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MULTICLASS EMERGING ORGANIC POLLUTION AND ASSOCIATED RISKS IN THE KLANG RIVER ESTUARY IN MALAYSIA

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By

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

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The occurrence, distribution and sources of multiclass emerging organic contaminants (EOCs) in the environmental matrices (estuarine water, sediment and biota) from Klang River estuary were examined. The targeted EOCs for this assessment were endocrine disrupting compounds (bisphenol A, 4-OP, 4-NP, E2, E1 and EE2), organo phosphorous pesticides (quinalphos, chlorpyrifos, diazinon) and pharmaceutically active compounds (primidone, sulfamethoxazole, dexamethasone, diclofenac, amoxicillin, progesterone, testosterone). Analytical methods of quantification for determination of multiclass EOCs were developed for three components of environmental matrices, namely estuarine water, sediment and biota matrices. The developed analytical methods were validated for linearity, extraction efficiency (% recovery), precision, method detection limit as well as matrix effects. Satisfactory optimization were achieved for the developed analytical methods with extraction efficiency between 51 to 126%, as well as excellent linearity ($r > 0.991$) and precision (%CV < 20). Results from this field study showed that prevalent contamination of Klang River estuary by EOCs with several compounds such as diclofenac, bisphenol A, progesterone, estrone and amoxicillin were predominantly detected in the three environmental matrices. For estuarine water samples, bisphenol A was the compound mostly detected, contributed about 54.77% of total concentration followed by amoxicillin (39.17%), estrone (2.16%) and diclofenac (1.67%). The highest concentration of EOCs in surface water samples was found in BPA at 597.30 ng/L, followed by amoxicillin at 102.31 ng/L. While for sediment samples, bisphenol A was the highest concentration detected at 16.84 ng/g followed by diclofenac (13.88 ng/g) and estrone (12.47 ng/g). The percentage of contribution (% of total concentration) is in order of bisphenol A (49.68%), diclofenac (16.19%), progesterone (10.37%) and E1 (9.25%). As for biota matrices, diclofenac (10.76 ng/g) was detected at the highest concentration in fish samples, while progesterone (9.57 ng/g) was the highest concentration found in the molluscs. Principal component analysis (PCA) has successfully extracted four principle components, revealing that the sources of EOCs in the estuary originated from water/waste treatment plants, medical waste discharges, industrial pollution and aquaculture/livestock activities. Estimation of human health risk assessment, calculated as hazard quotient (HQ) were less than 1, suggesting the consumption of fish and mollusc from Klang River estuary will not pose any health risk to the consumers. Meanwhile, environmental risk assessment, expressed as risk quotients (RQs) for all targeted compounds were also less than 1 for the three test species (phytoplankton, zooplankton and fish) evaluated. Hence, the targeted EOCs have not indicated significant risks to the ecosystem during the current assessment. Nonetheless, result from this field assessment is an important finding for pollution studies in Malaysian tropical coastal ecosystems particularly for organic micro-pollutant EOCs and can also serve as a baseline database for future reference.

Keywords: Emerging organic contaminants; Klang River estuary; environmental risk assessment; health risk assessment; coastal ecosystem

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PENCEMARAN PELBAGAI KELAS ORGANIK YANG BARU MUNCUL DAN RISIKO-RISIKO BERKAITAN DENGANNYA DI MUARA SUNGAI KLANG, MALAYSIA

Oleh

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November 2018

Pengerusi : Profesor Ahmad Zaharin Aris, PhD
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Kejadian, taburan dan sumber pencemaran sebatian organik EOC pelbagai kelas dalam matriks alam sekitar (air, sedimen, ikan dan moluska) di muara Sungai Klang telah diperiksa. Sebatian EOC yang disasarkan untuk kajian ini adalah pengganggu endokrin fenolik (bisfenol A, 4-OP, 4-NP), racun perosak organo fosforus (quinalfos, klofirifos, diazinon), hormon estrogenik (E2, E1, EE2) dan sebatian aktif farmaseutikal (primidon, sulfametosazol, desametason, diklofenak, amoksisilin, progesteron, testosteron). Kaedah analisis untuk penentuan EOC pelbagai kelas telah dibangunkan untuk tiga komponen matriks alam sekitar, iaitu air muara, sedimen muara dan biota. Kaedah analisis yang telah dibangunkan ini telah disahkan untuk kelinearan, kecekapan pengekstrakan (% pemulihan), ketepatan, had pengesanan, serta kesan matriks. Pengoptimuman kaedah analisis adalah memuaskan dengan peratusan kecekapan pengekstrakan bagi semua matriks adalah diantara 51% - 126%, kelinearan melebihi $r>0.991$ dan pekali variasi (CV) bagi ketepatan adalah tidak melebihi <20%. Hasil daripada penilaian lapangan ini menunjukkan pencemaran EOC di muara Sungai Klang dengan beberapa sebatian seperti diklofenak, bisfenol A, progesteron, estron dan amoksisilin dikesan pada ketiga-tiga matriks alam sekitar tersebut. Bagi sampel air muara, bisfenol A merupakan sebatian yang paling banyak dikesan, mewakili 54.77% kepekatan keseluruhan diikuti oleh amoksisilin (39.17%), estron (2.16%) dan diklofenak (1.67%). Kepekatan sebatian bisfenol A yang dikesan dalam sampel air muara adalah pada 597.30 ng/L, diikuti oleh amoksisilin pada 102.31 ng/L. Manakala, bagi sampel sedimen muara, kepekatan bisfenol A (16.84 ng/g) adalah yang paling tinggi dikesan, diikuti oleh diklofenak (13.88 ng/g) dan estron (12.47 ng/g). Sebatian bisfenol A mewakili sebanyak 49.68% kehadiran di dalam sampel sedimen muara diikuti oleh diklofenak (16.19%), progesteron (10.37%) dan estron (9.25%). Bagi matriks biota, diklofenak (10.76 ng/g) dikesan pada kepekatan tertinggi dalam sampel ikan, manakala progesteron (9.57 ng/g) merupakan kepekatan tertinggi yang hadir dalam siput paya bakau. Analisis prinsipal komponen (PCA) telah berjaya mengenalpasti empat komponen utama, menunjukkan sumber-sumber EOC di muara adalah berasal dari loji rawatan air/sisa, pelepasan sisa perubatan, pencemaran industri dan aktiviti akuakultur/ternakan. Anggaran penilaian risiko kesihatan manusia, dikira sebagai darjah bahaya (HQ) kurang dari 1, menunjukkan pengambilan ikan dan siput paya bakau dari muara Sungai Klang sebagai sumber makanan tidak akan menimbulkan risiko kesihatan kepada pengguna. Sementara itu, penilaian risiko alam sekitar, dinyatakan sebagai darjah risiko (RQs) untuk semua sebatian yang disasarkan juga kurang daripada 1 untuk tiga spesies ujian (fitoplankton, zooplankton dan ikan) yang telah dinilai. Oleh yang demikian, pencemaran EOC tidak menunjukkan risiko yang ketara kepada ekosistem semasa penilaian dilakukan. Walau bagaimanapun, hasil daripada penilaian lapangan ini adalah penemuan penting bagi kajian pencemaran ekosistem pantai tropika Malaysia terutamanya untuk kajian bahan pencemar EOC mikro organik dan boleh dijadikan pangkalan data asas bagi rujukan masa hadapan.

Kata kunci: pencemaran organik baru muncul; muara Sungai Klang; penilaian risiko alam sekitar; penilaian risiko kesihatan; ekosistem pantai

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LIST OF ABBREVIATIONS

ng/L	nano gram per litre
ng/g	nanogram per gram
pg/g	pictogram per gram
EE2	17α-ethynyl estradiol
E2	17β-estradiol
E1	estrone
EOCs	emerging organic contaminants
EDC	endocrine disrupting compound
OPPs	organophosphate pesticides
PhACs	pharmaceutically active chemicals
4-OP	4-octylphenol
4-NP	4-nonylphenol
BPA	bisphenol A
LC MS-MS	liquid chromatography mass spectrometry-mass spectrometry
Na_2-EDTA	tetrasodium ethylenediamine-tetraacetate dehydrate
PTFE	polytetrafluoroethylene
QuEChERS	Quick, Easy, Cheap, Effective, Rugged, Safe
MeOH	methanol
MeCN	acetonitrile
Al_2O_3	aluminium oxide
USEPA	United States Environmental Protection Agency
MRM	multiple reaction monitoring
MTBE	methyl tert butyl ether
NH_4OH	ammonium hydroxide
PCA	principal component analysis
ppt	part per trillion
RQ	risk quotient
HQ	hazard quotient
MEC	measured environmental concentration
PNEC	predicted no effect concentration
QA	quality assurance
QC	quality control
USDA	United States Department of Agriculture
LC50	lethal concentration
EC50	effective concentration
EU	European Union
SPE	solid phase extraction
PPCPs	pharmaceutical and personal care products
EDI	estimated daily intake
EFSA	European Food Safety Authority
TDI	tolerable daily intake
MAE	microwave assisted extraction
UAE	ultrasonic assisted extraction
PLE	pressurised liquid extraction
LLE	liquid-liquid extraction

SPME	solid phase micro extraction
GPC	gel permeation chromatography
Primi	primidone
Sulfa	sulfamethoxazole
Dexa	dexamethasone
Diaz	diazinon
Tes	testosterone
Proges	progesterone
Chlor	chlorpyrifos
Quina	quinalphos
Amox	amoxicillin
Diclo	diclofenac
APPCI	atmospheric photoionization pressure chemical ionization
NP_nEO	nonylphenol polyethoxylates
NP_1EC	nonylphenol monoethoxycarboxilic acid
OP_1EC	octylphenol monoethoxycarboxilic acid

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background of study

Emerging organic contaminant (EOC) consists various classes of chemical compounds such as naturally produced compounds including natural estrogens, natural androgens and phytoestrogen, as well as a wide range of industrial chemicals including synthetic hormones, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls, dioxins, phenolic xenoestrogens, pharmaceuticals and personal care products (PPCPs) and pesticides. These chemical contaminants have been detected in various environmental matrices at low level of concentrations, as low as part per trillion (ppt) level. Numerous studies have reported on the occurrence of EOCs in different types of environmental matrices as reported by Omar et al. (2013), when they detected concentration of dioxins between 1.910 WHO-TEQ pg/g to 3.305 WHO-TEQ pg/g in soil samples collected at selected Malaysian oil palm plantations. A study by Kuch & Ballschmiter, (2000) reported trace concentration of bisphenol A ranged from 4.8 ng/L to 10 ng/L in Sewage Treatment Work (STW) effluents and 0.5 ng/L to 14 ng/L in samples of river water. Phenolic endocrine disrupting compounds such as nonylphenol and octylphenol were detected in the ranged of 6 ng/g to 640 ng/g in sediment samples collected at Tokyo Bay as reported by Isobe et al. (2001). In the same study, Isobe et al. (2001) also reported concentrations of nonylphenol and octylphenol in the Tokyo metropolitan river water. The concentrations for both compounds in the river water were detected in the range between 0.01 ng/L to 1.08 ng/L. Emerging organic pollutants were also detected in Duoro River estuary, Portugal when Ribeiro et al. (2009) reported the presence of industrial pollutant (nonylphenol, octylphenol and bisphenol A) and phytoestrogens (daidzein, genistein and biochanin A) in the river water samples analysed. Bisphenol A was detected up to 10.7 ng/L, daidzein (888.4 ng/L), genistein (197.4 ng/L) and biochanin A (191.4 ng/L).

The pathway of these pollutants in the environment is mainly through wastewater effluent from sewage treatment plants, municipal treatment plants, hospital effluents and from livestock discharge (Sumpter and Jobling, 1995; Ying et al. 2002; Raman et al. 2004; Hutchins et al. 2007). Raman et al. (2004) evaluated estrogen content in animal waste and reported that 17α-estradiol, estrone and 17β–estradiol were major estrogen compounds contained in the waste samples collected. Hutchins et al. (2007) analysed effluents and suspended solid samples from lagoons that were affected by animal waste discharged and identified that estrone, 17α-estradiol, 17β–estradiol and estrone were among EOCs present in the samples analysed.

The occurrence of EOCs such as synthetic estrogenic hormones and pharmaceutical compounds in the aquatic environment have received much attention as these compounds have been detected in various aquatic compartments such as water, sediments and biota due to their high bioactivity, ubiquitous nature, toxicity and persistence in the environment (Aris et al. 2014). These pollutants have become a major problem in aquatic ecosystems because of high resistance to degradation and their tendencies to absorb organic matter, accumulate in sediment and concentrate in biota. Emerging pollutants such as estrogenic hormones were reported in water, sediment and biota by a number of researchers. Kuch et al. (2001) detected the presence of estrogenic hormone in river waters and effluents from sewage treatment work plants. Mean concentration for estrogenic hormones in STW effluents reported in their study was 1.4 ng/L while mean concentration for river water was 0.80 ng/L. Another study by Baronti et al. (2000) also reported the presence of estrogenic hormone in activated sludge treatment plants and in the receiving river water. They evaluated six treatment plants and the range of concentration was from 0.30 ng/L to 6.8 ng/L. Ribiero et al. (2009) conducted a monitoring on the level of EE2 in Douro River estuary, Portugal and they detected the concentration of EE2 in the range from below the detection limit (<18 ng/L) to 101.9 ng/L.

Mazotto et al. (2008) summarized that EOCs compound can bioaccumulate and biomagnify in aquatic organisms. Bioaccumulation study performed with an endobenthic freshwater oligochaete lumbriculus variegatus suggested that this organism has the potency to accumulate high amount of conjugated EOCs compounds (Liebig et al. 2005). A similar suggestion was also reported by Dussault et al. (2009) when they carried out bioaccumulation study of EOCs compounds in benthic invertebrates *Chrinomus tentans* and *Hyalella azteca*. Emerging organic contaminants (EOCs) are very toxic to a large number of exposed organisms. Robinson & Hellou, (2009), reported that EOCs such as estrogenic hormones and pharmaceutical compounds can affect the endocrine system of organism at concentration levels as low as nanogram per litre. A study by Andrew et al. (2010) concluded that exposure to a certain amount of estrogenic hormones could induced vitellogenin (VTG) production in the adult Sydney rock oyster, *Saccostrea glomerata*. VTG induction was also observed in adult male and female carps, *Cyprinus carpio* when certain dose of estrogenic hormones experimentally injected into these fishes (Sole et al. 2000). VTG has been proven as a useful biomarker for determining the estrogenicity of certain chemicals in aquatic organisms (Sumpter and Jobling, 1995).

Based on previous literatures, emerging pollutants have been ubiquitously detected in various matrices from different geographical origins, indicating global contamination of these compounds in the environment. Toxicity studies carried out on different test species showed evidence of bioaccumulation and biomagnification as well as intersex changes in aquatic organisms when exposed to trace concentrations of emerging organic compounds. Thus, due to adverse effect of these compounds to the ecosystem, extensive study should be conducted to understand the behaviour and effects of these compound in the environment.

1.2 Problem statement

Emerging pollutants such as endocrine disrupting compounds (EDCs), pharmaceutically active compounds and pesticides residues have generated wide attention by scientific and legislative communities in the recent decade because of their widespread presence in the environment and their ability to interfere with the hormonal systems. The ubiquitous presence of these pollutants particularly EDCs in the environment may pose a significant impact to the ecosystem and human health. Research shows that these compounds can disrupt the endocrine system of organism at concentrations as low as nanogram per litre (ng/L). Exposure to EDCs generates additional effects, such as alterations in male and female reproduction and changes in neuroendocrinology, behavior, metabolism and obesity, prostate cancer, thyroid and cardiovascular endocrinology. Endocrine disrupting compounds (EDCs) when absorbed in the body can increase and decrease normal hormone levels, mimic the body's natural hormone and alter the natural hormone production. This interruption in hormonal system may regulate metabolic activity in cells including cancer cells as well as proliferation of cancer and tumor progression. Therefore, due to various health consequences arising from the presence of EDCs, comprehensive research should be carried out for better understanding the behavior and effects of these pollution in the ecosystem as well as the exposed organisms in the environment.

Klang River has been classified as one of the polluted river in Peninsular Malaysia (Huang et al. 2015). It is situated at the heart of Greater Kuala Lumpur and Klang Valley (GKL & KV) and flowing through densely populated areas (estimated 8.0 million population as of 2018) such as Kuala Lumpur and Damansara, as well as industrial areas such as in Petaling Jaya and Shah Alam. The length of the river is approximately 120 km starting from upper catchment in Gombak district to the lower catchment in Klang district and the river ended in the estuary known as Klang River estuary. The total catchment area of Klang River covers an area of 1288 km^2 and most of this river basin has been developed for various purposes such as residential, commercial, industrial, utilities and squatter. Those activities along the basin have contributed to the deterioration of water quality gradually from upstream (class IIB-suitable for body contact and recreational purposes) to downstream (class III-unsuitable for touch and recreational purposes), with numerous pollution sources entering the river either from point source or non point source. The major sources of pollution in the Klang River basin have been identified to be originated from domestic waste, industrial area as well as sewage treatment plant and these pollution are expcted to end up in the estuary if no proper management of waste at the upper and middle cathment area. Based on report by Department of Irrigation and Drainage, in the Klang Valley alone, an estimated 50-60 tons of wastes end up in the river system daily. Hence, due to the socio-economic importance of Klang River estuary the the local community, a comprehensice assessment involving monitoring and risk analysis should be carried out for better protection of ecosystem as well as human population within this estuary.

1.3 Objectives of study

1. To optimize and validate methods for determination of EOCs in aqueous and solid environmental matrices, as well as biota samples.
2. To determine the level, occurence distribution pattern of EOC pollutant in the environmental (water, sediment) and biota matrices collected from the Klang River estuary.
3. To elucidate the potential sources of EOC contamination in the Klang River estuary ecosystem.
4. To analyse the environmental and human health risks associated with the presence of EOC in the Klang River estuary ecosystem.

1.4 Scope of study

Environmental emerging organic pollutants have been widely reported as a potential carcinogenic threat to human population. Release of EOCs to the environmental compartment have been extensively monitored and studied. Scientific and legislative communities have given significant attention to the presence of EOCs in the environment, particularly because of their potential adverse effect on human health and aquatic ecosystems. Review of related studies on EOCs in tropical regions has divulged the significant levels of these compounds in environmental and biota matrices due to domestic, agricultural and industrial wastes discharged. However, research on the environmental risk assessment of these compounds in the Malaysian coastal ecosystem has not been extensively investigated and reported. This research attempts to identify and characterize emerging pollutants in the selected polluted ecosystem focusing on Klang River estuary by integrating analytical method development, monitoring, and risk assessment approaches. This study focuses on the distribution of emerging organic pollutant in environmental compartment such as estuarine water and sediment. Biota samples such as fish and mollusk were also analyzed to study the occurrence and level of EOCs in these matrices at the sampling areas. This is to observe the occurrence and distribution of EOCs in sediment, water and aquatic biota that can lead to better understanding of inter-relationship between the studied matrices.

1.5 Significance of study

This study aim to establish a database for EOCs that can be further used for the purpose of environmental and human health risk assessment. It was noted that there was lack of database describing risk assessment for EOCs particularly for priority pollutants such as phenolic EDCs, estrogenic hormones and pharmaceutical compounds in the Malaysian coastal ecosystem. Therefore, risk assessment analysis for various EOCs particularly for compounds which have not yet been reported should be undertaken for better protection of environmental and human health population from these carcinogenic compounds. Outcome from this study will be useful for regulatory bodies in proposing better preventive measures for controlling carcinogenic pollutants entering environmental ecosystem. Outputs from this study also provide a breakthrough on method development particularly for marine environmental matrices and establishment of database, as well as evaluation of risk assessment for selected EOCs in the anthropogenically impacted Klang River estuary.

1.6 Research framework

The research framework for study on the emerging pollution and risk assessment of EOC in the Klang River estuary ecosystem is depicted in Figure 1.1.

1.7 Thesis outline

This thesis is organized into eight chapters as following:

i) Chapter 1 provides a general introduction for this study such as background of study, problem statement, scope of study, significant of study as well as research framework.
ii) Chapter 2 reviews of previous literature covering several aspects such as physicochemical properties of targeted emerging organic pollutants, analytical challenges for determination of EOCs in the environmental matrices, occurrence and level of EOCs in environmental and biota matrices, sources and fate, and environmental and human health risk assessment.
iii) Chapter 3 describes material and methods such as sampling area, chemical and material used, sample collection and treatment, extraction and clean up, LC MS-MS analysis, quality assurance and quality control as well as statistical analysis.
iv) Chapter 4 discusses on the optimization of analytical methodologies covering optimization for LC MS-MS analysis as well as for extraction and clean-up techniques of aqueous, solid and biota matrices.
v) Chapter 5 discusses the presence, occurrence and sources of EOCs in the surface water of the Klang River estuary, and the risk of EOCs to this ecosystem.
vi) Chapter 6 looks into the occurrence, distribution and potential sources of EOCs in the sediment of Klang River estuary ecosystem.
vii) Chapter 7 discusses on the occurrence and level of EOCs in the biota samples collected from Klang River estuary and human health risk associated with the presence of EOCs in the those matrices.
viii) Chapter 8 provide a summarynof thesis and recommendation for future research.

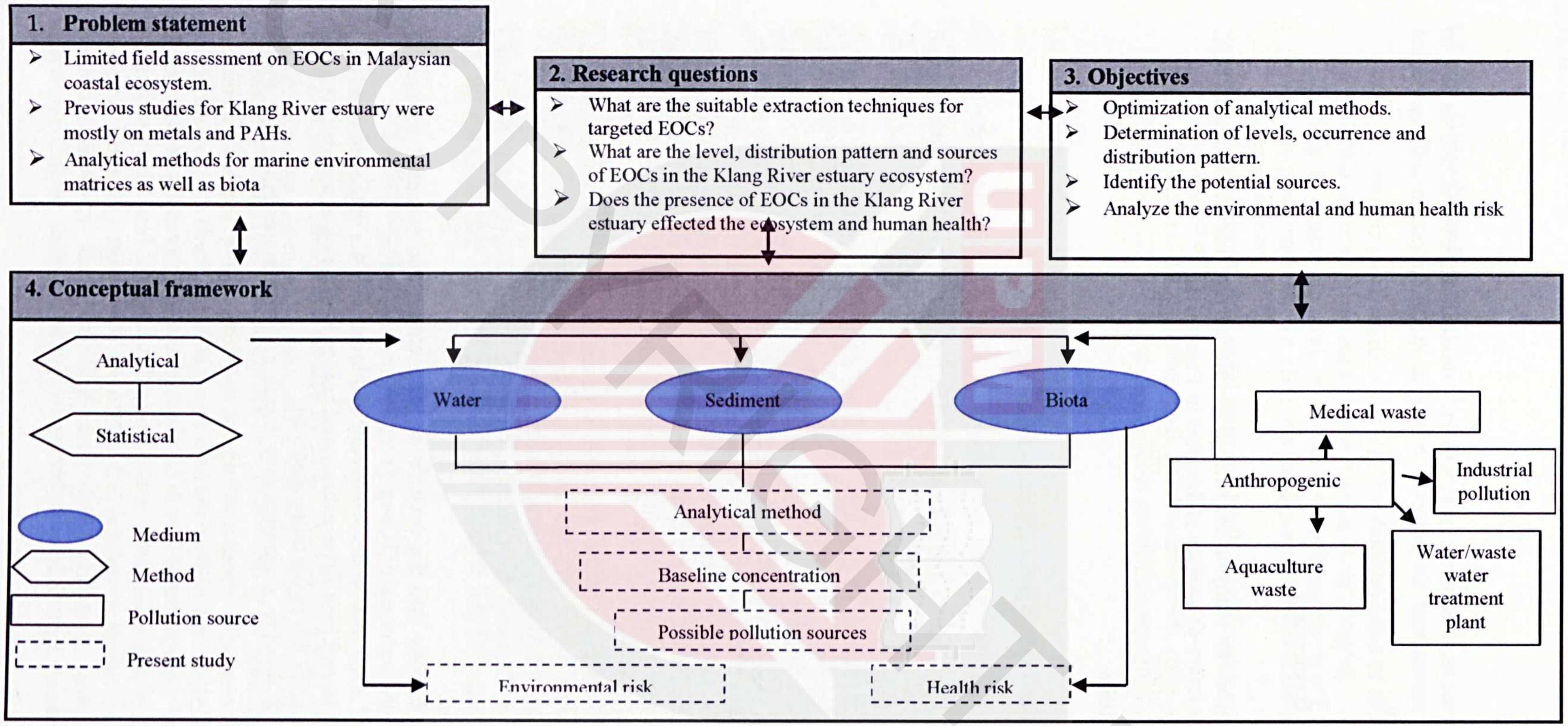

Figure 1.1 : Research framework for study on emerging organic pollution and risk assessment of Klang River estuary ecosystem

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BIODATA OF STUDENT

Tuan Mohamad Fauzan Tuan Omar was born on 22th February 1983 in Temerloh, Pahang. He received his early education at Sekolah Kebangsaan Kampung Pek (Machang), Maahad Syamsul Maarif (Lelaki), Machang and Maahad Muhammadi (Lelaki), Kota Bharu, Kelantan. After completing his foundation of science at Pusat Asasi Sains Universiti Malaya (PASUM-2003), he continued his highest education at Universiti Malaysia Terengganu (UMT), where he obtained his bachelor degree in Analytical and Environmental Chemistry (2006) and Universiti Sains Malaysia (USM) for his Master of Science (2012). In 2015, he received scholarship from Ministry of Higher Education under MyBrain 15 to pursue PhD study in the field of Environmental Quality and Conservation at Faculty of Environmental Studies, Universiti Putra Malaysia.

Tuan Mohamad Fauzan has more than 10 years working experience in both private and government sector, having started his career as a quality control chemist at Chemical Company Malaysia (CCM) Duopharma Biotech in 2006 after graduation. He then joined Malaysian Palm Oil Board (MPOB) as a Research Officer from 2007 until 2015.

His research interest is on the analytical chemistry specializing on the analytical method development using high end instrumentation techniques such as Gas Chromatography Mass Spectrometry, Liquid Chromatography Mass Spectrometry, Inductively Coupled Plasma Mass Spectrometry and various other instrumentation techniques. He has a wide experience in analyzing contaminants in food and environmental matrices which he gained during working period in MPOB and also for his PhD research. He also involved in the implementation of MS ISO 17025 in the Pesticide Residue Laboratory, MPOB and was appointed as Deputy Technical Manager for the lab. His research profile can be viewed at Scopus (ID: 57189709490);Researchgate_(https://www.researchgate.net/profile/Tuan_Fauzan_Tan_Omar); OrCiD (https://orcid.org/000-0002-8175-2436) and can be contacted at tmfauzan1612@gmail.com.

LIST OF PUBLICATIONS

Journal (Published)

Omar, T.F.T., Aris, A.Z., Yusoff, F.M., Mustafa, S. 2018. Risk assessment of pharmaceutically active compounds (PhACs) in the Klang River estuary, Malaysia, *Environmental Geochemistry and Health*, https://doi.org/10.1007/s10653-018-0157-1, Q1, Impact factor = 2.994.

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Omar, T.F.T., Aris, A.Z., Yusoff, F.M., Mustafa, S. Occurrence and level of emerging organic contaminant in fish and mollusk from Klang River estuary, Malaysia and assessment on human health risk, submitted to Environmetal Pollution-under revision.

Proceeding (Oral presentation)

Tuan Fauzan Tuan Omar, Ahmad Zaharin Aris, Nor Farhanna Mokhtar, Hanisah Mohmad Nasir, 2015. Presence of Endocrine Disrupting Compounds (EDCs) in domestic effluents of Klang Valley, Malaysia, Oral presentation, UNU-GIST Joint Programme Symposium, 11-12 November 2015, Marco Polo Ortigas, Manila, the Phillipines.

Tuan Fauzan Tuan Omar, Ahmad Zaharin Aris, Fatimah Md. Yusoff, Shuhaimi Mustafa, 2018. Presence of emerging organic contaminants in fish and mollusc from Klang River estuary, Malaysia and assessment on human health risk, Oral presentation, 11th Society of Environmental Toxicology and Chemistry (SETAC) Asia Pacific 2018, 16-19 September 2018, EXCO Daegu, Republic of Korea.

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