogenic sources such as the industrial activities and, as a group, are one of the persistent organic pollutants (POPs).

The Malaysian rivers and estuaries are constantly exposed to various types of pollutants. The pollution problems have drawn intense public attention with the increasing industrialization and urbanization in Malaysia since the 1980s and the sources of land and sea-based pollution in the Malaysian aquatic environment have been overviewed (Shahbazi et al., 2010). Huge threats are posed on the aquatic environment in Malaysia by domestic discharge, industrial and agricultural effluents, and sewage contamination. A significant threat is particularly imposed on the aquatic environment by the wide use of *synthetic detergents in urban areas and industries.* In fact, pollutants associated with sewage are released into the aquatic environment through spills or leaks of household detergents, municipal and industrial effluents, and domestic waste (Takada et al., 1992). The rapidly-growing population and concomitant increase in the use of detergents result in release of a wide array of pollutants, including LABs, into the aquatic ecosystem. The LABs derive from industrial and domestic wastes and are transported to the aquatic environment through lateral transport, urban runoff, and drainage, among others (Rinawati et al., 2012). In addition, a large amount of untreated sewage enters the coastal environment when the storm water drainage systems and the sewage systems are combined as a result of rainstorm overloads. This seriously pollutes the waterways and surrounding areas (Isobe et al., 2004).

Earlier research (Tsutsumi et al., 2002) has shown that the origins and distribution of LABs in Malaysia differ across locations. For example, in the west coast of Peninsular Malaysia, the high urban development and intense industrial activity introduce LABs into the aquatic environment from non-point sources, including urban run-off, and point sources like factories. Nevertheless, there is still limited information on the environmental distribution of LABs in Malaysia (Isobe et al., 2004). Therefore, it is an obligation to investigate the amounts and sources of the LABs that are released into the aquatic environment.

Molecular markers are extremely useful for detection of sewage and domestic waste and identification of the sources and transport pathways of sewage in the aquatic environment (Takada and Eganhouse, 1998; Eganhouse, 2004; Dwiyitno et al., 2016). In this context, the LABs are a group of the most useful markers for tracing organic contaminants from point and non-point sources of pollution due to their stability in sediments and biodegradation during transport. Such molecular markers of sewage pollution as the LABs can be utilized to detect of sewage pollution in Malaysian rivers (Tsutsumi et al., 2002; Isobe et al., 2007; Alkhadher et al., 2015). Consequently, this study investigates the levels and distribution of LABs in the Malaysian aquatic environment.

1.2 Problem statement

The rivers and estuaries in the urban, industrial, and agricultural areas of Peninsular Malaysia are contaminated to various degrees with sewage (Isobe et al., 2004). The rivers under study (i.e., Perlis, Kedah, Merbok, Perai, Perak, Klang, Melaka, Segget, Kuantan, Terengganu, and Kelantan rivers) are surrounded by fast-growing industries and urban centers, which impose high health risks to the public and the riverine environment through sewage discharges. Thus, monitoring LABs contaminants as sewage indicators is very important.

Huge amounts of untreated wastewater or poorly-treated sewage are being discharged into the aquatic ecosystems of Peninsular Malaysia. Stranded or remobilized LABs attached to suspended particulates and sediments may also become available to filter feeders, particularly clams that inhabit the inter-tidal and shallow sub-tidal seabed. One of these filter feeder organisms is *Paphia undulata* (*P. undulata*), which is an important protein source in West Malaysia. However, it can sequester many lipophilic organic compounds such as the LABs and it can, thus, be a good biomonitor of these contaminants. At present, no information is available regarding the concentrations of LABs in short-neck clam or carpet clam (*P. undulata*) originating from the rivers and estuaries of Peninsular Malaysia. In consequence, this study aims at investigating the concentrations, distribution, and possible sources of LABs that are accumulated by short-neck clams (*P. undulata*) in this region. LABs are a suite of chemical markers that have been successfully utilized as organic molecular markers for evaluating the source of sewage pollution (Eganhouse, 1997). Due to their exclusive association with human activities, LABs can be used as evidence of anthropogenic impact on the marine environment. Most of LABs production is used to manufacture linear alkylbenzene sulfonates (LAS), which is used in household synthetic detergents production (Eganhouse et al., 1983). Because of this, LABs are fast becoming the most common raw material in the manufacturing of household detergents. Due to its improved biodegradability and cost-effectiveness, LABs have completely replaced the older branched alkylbenzene in the production of surfactants that have been used in household laundry detergents and dishwashing applications since the 1960s.

Environmental protection against release of hazardous materials is a major scientific, social, and economic purpose of the world today. Contamination of coastal areas can be looked upon as a serious threat to human health and natural resources. In this regard, clear understanding of the distribution and sources of LABs in the environment is the first step to control and reduce the negative impacts of these contaminants on the aquatic environment and public health. In this respect, investigation of contamination with the LABs has been carried out in various locations across the globe during recent years (Heim et al., 2004; Hartmann et al., 2005). However, this issue has not been well-addressed in the aquatic ecosystems of Peninsular Malaysia so far and, hence; further studies need to be performed in order to develop a better understanding of the problem. To the researcher's best knowledge, this is the first study investigating the levels and distribution of LABs in all the major rivers in Peninsular Malaysia.

1.3 Significance of the study

One of the most significant environmental concerns in the third millennium is safeguarding water resources, including the aquatic ecosystem (World Bank, 2010). Therefore, scrutinizing the natural waterways and implementing suitable management of wastewater for emerging contaminants have become unavoidable actions to ensure good quality of water and a healthy ecosystem. This study evaluated the levels of LABs in different rivers and estuaries in Peninsular Malaysia and compared between the rivers in these parameters. This study is significant since it generated valuable data on the concentrations and sources of LABs in the riverine and estuarine sediments of selected rivers all over Peninsular Malaysia (i.e., Perlis, Kedah, Merbok, Perai, Perak, Klang, Melaka, Segget, Kuantan, Terengganu, and Kelantan rivers). The study provides assessment of the extent of pollution with LABs in these rivers. Moreover, in order to efficiently control release of LABs into the environment, the present study provides data on the sources of LABs in the studied rivers.

On the other hand, there are some reported studies that evaluated the LAB concentrations in aquatic organisms such as green mussel (*Perna viridis*) (e.g., Tsutsumi et al. (2002) and Isobe et al. (2007)). The bivalves can be good biomonitor for contaminants like the LABs because of their sessile living style, high abundance, ease of culture in the laboratory, and convenient sampling. They occupy an important position in the food chain and can tolerate a high amount of contaminants without dying. Within this context, short-neck clams (*P. undulata*) is considered as an important protein source in West Malaysia. It has the ability to sequester many lipophilic organic compounds such as LABs and can be a good biomonitor. The different species of LABs may have different bioavailabilities for short-neck clams (*P. undulata*) and only the bioavailable fractions of the contaminants can pass through the food chain. Hence, this study is significant in that it evaluated suitability of short-neck clams (*P. undulata*) as sentinel biomonitor of LAB pollution was also evaluated.

Fine materials like clay, sand, and shell fragments in the water column may act as sorptive materials for organic contaminants (Martins et al., 2010) and all kinds of pollution stemming from human activities and reaching to surface water systems will eventually settle down in surface sediments (Abdullah et al., 1999; Vaezzadeh et al., 2014; Keshavarzifard, et al., 2015), which constitute the sink for the organic contaminants that are strongly associated with the suspended particulate matter. In this respect, most of the contaminants demonstrate their fingerprints in the sediments and, therefore, sediment analysis has certain advantages over the analysis of water. Thus, the study of LABs in sediments is of high importance due to the high affinity of LABs with sewage and suspended particles. Owing to that the sedimentary ecosystems are exposed to the accumulation of LABs in the sediments because of the increasing pollution level along the rivers and estuaries (Alkhadher *et al.*, 2016), the results of this study will help in specifying whether or not the sediment ecosystem in Malaysia is affected by sewage pollution by using LABs as indicatore markers.

1.4 The objectives of the study

The main objective of this study was to analyze the amount of pollution of the surface sediments and tissues of *P. undulata* with LABs originating from anthropogenic sources. The specific objectives of the study were:

I. To determine the concentrations, distribution and compositions of LABs in sediments and short-neck clams (*P. undulata*) tissues in the selected rivers around Peninsular Malaysia.
II. To identify the degree of LABs degradation in the sediments and short-neck clams (*P. undulata*) tissues in Peninsular Malaysia`` using diagnostic indices.
III. To investigate the relationships between the concentrations of LABs in sediments and tissues of short-neck clams (*P. undulata*) in the studied areas.

1.5 Hypotheses

This study initiated based upon the hypotheses as listed below:

i. There is no significant difference between the mean concentrations of LABs in the sediment and tissues of *P. undulata* in the rivers of Peninsular Malaysia due to similar source of pollution.
ii. Raw and primary sewage effluents are the major sources of LABs in sediments and tissues of *P. undulata* due to inadequate and/or improper treatment plants in the study area.
iii. *P. undulata* is capable of accumulation of LABs in tissues due to hydrophobic characteristics of LABs.

1.6 Research questions

The major questions which this research sought to provide answers for were:

(1) What are the distributions, concentrations, and compositions of LABs in the sediments and tissues of short-neck clams (*P. undulata*) in the studied rivers and estuaries?
(2) To what extent were the LABs biodegraded in the aquatic environment?
(3) Are there significant correlations between the levels of the investigated LABs in the sediments and total organic carbon (TOC) in the studied rivers?
(4) What are the strengths and directions of the correlation between LABs in sediments and tissues of short-neck clams (*P. undulata*) in the studied rivers?

1.7 Thesis structure

The thesis structure is a simply flow chart describing the thesis design contents. The first chapter is an Introduction to the study. It provides background on the study, the research problem, significance of the study, and the research questions and objectives. The second chapter is the literature review chapter. It provides a comprehensive review of previous related research on distribution, sources, pathways, and fate of organic contaminants in the environment across the globe, with emphasis on LABs and on Peninsular Malaysia.

The third chapter is the methodology chapter. It describes the study area, sampling locations, sample preparation, and sample analysis. The forth chapter presents and discusses the study results. The first, second, and third sections of this chapter present the results related to the distribution and sources of LABs in the sediments. Thus, these three sections cover the first research objective. The fourth, fifth, and sixth sections of the chapter discuss the results pertaining to the distribution and sources of LABs in short-neck clams (*P. undulata*), thus addressing the second research objective.

Finally, the fifth chapter highlights the main conclusions of this study and gives recommendations for future research.

REFERENCES

Abdullah, A.R., Tahir, N.M., Loong, T.S., Hoque, T.M. and Sulaiman, A.H., 1999. The GEF/UNDP/IMO Malacca Straits Demonstration Project: Sources of Pollution. *Marine Pollution Bulletin*, 39 (1-12), 229-233.

Abdullah, N.H., Mohamed, N., Sulaiman, L.H., Zakaria, T.A. and Abdul Rahim, D., 2016. Potential Health Impacts of Bauxite Mining in Kuantan. *Malaysian Journal of Medical Sciences,* 23(3): 1-8.

Abessa, D.M.S., Scott, C., R., Bauer, R.R.F., Eduinetty, S.C.M.P., Hotelani, M.A. and Sarkis, J.E., 2005. Influence of a Brazilian sewage outfall on the toxicity and contamination of adjacent sediments. *Marine Pollution Bulletin*, 50, 875-885.

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.

Agasen, E., Del Mundo, C. and Matias, G., 1998. Assessment of Paphia undulata in Negros Occidental/Guimaras Strait waters. *Journal of Shellfish Research*, 17: 1613-1617.

Ahmad, A.K., Mushrifah, I. and Othman M.S, 2009. Water Quality and Heavy Metal Concentrations in Sediment of Sungai Kelantan, Kelantan, Malaysia: A Baseline Study. *Sains Malaysiana,* 38(4) (2009): 435–442.

Amneera, W.A. Najib, Z.A.W., Yusof S.R.M. and Ragunathan, S., 2013. Water QualityIndexof Perlis River, Malaysia. *International Journal of Civil and Environmental Engineering*, 13 ,21.

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.

Almeida D.J., 1994. Dufaux M, Taarit Y, Naccache C. Linear alkylbenzene.*Journal of the American Oil Chemists' Society*, 71:675–94.

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., 2015. 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., 2016. 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.

Al-Shami, S., Rawi, C.S.M., Nor, S.A.M., Ahmad, A.H. and Ali, A., 2010a. Morphological deformities in Chironomus spp. (Diptera: Chironomidae) larvae as a tool for impact assessment of anthropogenic and environmental stresses on three rivers in the Juru River system, Penang, Malaysia. *Environmental Entomology*, 39, 210-222.

Baumard, P., Budzinski, H. and Garrigues, P., 1998a. Polycyclic aromatic hydrocarbons in sediments and mussels of the western Mediterranean Sea. *Environmental Toxicology and Chemistry*, 17, 765-776.

Baumard, P., Budzinski, H., Garrigues, P., Sorbe, J., Burgeot, T. and Bellocq, J., 1998b. Concentrations of PAHs (polycyclic aromatic hydrocarbons) in various marine organisms in relation to those in sediments and to trophic level. *Marine Pollution Bulletin*, 36, 951-960.

Baumard, P., Budzinski, H., Garrigues, P., Dizer, H. and Hansen, P., 1999a. Polycyclic aromatic hydrocarbons in recent sediments and mussels (Mytilus edulis) from the Western Baltic Sea: occurrence, bioavailability and seasonal variations. *Marine Environmental Research*, 47, 17-47.

Baumard, P., Budzinski, H., Garrigues, P., Narbonne, J., Burgeot, T., Michel, X. and Bellocq, J., 1999b. Polycyclic aromatic hydrocarbon (PAH) burden of mussels (Mytilus sp.) in different marine environments in relation with sediment PAH contamination, and bioavailability. *Marine Environmental Research*, 47, 415-439.

Baumard, P., Budzinski, H., Michon, Q., Garrigues, P., Burgeot, T. and Bellocq, J., 1998c. Origin and bioavailability of PAHs in the Mediterranean Sea from mussel and sediment records. *Estuarine, Coastal and Shelf Science*, 47, 77-90.

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.

BKWPPLK-Bahagian Kemajuan Wilayah Persekutuan dan Perancangan Lembah Klang., 1998. AGISwlk: Aplikasi Sistem Maklumat Geografi Wilayah Lembah Klang, Jilid II-Analisis dan Aplikasi. Jabatan Perdana Menteri.

Boonyatumanond, R., Wattayakorn, G., Togo, A. and Takada, H., 2006. Distribution and origins of polycyclic aromatic hydrocarbons (PAHs) in riverine, estuarine, and marine sediments in Thailand. *Marine Pollution Bulletin*, 52(8), 942-956.

Boonyatumanond, R., Murakami, M., Wattayakorn, G., Togo, A. and Takada, H., 2007. Sources of polycyclic aromatic hydrocarbons (PAHs) in street dust in a tropical

Asian mega-city, Bangkok, Thailand. *Science of the Total Environment*, 384, 420-432.

Bouloubassi, I. and Saliot, A., 1993. Dissolved, Particulate and Sedimentary Naturally Derived Polycyclic Aromatic-hydrocarbons in a Coastal Environment - Geochemical Significance. *Marine Chemistry*, 42, 127-143.

Bruner, K. A., Fisher, S. W. and Landrum, P. F., 1994. The Role of the Zebra Mussel, Dreissena polymorpha, in Contaminant Cycling: I. The Effect of Body Size and Lipid Content on the Bioconcentration of PCBs and PAHs. *Journal of Great Lakes Research*, 20, 725-734.

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.

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

Carpenter, K. and Niem, V., 1998. FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Volume 1. Seaweeds, corals, bivalves and gastropods. Rome: *Food and Agriculture Organization of the United Nations.*

Cavalcante, R.M., Sousa, F.W., Nascimento, R.F., Silveira, E.R. and Freire, G.S.S., 2009. The impact of urbanization on tropical mangroves (Fortaleza, Brazil): Evidence from PAH distribution in sediments. *Journal of Environmental Management*, 91 (2), 328-335.

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.

Chouksey, M.K, Kadam, A.N and Zingde, M.D., 2004. Petroleum hydrocarbon residues in the marine environment of Bassein-Mumbai. *Marine Pollution Bulletin*, 49, 637-647.

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.

Costa, R.L.D., and Carreira, R.S., 2005. A comparison betweenfaecal sterols and coliform counts in the investigation of sewage contamination in sediments. Brazilian *Journal of Oceanography,* 53(3/4):157–167.

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.

Cubadda, F., Conti, M. E. and Campanella, L., 2001. Size-dependent concentrations of trace metals in four Mediterranean gastropods. *Chemosphere*, 45, 561-569.

Dame, R. F., 2011. Ecology of marine bivalves: an ecosystem approach, CRC Press.

Dauner,A.L.I. and Martins,C.C., 2015a. Spatial and temporal distribution of aliphatic hydrocarbons and linear alkylbenzenes in the particulate phase from a subtropical estuary (Guaratuba Bay, SW Atlantic) under seasonal population fluctuation. *Science of the Total Environment*, 536, 750–760

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

DOE. 2010. Department of Environment. Malaysia Environmental Quality Report 2010.

DOSM. 2012. Department of Statistics Malaysia, Key Summary Statistics for Local Authority Areas, Malaysia 2010. (Accessed on 5 February 2015. Retrieved 19 April 2012). https://www.statistics.gov.my.

DOSM. 2017. Department of Statistics Malaysia, Malaysia - Water and Waste Water Treatment, Malaysia 2017. (Accessed on 2016. Retrieved 12 June 2017). https://www.export.gov/article?id=Malaysia-Water-Industry

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

Dickhut, R., Canuel, E., Gustafson, K., Liu, K., Arzayus, K., Walker, S., Edgecombe, G., Gaylor, M. and MacDonald, E., 2000. Automotive sources of carcinogenic polycyclic aromatic hydrocarbons associated with particulate matter in the Chesapeake Bay region. *Environmental science and technology*, 34 (21), 4635-4640.

DOS. 2010. Population Distribution and Basic Demographic Characteristics, Department of Statistics, Kuala Lumpur.

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.

Dwiyitno, L. D., Inga, N., Nuri, A., Hari, E. I., Hanifah, N. L., Farida, A., Sonja, K. and Jan, S., 2016. Accumulation patterns of lipophilic organic contaminants in surface sediments and ineconomic important mussel and fish species from Jakarta Bay, Indonesia. *Marine Pollution Bulletin*, 07435; 767-777.

Eganhouse, R. P. and Kaplan, I. R., 1982. Extractable organic matter in municipal wastewaters, 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 and 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, RP., 1986. Long-chain alkylbenzenes: their analytical chemistry, environmental occurrence and fate. *International Journal of Environmental Analytical Chemistry*, 26, 241-263.

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: Molecular Markers in Environmental Geochemistry (pp. 1-20). Washington D. C: American Chemical Society, Washington DC. 1-20.

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 on surfactants,* 12: 1–2.

EQA. 1974. Environmental Quality Act 1974 (Act 127), Regulations, Rules and Orders, Department of Environment (DOE), Ministry of Science, Technology and Innovation (MOSTI) Malaysia.

Gagné, F., Blaise, C., Pellerin, J. and André, C., 2007. Neuroendocrine disruption in Mya arenaria clams during gametogenesis at sites under pollution stress. *Marine Pollution Bulletin Research,* 64:87–107.

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.

Ghahramanpouri, A, Lamit, H. and Sedaghatnia, S., 2012. Behavioural Observation of Human Stationary and Sustained Activities in Pedestrian Priority Streets of Johor Bahru. *Journal of Construction in Developing Countries*, 17(2), 105–116.

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.

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 and Technology,* 35 (10): 2040-2048.

Fang G-C, Chang C-N, Wu Y-S, Fu PP-C, Yang IL and Chen M-H., 2004. Characterization, identification of ambient air and road dust polycyclic aromatic hydrocarbons in central Taiwan, Taichung. *Science Total Environmental*, 327(1-3), 135-146.

Fatema., K., Omar., W.M.W and Isa1., M.M., 2013. Limnology of Merbok Estuary, Kedah, Malaysia. *Bangladesh Journal of Zoology*, 41(1): 13-19, 2013.

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. and Kipli, S., 2014. Usefulness of Bioindicators and Biomarkers in Pollution Biomonitoring, Malaysia. Sains Malaysiana 40: 93–99. *International Journal of Biotechnology for Wellness Industries*, 3, 19-26

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.

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.

Hill, M. K., 2004. Understanding Environmental Pollution. 2nd ed. Understanding Pollution. Cambridge: *Cambridge University Press, 1-29.*

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.

Hua, A.K and Ping, O.W., 2016. Sustainable Development in Water Resources. Case Study: A Review of Malacca River, *International Academic Research Journal of Social Science,* 2(1) 1-5.

Hunter, K.S. and Van Cappellen, P., 2000. Reply to 'Comment on kinetic modeling of microbially-driven redox chemistry of subsurface environments: coupling transport, microbial metabolism and geochemistry'by J. Griffioen. *Journal of Hydrology*, 228 (3): 289-291.

Ibrahim, Z.Z., 1989. An integrated approach to the investigation of an equatorial estuary: the Klang River Estuary, Malaysia. Published thesis, University of Southampton.

Indah Water Konsortium Sdn, Bhd. Sustainability report, 2013, https://www.iwk.com.my (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.

Ishak H.O. and Soffie., W.M., 2003. National Report of Malaysia on the Formulation of a Transboundary Diagnostic Analysis and Preliminary Framework of a Strategic Action Programme for the Bay of Bengal. United Nations Environment Programme East Asian Regional Coordinating Unit.

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.

Isobe, T., H. Takada, M. Kanai, S. Tsutsumi, K. O. Isobe, R. Boonyatumanond, and M. P. Zakaria., 2007. Distribution of polycyclic aromatic hydrocarbons (PAHS) and phenolic endocrine disrupting chemicals in South and Southeast Asian mussels. *Environmental Monitoring Assessment,* 135(1-3):423-440.

Islam, S. and Tanaka, M., 2004. Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. *Marine Pollution Bulletin*, 48, 624–649.

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.

Jusoh, J., Hamid, N.A., Najib, N.U.M., 2015. The Expectation and Satisfaction of the First Time and Return Tourists toward the Heritage Attractions in Melaka. *Pertanika Journal of Social Sciences and Humanities*, 23(1):195–208.

Karickhoff, S. W., Brown, D. S. and Scott, T. A., 1979. Sorption of hydrophobic pollutants on natural sediments. *Water Research*, 13, 241-248.

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.

Keshavarzifard, M., Zakaria,M.P, and Tan Shau Hwai., 2016. Bioavailability of polycyclic aromatic hydrocarbons (PAHs) to short-neck clam (Paphia undulata) from sediment matrices in mudflat ecosystem of the west coast of Peninsular Malaysia. *Environ Geochem Health*, DOI 10.1007/s10653-016-9835-z.

Kharas, H, Zeufack, A and Hamdan M., 2010. Cities, People, and the Economy: A Study on Positioning Penang, Kuala Lumpur: Khazanah Nasional Berhad.

Khuzaimah, Z., Ismail, M.H. and Mansor, S. 2013. Mangrove changes analysis by remote sensing and evaluation of ecosystem service value in Sungai Merbok's mangrove forest reserve, Peninsular Malaysia. In Lecture Notes in Computer Science, Proceedings of the 13th International Conference in Computational Science and Its Applications–ICCSA. Part II, Ho Chi Minh City, Vietnam, 24–27 June 2013. *Springer: Berlin, Germany*, 2013; pp. 611–622.

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

KJERFVE, B., 1979. Measurement and analysis of water current, temperature, salinity and density. In: Estuarine hydrography and sedimentation. Cambridge, 186-216.

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.

Kozaki D, Rahim, M.H.Ab, Ishak, W.M.F.W, Yusoff, M.M, Nobutake, N and Kazuhiko, T., 2016. Assessment of the River Water Pollution Levels in Kuantan, Malaysia, Using Ion-Exclusion Chromatographic Data, Water Quality Indices, and Land Usage Patterns, Libertas Academica, Air, Soil and *Water Research,* 2016:9 1–11 doi:10.4137/ASWr.S33017.

Kumata, H., Masuda, K., Yamada, J. and Takada, H., 2000. Water-Particle Distribution of Hydrophobic Micro Pollutants in Storm Water Runoff. *Polycyclic Aromatic Compounds*, 20: 39-54.

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

Lovatelli, A., 1988. FAO Corporate Document Repository, Status of mollusc culture in selected Asian countries.

Liu, L.Y., Wang, J.Z., Wong, C.S., Qiu, J.W. and Zeng, E.Y., 2013a. Application of multiple geochemical 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.

JPBD. 2007. Penang Structure Plan 2020. Penang State: Town and Country Planning Department.

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.

Maier, R. M., 2006. Biological Processes Affecting Contaminant Transport and Fate. In Pepper, L. L., Gerba, C.P. and Brusseau, M. L. (eds.). *Environmental and Pollution Science*, Oxford: Elsevier: 105-120.

Maioli, O. L., Rodrigues, K. C., Knoppers, B. A. and Azevedo, D. A., 2011. Distribution andsources of aliphatic and polycyclic aromatic hydrocarbons in suspended particulatematter in water from two Brazilian estuarine systems. *Continental Shelf Research,* 31: 1116–1127.

Maliszewska-Kordybach, B., Smreczak, B., and Klimkowicz-Pawlas, A., 2009. Concentrations, sources, and spatial distribution of individual polycyclic aromatic hydrocarbons (PAHs) in agricultural soils in Eastern part of EU: Poland as a case study. *Science the Total Environment*, 407, 3746-3753

Manalo, L. M. and Campos, A. D. N., 2011. Filtration and respiration rates of the short-necked clam Paphia undulata (Born, 1778)(Mollusca, Pelecypoda: Veneridae) under laboratory conditions. *Science Diliman*, 22.

Maugh, T.H., 1978. "Chemical carcinogens: The scientific basis for regulation", *Science*, 201, 1200-1205.

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., 2016. 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.

Masoud, M.S., Mahmoud, Th.H. and Abdel-halim, A.M., 2001. Chemical studies of El-Mex Bay, Alexandria. Proceeding of the Second Conference and Exhibition for Life and Environment, 3-5 April, Alexandria, 339-60.

Medeiros, P. M. and Caruso Bıcego, 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.

Mehta, A.J., Hayter, E.J., Parker, W.R., Tester, A.M., 1987. Cohesive sediment transport processes. in: Committee on Sedimentation Control to Reduce Maintenance Dredging in Estuaries MB, National Research Council (Ed.), Sedimentation control to reduce maintenance dredging of navigational facilities in estuaries: report and symposium proceedings. *National Academy Press*, Washington, D.C., 356.

Mehta, K.V., 2010. Physicochemical characteristics and statistical study of groundwater of some places of vadgam taluka in banaskantha district of Gujarat State (India). *Journal of Chemical and Pharmaceutical Research,* 2(4), 663-670.

Meyers, Robert A., 1998. Encyclopedia of Environmental Analysis and Remediation.; New York, *John Wiley and Sons*, Inc: 8.

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.

Mirsadeghi, S. A., 2010. Bioaccumulation and Hzard Assessment of Polycyclic Aromatic Hydrocarbons in Cockle (Anadara Granosa L.) From Selected Intertidal Mudflats of Peninsular Malaysia. PhD Thesis, Universiti Putra Malaysia.

Mirsadeghi, S.A., Zakaria, M.P., Yap, C.K. and Gobas, F., 2013. Evaluation of the potential bioaccumulation ability of the blood cockle (Anadara granosa) for assessment of environmental matrices of mudflats. *Science of The Total Environment*, 454, 584-597.

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

Ngwa, E.N., Kengne, A.P., Tiedeu-Atogho, B., Mofo-Mato, E.P. and Sobngwi, E., 2015. Persistent organic pollutants as risk factors for type 2 diabetes. Diabetology and metabolic syndrome, 30:7-41. doi: 10.1186/s13098-015-0031-6.

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, M.S.F.M., Sidek, L.M., Basri, H., Husni, M.M.M., Jaafar, A.S., Kamaluddin, M.H., Majid, W.H.A.W.A., Mohammad, A.H. and Osman, S.O., 2016. Development of Flood Forecasting Using.

Norhana, W.N and Nor Ainy, M., 2004. Bacteriological quality of some molluscan shellfish from growing waters of Peninsular Malaysia. *Malaysia Fisheries,* J.3: 27-38

Nursuhayati A.S., Yusoff F.M. and M. Shariff., 2013. Spatial and Temporal Distribution of Phytoplankton in Perak Estuary, Malaysia, During Monsoon Season., *Journal of Fisheries and Aquatic Science,* 8 (4) 480-493, ISSN 1816-4927 / DOI: 10.3923/jfas. 2013.480.493.

Oller I, Malato S, and Sánchez-Pérez, J.A., 2011. Combination of advanced oxidation processes and biological treatments for wastewater decontamination, A review. *Science Total Environmental,* 409:4141–4166

Ong, J.E. Gong, W.K. Wong, C.H. and Zubirh. J. D., 1991. Characterization of a Malaysian Mangrove Estuary. "Mangrove: Malaysia"; Centre File:3-P-82-0192, *Universiti Sains Malaysia, Penang, Malaysia,* 1991, pp 1-2.

Othman F., Alaa E.M.E. and Mohamed I., 2012. Trend analysis of a tropical urban river water quality in Malaysia, Journal of Environmental Monitoring, Cite this: J. *Environmental Monitoring*, 14, 3164, Received 15th August 2012, Accepted 12th October 2012 DOI: 10.1039/2em30676

Ouyang, Y., Zhang, J.E. and Ou, L.-T., 2006. Temporal and spatial distributions of sediment total organic carbon in an estuary river. *Journal of Environmental Quality,* 35, 93-100.

United Nations, World Urbanization Prospects: The 2003 Revision (New York: UN, 2004).

Payet, C., Bryselbout, C., Morel, J.L. and Lichtfouse, E., 1999. Fossil Fuel Biomarkers in Sewage Sludges: Environmental Significance. *Naturwissenschaften,* 86, 484-488.

Peters, K. E. and Moldowan, J. M., 1993. The Biomarker Guide: Interpreting molecular fossils in petroleum and ancient sediments; Prentice Hall, Englewood Cliffs, New Jersey, 363p.

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 and Technology,* 30 (9): 2776-2783.

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.

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. and Hashim, N.R., 2011. Hydrocarbon Contamination in Mangrove Sediment of Linggi River: A Pilot Study. in: Zakaria MP, Mohamed MI, Kasmin S (Eds.), Contemporary Environmental Quality Management in Malaysia and Selected Countries. Universiti Putra Malaysia Press, Serdang, 25-33.

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.

Retnam, A., Zakaria, M. P., Juahir, H., Aris, A. Z., Zali, M. A. and Kasim, M. F., 2013. Chemometric techniques in distribution, characterisation and source apportionment of polycyclic aromatic hydrocarbons (PAHS) in aquaculture sediments in Malaysia. *Marine Pollution Bulletin*, *69*(1), 55-66.

Rinawati, K.T., Koike, H., Kurumisawa, R., Ito, M., Sakurai, S., Togo, A., Saha, M., Arifin, 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*, 2017–218, 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.

Rogers, H.R., 1996. Sources, Behaviour and Fate of Organic Contaminants During Sewage Treatment and in Sewage Sludges. Quellen, Verhalten und Verbleib von organischen Schadstoffen während der Abwasserbehandlung und in Klärschlämmen. *The Science of the Total Environment*, 185(1-3), 3-26.

Rohasliney, H., 2011. Fish Feeding Guild in the Polluted River, Pengkalan Chepa River, Kelantan, Malaysia. International Conference on Environmental, Biomedical and Biotechnology, vol.16 Press, Singapoore

Sakari, M., Mohamed, C. a. R. and Zakaria, M. P. Chemical characterization of atmospheric transported polycyclic aromatic hydrocarbons in peninsular Malaysia: A quarter century view. In: Space Science and Communication, 2009. IconSpace 2009. International Conference on, 2009. IEEE, 195-199.

Sakari, M. and Zakaria, M.P., 2013. Distribution, Characterization and Origins of Polycyclic Aromatic Hydrocarbons (PAHs) in Surficial Sediment of Penang, Malaysia: The Presence of Fresh and Toxic Substances. *World Applied Sciences Journal,* 23.

Schoellhamer, D.H., William, H.M. and Ashish, J.M., 2000. Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay. *Proceedings in Marine Science,* Elsevier, 343-357.

Schumacher, B.A., 2002. Methods for the determination of total organic carbon (TOC) in soils and sediments. *Ecological Risk Assessment Support Center*, 1-23.

Shahbazi, A., 2009. Green-Lipped Mussels (Perna Viridis) as Biomarkers of Petroleum Hydrocarbon Contamination in Selected Coastal Waters of Peninsular Malaysia. PhD Thesis, Universiti Putra Malaysia.

Shahbazi, A., Zakaria, M. P., Yap, C. K., Tan, S. G., Surif, S., Mohamed, C. a. R., Sakari, M., Bakhtiari, A. R., Bahry, P. S. 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, 248-263.

Sherblom, P. M.; Gschwend, P. M. and Eganhouse, R. P., 1992. Aqueous solubilities, vapor pressures, and 1-octanol-water partition coefficients for C9-C14 linear alkylbenzenes. *Journal of Chemical and Engineering*, 37, 394-399.

Shamsuddin, S., 2011. Townscape Revisited: Unravelling the Character of the Historic Townscape in Malaysia. 1st Edition. Johor, Malaysia: Universiti Teknologi Malaysia Press.

Simoneit, B.R.T., 1982. Some applications of computerized GC-MS to the determination of biogenic and anthropogenic organic matter in the environment. Intern. *Environmental Toxicology and Chemistry,* 12, 177-193.

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.

Souza, D.S.M., Ramos, A.P.D. and Flores-Nunes, F., 2012. Evaluation of tropical water sources and mollusks in southern Brazil using microbiological, biochemical, and chemical parameters. *Ecotoxicol Environment,* Saf 76:153–161

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

Suratman, S. Mohd M.I. Sailan, Y.Y. Hee, E.A. Bedurus and M.T. Latif., 2015. A Preliminary Study of Water Quality Index in Terengganu River Basin, Malaysia, *Sains Malaysiana*, 44(1)(2015): 67–73

Swisher, R. D., 1987. Surfactant Biodegradation, 2nd edition. Dekker, New York.

Swaileh, K. and Adelung, D., 1994. Levels of trace metals and effect of body size on metal content and concentration in Arctica islandica L. (Mollusca: Bivalvia) from Kiel Bay, Western Baltic. *Marine Pollution Bulletin*, 28, 500-505.

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,* 346, 281-290.

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

Takada, H. 1989. Dissertation. Linear alkylbenzenes and linear alkylbenzenesulfonates in urban aquatic environments: their distribution, behaviors, and significant in environmental chemistry. Ph.D. *Tokyo Metropolitan University, Japan.*

Takada, H. and Ishiwatari, R., 1990. Biodegradation experiments of linear alkylbenzenes (LABs): isomeric composition of C12 LABs as an indicator of the degree of LAB degradation in the aquatic environment. *Environmental Science and Technology,* 24(1), 86-91.

Takada, H., Onda, T. and Ogura, N., 1990. Determination of polycyclic aromatic hydrocarbons in urban street dusts and their source materials by capillary gas chromatography. *Environmental Science and Technology,* 24, 1179-1186.

Takada, H., Onda, T., Harada, M. and Ogura, N., 1991. Distribution and sources of polycyclic aromatic hydrocarbons (PAHs) in street dust from the Tokyo Metropolitan area. *Science of the Total Environment, 107*, 45-69.

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.

Takada, H., Farrlngton, 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, 1062-1072.

Takada, H., Satoh, F., Bothner, M.H., Tripp, B.W., Johnson, C.G. and Farrington, J.W., 1997. Anthropogenic Molecular Markers: Tools To Identify the Sources and Transport Pathways of Pollutants. *American Chemical Society,* 671, 178-195.

Takada, H. and Eganhouse, RP., 1998. Molecular markers of anthropogenic waste. In: Meyers, RA. (Ed.), Encyclopedia of Environmental Analysis and Remediation. *Wiley, New York,* 2883-2940.

Tam, N.F.Y., Ke, L., Wang, X.H. and Wong, Y.S., 2001. Contamination of polycyclic aromatic hydrocarbons in surface sediments of mangrove swamps. *Environmental Pollution,* 114 (2), 255-263.

Trivedi, R., and Jain, V., 2001. Detergents and the Environment: The Canadian Experience and the Indian Scenario, *In* Southey, C., Kaushik, N. and Trivedi, R.K. (eds). Environmental Risk Assessment and Synthetic Detergents. New Delhi: *Tata McGraw-Hill Publishing Company Limited,* 183-199.

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

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. A.Z. Aris et al. (eds.), *From Sources to Solution,* 451-455.

Vaezzadeh, V., Zakaria, M.P., Mustafa, S., Ibrahim, Z.Z., Shau-Hwai, A.T., Keshavarzifard, M., Magam, S.M. and Alkhadher, S.A.A., 2015. Source type evaluation of polycyclic aromatic hydrocarbons (PAHs) in surface sediments from the Muar River and Pulau Merambong, Peninsular Malaysia. *Environmental Forensic,* 16, 135-142.

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.

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

Volkman, J.K., Revill, A.T. and Murray, A.P., 1997. Applications of biomarkers for identifying sources of natural and pollutant hydrocarbons in aquatic environments. *In:* ACS Symposium Series, 1997. *Washington, DC: American Chemical Society,* 110-132.

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, W.-X. and Fisher, N. S., 1997. Modeling the influence of body size on trace element accumulation in the mussel Mytilus edulis. *Marine Ecology Progress Series,* 161, 103-115.

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, 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, Y., Li, X., Li, B.H., Shen, Z.Y., Feng, C.H. and Chen, Y.X., 2012. Characterization, sources, and potential risk assessment of PAHs in surface sediments from nearshore and farther shore zones of the Yangtze estuary, China. *Environmental Science Pollution Research,* 19, 4148-4158.

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

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 Total Environment,* 487, 528–536. doi:10.1016/j.scitotenv.2014.04.067.

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

Yusoff, F.M., M. Shariff and N. Gopinath., 2006. Diversity of Malaysian aquatic ecosystem and resources. *Aquatic Ecosystem Health and Management*, 9:119-135.

Youngblood, W.W. and Blumer, M., 1975. Polycyclic aromatic hydrocarbons in the environment: homologous series in soils and recent marine sediments. *Geochimica et Cosmochimica Acta,* 39, 1303-1314.

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 and Technology,* 36(9), 1907–1918.

Zakaria, M.P., and Takada, H., 2003. Biogeochemistry of Polycyclic Aromatic Hydrocarbons (PAHs) and Linear Alkylbenzenes (LABs) in Klang River and Estuary: Understanding the Transport of PAHs from Rivers to the Straits of Malacca. Aquatic Resource and Environmental Studies of the Straits of Malacca. *Managing the Straits through Science and Technology,* 275-289.

Zeng, E.D., Khan, A.Z., and Tran, K., 1995. Using linear alkylbenzenes to trace sewage-derived organic materials off San Diego, California. Southern California. *Coastal Water Research project*, Annual Report: 63-70.

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 Z, Liang, B. and Zeng, E., 2011. Occurrence of polycyclic aromatic hydrocarbons in surface sediments of a highly urbanized river system with special reference to energy consumption patterns. *Environmental Pollution,* 159:1510–1515

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, 724-730.

Zullyadini A. Farhana, R.S., Che, R., Omar., M.A. and Ismail, W.R. 2016. Rivers and Lakes as Natural Heritage: *Water Quality Status in the Northern States of Peninsular Malaysia*, Kemanusiaan Vol. 23, Supp. 1, (2016), 109–128.

Zitko, V. 2003. Chlorinated pesticides: Aldrin, DDT, Endrin, Dieldrin, Mirex. In: *The handbook of environmental chemistry*