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Heavy Metals Concentrations in Stormwater and Tilapia Fish (*Oreochromis Niloticus*) in Kuala Lumpur Holding and Storage SMART Ponds

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ABSTRACT

The issue of heavy metal contamination in urban stormwater has become a major concern for environmental pollution control agencies worldwide due to toxic effects on aquatic organisms and human health. The aim of this study is to determine the levels of heavy metals (Pb, Cd, Cu, Cr and Zn) in surface stormwater and tilapia fish (*Oreochromis niloticus*) obtained from holding and storage ponds of the Stormwater Management and Road Tunnel (SMART) Project in Kuala Lumpur, Malaysia. Results have indicated that the concentrations of all heavy metals in stormwater were lower than the recommended water quality criteria established by the United States Environmental Protection Agency (US EPA). On the other hand, the concentrations of Cd, Cu, Pb and Zn detected in fish were below threshold values suggested by the Food and Agriculture Organization (FAO) and Malaysian Food Regulations (MFR) standards. Only Cr was much higher than FAO limits for fish consumption. Additionally, the content of Cr, Pb and Zn was higher in fish samples collected from holding pond compared to those in storage pond. As the study reflects that Cr in tilapia fish from SMART ponds is of a

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high concentration, certain harmful effects on human health may result. Accordingly, the research recommends avoiding fishing from ponds, as they accumulate a significant amount of waste consumed by the fish.

Keywords: Heavy metals, *Oreochromis niloticus*, SMART ponds, stormwater ponds, tilapia fish

INTRODUCTION

Rapid urbanization and daily human activities are significant sources of pollutants that affect the quality of urban stormwater. Due to their direct adverse effects on the receiving waters and also on human health, environmental pollution control agencies worldwide have become greatly concerned about concentrations of heavy metals in urban stormwater (Joshi & Balasubramanian, 2010). As stormwater flows over different impermeable surfaces, it picks up and transports pollutants such as heavy metals, nutrients, and organic chemicals and discharges them directly to local receiving water bodies (Brown & Peake, 2006). It could be considered that the concentrations of heavy metals in stormwater can be controlled by different factors such as climate, nature of fuels used, the type of vehicles, average daily traffic, etc. (Leung & Jiao, 2006). The majority of heavy metals which penetrate the various bodies of water are normally associated with particulates and, as a result of settling time, they accumulate in the bottom sediments of the receiving water. Therefore, they become available for bioaccumulation in organism life in the ponds (Stead-Dexter & Ward, 2004; Stephansen et al., 2012).

As a matter of fact, fish is situated at the top of the aquatic food chain. As a result, great amounts of heavy metals can normally be accumulated from water, food, and sediments (Yılmaz et al., 2007). What makes the problem worse is the fact that fish consumption is a major route of chemical exposure for human beings (Ikem et al., 2003). Thus, the fish needs to be carefully examined to ensure that unnecessary high levels of toxic metals are not being transferred to humans through fish consumption. However, fish is also an important food resource for human beings worldwide, providing a beneficial source of high quality proteins, minerals and vitamins (Chen et al., 2013).

In urban stormwater management, stormwater ponds are widely used to provide protection of downstream areas from flooding through temporary storage of stormwater runoff from impermeable surfaces. Moreover, stormwater ponds improve the quality of stormwater typically by removal of suspended solids and associated pollutants (Krishnappan & Marsalek, 2002). The SMART Project is designed primarily to reduce the stormflow from the upper Klang/Ampang catchment area away from the Kuala Lumpur city centre to a manageable quantity within the capacity of the Klang River.

Since the SMART Project began operations in 2007 (Khalil et al., 2011), the stormwater wastes in the SMART ponds have a high chance for accumulation to an extent that exceeds permissible water quality standards. It is hypothesized that resident organisms will be implicated by the accumulation of metals and adversely-beneficial compounds. Therefore, the ultimate objective of this study is to determine the concentrations of heavy metals, specifically Cd, Cr, Cu, Pb, and Zn in surface stormwater, as well as in tilapia fish (*O. niloticus*) of the SMART ponds receiving stormwater runoff from different land use areas in the Ampang/Klang catchment.

MATERIALS AND METHODS

Site Description

The stormwater management ponds were constructed as a part of the SMART project, which is part of the overall Kuala Lumpur Flood Mitigation System. The SMART project mainly consists of two ponds namely, the holding pond and the storage pond. Both of these are connected to the SMART tunnel. The holding pond was designed to retain excess floodwater diverted from the confluence of the Klang and Ampang Rivers during major storm events when the total discharge in the rivers' confluence exceeds 70 m^3/s. The diverted floodwater is temporarily held until it reaches a certain permitted level before being released through the SMART Tunnel (bypass tunnel) to a storage pond (Dominic et al., 2016). The pond is located in Kampung Berembang, (3°09'51.8"N, 101°44'35.6"E) with an area of 8 hectares having a capacity of 0.6 million m^3. On the other hand, the storage pond is situated in Taman Desa, (3°06'08.4"N, 101°41'31.5"E) with an area of 23 hectares and a capacity of 1.4 million m^3. The catchments area is approximately 121 km^2 consisting of parking areas, building roofs and a bridge in addition to motorways. The primary sources of pollution in the study area are motor vehicle emissions, vehicle tyre wear, road asphalt, building materials and atmospheric deposition. According to meteorological measurements taken between 2014 and 2017 (provided by the Malaysian Meteorological Services Department), the average annual precipitation in the study area is 2790.7 mm. The annual mean temperature is 27°C with the monthly mean temperature varying from maximum 32°C to minimum 23°C (Dominic et al., 2015).

Sample Collection

The stormwater and fish samples were collected in November 2016 (approximately one month after diverting stormwater flow to SMART ponds). In each pond, two stations closer to the centre of the pond were selected for surface stormwater sampling. The samples were obtained from 50-cm depth in triplicate from four stations named as HPS1, HPS2, SPS1 and SPS2. The samples were collected in acid washed polyethylene bottles, kept in an ice box, and transported to the laboratory for the further analysis. Tilapia fish (*Oreochromis niloticus*) samples were caught randomly over the ponds in triplicate, washed with distilled water, kept in separate polythene bags, placed in ice-cooled containers and immediately transported to the laboratory. Upon arrival at the laboratory, samples were washed with ultrapure water, weighed, measured by total length and kept frozen at -20ºC (El-Moselhy et al., 2014; Mendil et al., 2010). The fish samples ranged from 22–25 cm in total length and 170–280 g in body weight.

Sample Preparation and Analysis

Stormwater sampling and analytical techniques were performed in accordance with APHA Standard Methods (American Public Health Association [APHA], 2005). Briefly, about 100 mL of each of the stormwater samples were passed through a 0.45 mm cellulose nitrate membrane filter. The filtrate samples were therefore acidified to pH < 2 using ultrapure nitric acid (ACS Reagent, 70%). The samples were then refrigerated at 4ºC before analysis. The fish samples were dissected and washed with double distilled water (Malik et al., 2010). Dorsal muscle samples were taken, homogenized and weighed for the metal analysis. Individual samples were oven-dried at 80ºC for 48 h in acid-washed petri dishes and were ground to a fine powder. Approximately 0.5 g dry weight of powdered muscle was digested in a 10 ml of concentrated nitric acid (R&M Grade 69%). Samples were heated first at low temperature (40°C) for 1 h and then at 140°C for at least 3 h (Yap et al., 2002). Digested samples were filtered through pre-washed 0.45 μm cellulose nitrate membrane filter (Alam et al., 2002). The samples were then diluted with ultrapure water to 50 mL and preserved at 5ºC until further analysis (Bashir et al., 2011). Blanks were used simultaneously in each batch of analysis. The heavy metal analyses were conducted using A Perkin-Elmer ELAN DRC-e Inductively Coupled Plasma Mass Spectrometer (ICP-MS, Canada).

Reagents and Standards

All reagents used during analysis were of analytical reagent grade. Ultrapure water (Milli-Q System, Millipore) was used for all dilutions. Ultrapure quality nitric acid (HNO_3) (R&M Grade 69%) was used for digestion of fish samples. The suitable standard solutions for the calibration were prepared by dilution of the stock solution of 10 mg/L. All the plastic and glassware were cleaned by soaking in dilute HNO_3 and rinsed several times with ultrapure water prior to use. The quality of the analytical procedures was checked with a Certified Reference Material DORM-4, fish protein for trace metals (NRCC, Canada) (Table 1).

Table 1
Observed and certified values for the elements in standard reference material (Dorm-4) (µg g^{-1} dry weight)

Element	Observed value **(mean ± SD)**	Certified value	Recovery (%)
Cd	**0.266±0.001**	**0.299 ± 0.018**	**89**
Cr	**2.031±0.021**	**1.87 ± 0.18**	**109**
Cu	**15.85±0.373**	**15.7 ± 0.46**	**101**
Pb	**0.394±0.003**	**0.404 ± 0.062**	**98**
Zn	**47.92±01.32**	**51.6 ± 2.8**	**93**

Statistical Analyses

Results of heavy metal concentrations were analysed using SPSS software 23. Independent t-test at 95% was used to determine the significant differences of all heavy metals investigated in stormwater and fish between holding and storage SMART ponds ($P < 0.05$).

RESULTS AND DISCUSSION

Heavy Metal Concentrations in Stormwater

The concentrations (µg/l) of heavy metals in stormwater of SMART ponds are presented in Table 2. The study results revealed that the concentration levels of heavy metals (Cr, Cd, Pb and Zi) in holding pond were higher than those in storage pond; while Cu was found to be the opposite being higher in a storage pond. The reason for that might be due to the fact that a holding pond was the first recipient for urban stormwater runoff which came into contact with debris and various pollutants. Both SMART ponds exhibited small decreases in metal concentrations between the stations in each pond. This could be due to different heavy metals exhibiting different behaviours. For instance, Zn, Cu, and Cd are found to be associated with the dissolved phase (e.g. colloidal material), (Huber et al., 2016), while Pb is strongly associated and bound to particles and Cr is relatively bound to organic matter (Karlsson et al., 2010).

On the level of stations, the concentration of Cr ranged from 9.8 µg/L at SPS1 to 15.8 µg/L at HPS1. On the ponds level, the mean values of Cr were 14.7 µg/L and 10.7 µg/L for holding pond (HP) and storage pond (SP) respectively. In urban stormwater runoff, the major source of Cr is the body surface of vehicles, which is coated with hexavalent Cr for corrosion prevention (Aryal et al., 2010). There was a significant difference in the mean of Cr level between the ponds (p=0.001, t=5, df=10) (Table 3). The mean values of Cr in the stormwater of both ponds were found to be lower than the acute criteria (CMC) (570 µg/l) and chronic criteria (CCC) (74 µg/l) allowed by United States Environmental Protection Agency (US EPA, 2017).

The highest concentration of Cu in stormwater samples was measured in SPS2 and was found to be 3.69 µg/L; while its lowest concentration was measured in HPS1 reaching 2.75 µg/L. On the part of ponds, the mean concentration of Cu in stormwater of SP was slightly higher compared to its concentration in HP (3.5 µg/L and 3.08 µg/L respectively). This could be attributed to motorway dust from the SMART Tunnel that washes off to SP during diversion of the excess stormwater runoff from HP. Statistical analysis using independent t-test indicates no significant difference results of the Cu levels between the ponds (p=0.06, t= -2.2, df=10). The Cu contamination in urban stormwater is associated with specifically: the intensity of vehicular traffic (Gunawardena et al., 2013); vehicle brake emissions (Davis et al., 2001) and corrosion of building materials (e.g., roofs, pipes, etc.) (Göbel et al., 2007). Cu values were far below threshold levels of US EPA guidelines CCC (9 µg/l) and CMC (13 µg/l).

The mean value of Zn was 19.63 µg/l in stormwater samples collected from HP, and 15 µg/l for samples collected from SP. On the level of stations, the concentrations of Zn ranged from 14.98 at SPS2 to 20.4 µg/l at HPS2. The results revealed that there was a significant difference in the mean of Zn levels between the ponds ($p<0.001$, t=7, df=9). According to the study results, the levels of Zn in both ponds were lower than permissible standard levels of US EPA (120 µg/l). It could be mentioned that the concentrations of Zn are varied in the runoff of traffic area compared with other heavy metals due to its existence in crumbs of car tyre rubber and other galvanized structures (Huber et al., 2016). In urban areas, galvanized metals and tyre wear are the two greatest sources of zinc contamination (Vos & Janssen, 2009).

Cd and Pb at the two studied ponds were found to have concentrations lower than the permissible limits of the US EPA guidelines (0.72-1.8 µg/l and 2.5-65 µg/l respectively). The level of Cd in stormwater samples ranged from 0.03 µg/l at SPS1 to 0.09 µg/l at HPS1. From the perspective of ponds, the mean value of Cd in HP 0.07 µg/l was slightly higher than that in SP, 0.05 µg/l. The results revealed no significant difference in the mean of Cd levels between the ponds ($p=0.13$, t=1.7, df=10). On the other hand, the mean of Pb values in both the ponds were significantly different ($p<0.001$, t=11, df=10). In urban runoff, the major contributors for Cd contamination are building walls and atmospheric deposition (Davis et al., 2001), while vehicles are the largest source of lead contamination in the urban environment. According to Hwang et al. (2016), lead has been added to gasoline as well as many vehicle parts, including wheel rims, batteries, aluminium alloys and wheel balancing weights.

Table 2
Heavy metal concentrations (µg/L) in surface stormwater of SMART ponds

Location	Cd mean ± SE	Cr mean ± SE	Cu mean ± SE	Pb mean ± SE	Zn mean ± SE
Holding Pond (HP)					
HPS1[a]	0.09±0.00	15.8±0.9	2.75±0.06	1.92±0.02	18.77±0.7
HPS2[b]	0.05±0.00	13.5±0.6	3.41±0.13	2.38±0.02	20.43±0.6
Total mean	0.07±0.03	14.67±1.7	3.08±0.4	2.15±0.3	19.63±1.3
Storage Pond (SP)					
SPS1[c]	0.03±0.00	9.8±0.2	3.31±0.06	0.69±0.02	15.08±0.6
SPS2[d]	0.07±0.00	11.6±0.4	3.69±0.07	0.98±0.03	14.98±0.6
Total mean	0.047±0.02	10.7±1.1	3.5±0.23	0.83±0.16	15.0±0.9
USEPA-(CMC)e	1.8	570	13	65	120
USEPA-(CCC)[f]	0.72	74	9.0	2.5	120

[a] holding pond station1, [b] holding pond station2, [c] storage pond station1, [d] storage pond station2
[e] CMC: criterion maximum concentration (acute effect), [f] CCC criterion continuous concentration (chronic effect)

Table 3
Independent t-test differences between heavy metals concentrations in stormwater of SMART ponds

	F	t	df	Sig. (*P*-value)
Cd	4.928	1.7	10	0.13
Cr	0.51	4.8	10	0.001
Cu	3.4	-2.2	10	0.06
Pb	22.2	11	10	0.000
Zn	0.13	7	9	0.000

Independent t-test at 95% significance: ($P < 0.05$)

Heavy Metal Concentrations in Fish

Heavy metals can enter fish via five main pathways (water, gills, skin, food and non-food particles), mixed with blood, and are carried to either a storage point or to the liver for its storage or transformation (Shinn et al., 2009). Heavy metal accumulation in fish tissues depends not only on concentrations in the environment but also on many geochemical and biological factors that influence the bioavailability of metals, such as: fish size; temperature; pH; and organic ligands (Camusso et al., 1995). In tilapia fish, the concentrations of heavy metals (Zn, Cu, Pb, Cr and Cd) collected from SMART ponds are given in Table 4. As can be seen in Table 5, independent t-test analysis shows that all heavy metal concentrations were significantly different between HP and SP ($p < 0.001$, df = 4). Cr levels in analysed fish obtained from HP were higher (22.03 µg/g) than those in SP (19.1 µg/g). Moreover, the mean of Cr values from both ponds were higher than the levels recommended by Food and Agriculture Organization of the United States (FAO, 1983) (2.0 µg/g), and much higher than those reported from Ampang Hilir Lake (Said et al., 2012) (2.15 µg/g). It has been reported that Cr (III) is a fundamental nutrient that potentiates the action of insulin and hence it affects fat, protein and glucose metabolism (Taghipour & Azizi, 2010). Conversely, Cr (VI) is a well-known human carcinogen (Tuzen & Soylak, 2007).

In the same vein, Zn is an important element in human nutrition which fulfils several biochemical functions in human metabolism. However, an excessive intake of Zn can cause critical adverse effects (Scherz & Kirchhoff, 2006). With regard to HP tilapia fish, the content of Zn was found to be slightly higher (15.39 µg/g) than that in SP (12.34 µg/g). Furthermore, the concentrations of Zn in both ponds for tilapia fish were far below the threshold values established by FAO (1983) (30 µg/g) and Malaysian Food Regulation (MFR, 1985) MFR (100 µg/g). The results show that Zn values are lower than those reported on UPM Pond (Yap et al., 2015) (15.70 µg/g). Conversely, Zn achieved higher values compared to those reported on Ampang Hilir Lake (1.86 µg/g).

Cu is also an essential element which plays a vital role in biological systems. Nevertheless, high intake of Cu can cause adverse health risks (Sivaperumal et al., 2007). The content of Cu in muscles of fish samples from SP was found to be slightly higher (0.77 µg/g) than those collected from HP (0.65 µg/g). However, Cu levels in the SMART ponds were lower than the maximum permitted concentrations proposed by FAO and MFR (10 μg/g and 30 μg/g respectively). They were also found to be lower than the results obtained by previous studies on Ampang Hilir Lake, and UPM ponds (4.06 μg/g and 1.42 μg/g respectively).

Pb and Cd are known as toxic elements that up until recently have had an unknown biological function. They have been shown to have carcinogenic consequences on humans and aquatic biota (Malik et al., 2010). In this study, the concentration level of Cd in fish samples was extremely low, 0.003 μg/g at SP and slightly lower at HP 0.002 μg/g. However, Cd absorption constitutes a serious risk to humans, since it may cause reproductive deficiencies, kidney diseases and skeletal damage (Järup, 2003). With regard to Pb, the levels of concentration were 0.23 and 0.19 μg/g for analysed fish samples in both HP and SP respectively. It has been reported that the effects of lead in the body are characterized by decline in both intellectual and cognitive growth in children. Similarly, it increases cardiovascular diseases and blood pressure irregularity in adults Commissions of the European Communities (COEC, 2001). The levels of Cd and Pb in tilapia fish in the two ponds were lower than those obtained in the studies mentioned above, and below the maximum lead level permitted by the FAO and MFR, as shown in Table 4.

Overall, Cr, Pb and Zn in tilapia fish caught from HP were found to have concentrations higher than those collected from SP. This could be due to two main reasons. First: HP is the initial recipient for pollution loads in stormwater runoff that come from different land uses in the urban catchment of Ampang-Klang. Second: urban stormwater runoff diverted to HP is often held at least for a period of 6 hours before being released to the SP via the SMART tunnel. Thus, sediment and other stormwater runoff pollutant loads find enough time to be settled down in the bottom of HP stormwater body. Over time, such pollutants as heavy metals become available for bioaccumulation in tilapia fish of HP.

In contrast, Cd and Cu in fish samples showed slightly higher concentrations in SP compared to those in HP. In fact, there are two possibilities behind these high levels. The first might be attributed to the SMART motorway tunnel dust resulting from traffic activities (an average of 25,000 vehicles per day pass through the motorway tunnel). This dust is washed off by stormwater diverted from HP through the SMART tunnel and subsequently discharged into SP. The second possibility might be due to the atmospheric pollutant deposition as an important source for Cd and Cu contamination (Davis et al., 2001). It is worth mentioning here that SP is very far from any urban or industrial activities and, thus, their pollution.

The high concentrations of Cr detected in the muscles of tilapia fish in the SMART ponds renders these fish unsafe for human consumption, Therefore, it could be reported that local community members are not encouraged to have fish, obtained directly from the ponds or indirectly from the Kerayong River when excess stormwater is diverted back from ponds to the river during heavy rainfall events in the Klang/ Ampang areas.

Table 4
Heavy metal concentrations (µg/g dry wt) in the muscles of tilapia fish from SMART ponds

Location	**Cd** mean ± SE	**Cr** mean ± SE	**Cu** mean ± SE	**Pb** mean ± SE	**Zn** mean ± SE	References
HP	0.002 ± 0.00	22.03 ± 0.2	0.65 ± 0.00	0.23 ± 0.00	15.39 ± 0.1	This study
SP	0.003 ± 0.00	19.1 ± 0.2	0.77 ± 0.01	0.19 ± 0.00	12.34 ± 0.1	
Ampang Hilir Lake	0.18	2.15	4.06	0.97	1.86	(Said et al., 2012)
UPM Pond	0.84	-	1.42	1.64	15.70	(Yap et al., 2015)
	-	2.0	10	4	30	FAO (1983)
	1.0	-	30	2.0	100	MFR (1985)

Table 5
Independent t-test differences of heavy metals concentrations in tilapia fish from SMART ponds

	F	t	df	Sig. (*P*-value)
Cd	1.535	-25.86	4	0.000
Cr	0.009	10.31	4	0.000
Cu	0.297	-16.31	4	0.000
Pb	0.672	53.94	4	0.000
Zn	0.101	10.84	4	0.000

Independent t-test at 95% significance: ($P < 0.05$)

CONCLUSION

The results of this study demonstrated that the studied heavy metal concentrations in the stormwater of SMART ponds (holding and storage ponds) are found to be lower than the water quality criteria proposed by USEPA. According to the study results, the concentrations of Cr, Cd, Pb and Zi in stormwater samples of HP were found to be higher than those in SP except for Cu in SP which was higher. In tilapia fish (*O. niloticus),* the content of Cr, Pb and Zn was higher in the samples collected from HP. Further, the concentrations of Cd, Cu, Pb and Zn detected in fish samples of this study were below the threshold values suggested by FAO and Malaysian Food Regulations (MFR). Nevertheless, the level of Cr was much higher than the recommended limit of FAO for fish consumption. Accordingly, people who could have access to fishing from these ponds are not encouraged to do so where consuming fish with high levels of Cr can cause an adverse effect on their health. However, the current study emphasizes that, in such aquatic ecosystems, fish is considered as an important bioindicator of heavy metal contamination. On the other hand, the SMART ponds have the ability of developing the stormwater runoff quality coming from urban areas. In addition to serving flood control, these ponds can retain sediment and other pollutants associated with settleable particulates.

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REFERENCES

Alam, M. G. M., Tanaka, A., Allinson, G., Laurenson, L. J. B., Stagnitti, F., & Snow, E. T. (2002). A comparison of trace element concentrations in cultured and wild carp (Cyprinus carpio) of Lake Kasumigaura, Japan. *Ecotoxicology and Environmental Safety, 53*(3), 348-354.

Aryal, R., Vigneswaran, S., Kandasamy, J., & Naidu, R. (2010). Urban stormwater quality and treatment. *Korean Journal of Chemical Engineering, 27*(5), 1343-1359.

American Public Health Association. (2005). *Standard methods for the examination of water and wastewater* (21st ed.). Washngton, D.C., USA: American Public Health Association.

Bashir, F. A., Shuhaimi-Othman, M., & Mazlan, A. G. (2011). Evaluation of trace metal levels in tissues of two commercial fish species in Kapar and Mersing coastal waters, Peninsular Malaysia. *Journal of Environmental and Public Health,* http://dx.doi.org/10.1155/2012/352309

Brown, J. N, & Peake, B. M. (2006). Sources of heavy metals and polycyclic aromatic hydrocarbons in urban stormwater runoff. *Science of the Total Environment, 359*(1-3), 145-155.

Camusso, M., Vigano, L., & Balestrini, R.. (1995). Bioconcentration of trace metals in rainbow trout: A field study. *Ecotoxicology and Environmental Safety, 31*(2), 133-141.

Chen, X., Han, C., Cheng, H., Liu, J., Xu, Z., & Yin, X. (2013). Determination of mercurial species in fish by inductively coupled plasma mass spectrometry with anion exchange chromatographic separation. *Analytica Chimica Acta, 796*, 7-13.

Commission of the European Communities. (2001). Commisssion Regulation (EC) n. 221/2002 of the 6 February 2002 amending regulation (EC) n. 466/2002 setting maximum levels for certain contaminants in foodstuffs. *Official Journal of the European Communities.*

Davis, A. P., Shokouhian, M., & Ni, S. (2001). Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere, 44*(5), 997-1009.

Dominic, J. A., Aris, A. Z., & Sulaiman, W. N. A.. (2015). Factors controlling the suspended sediment yield during rainfall events of dry and wet weather conditions in a tropical urban catchment. *Water Resources Management, 29*(12), 4519-4538.

Dominic, J. A., Aris, A. Z., Sulaiman, W. N. A., & Tahir, W. Z. W. M. (2016). Discriminant analysis for the prediction of sand mass distribution in an urban stormwater holding pond using simulated depth average flow velocity data. *Environmental Monitoring and Assessment, 188*(3), 191.

El-Moselhy, K. M, Othman, A. I., El-Azem, H. A., & El-Metwally, M. E. A. (2014). Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt. *Egyptian Journal of Basic and Applied Sciences, 1*(2), 97-105.

Food and Agriculture Organization of the United States. (1983). *Compilation of legal limits for hazardous substances in fish and fishery products*. Retrieved December 3, 2016, from http://www.fao.org/docrep/014/q5114e/q5114e.pdf

Göbel, P, Dierkes, C, & Coldewey, WG. (2007). Storm water runoff concentration matrix for urban areas. *Journal of Contaminant Hydrology, 91*(1-2), 26-42.

Gunawardena, J., Egodawatta, P., Ayoko, G. A, & Goonetilleke, A. (2013). Atmospheric deposition as a source of heavy metals in urban stormwater. *Atmospheric Environment, 68*, 235-242.

Huber, M., Welker, A., & Helmreich, B.. (2016). Critical review of heavy metal pollution of traffic area runoff: Occurrence, influencing factors, and partitioning. *Science of the Total Environment, 541*, 895-919.

Hwang, H. M, Fiala, M. J., Park, D., & Wade, T. L. (2016). Review of pollutants in urban road dust and stormwater runoff: Part 1- Heavy metals released from vehicles. *International Journal of Urban Sciences, 20*(3), 334-360.

Ikem, A., Egiebor, N. O., & Nyavor, K. (2003). Trace elements in water, fish and sediment from Tuskegee Lake, Southeastern USA. *Water, Air, and Soil Pollution, 149*(1-4), 51-75.

Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin, 68*(1), 167-182.

Joshi, U. M., & Balasubramanian, R. (2010). Characteristics and environmental mobility of trace elements in urban runoff. *Chemosphere, 80*(3), 310-318.

Karlsson, K., Viklander, M., Scholes, L., & Revitt, M.. (2010). Heavy metal concentrations and toxicity in water and sediment from stormwater ponds and sedimentation tanks. *Journal of Hazardous Materials, 178*(1), 612-618.

Khalil, N., Husin, H. N., Mahat, N., & Nasir, N. (2011). Sustainable environment: issues and solutions from the perspective of facility managers. *Procedia Engineering, 20*, 458-465.

Krishnappan, B. G., & Marsalek, J. (2002). Transport characteristics of fine sediments from an on-stream stormwater management pond. *Urban Water, 4*(1), 3-11.

Leung, C. M., & Jiao, J. J. (2006). Heavy metal and trace element distributions in groundwater in natural slopes and highly urbanized spaces in Mid-Levels area, Hong Kong. *Water Research, 40*(4), 753-767.

Malaysian Food Regulation. (1985). *Malaysian law on food and drugs*. Kuala Lumpur: Malaysian Law Publishers.

Malik, N., Biswas, A. K., Qureshi, T. A., Borana, K., & Virha, R. (2010). Bioaccumulation of heavy metals in fish tissues of a freshwater lake of Bhopal. *Environmental Monitoring and Assessment, 160*(1-4), 267-276.

Mendil, D.i, Demirci, Z., Tuzen, M., & Soylak, M. (2010). Seasonal investigation of trace element contents in commercially valuable fish species from the Black sea, Turkey. *Food and Chemical Toxicology, 48*(3), 865-870.

Said, K. S., Shuhaimi-Othman, M., & Ahmad, A. K. (2012). The determination of water quality and metal concentrations of Ampang Hilir Lake, Selangor, Peninsular Malaysia. *Pakistan Journal of Biological Sciences, 15*(9), 437.

Scherz, H., & Kirchhoff, E. (2006). Trace elements in foods: Zinc contents of raw foods—A comparison of data originating from different geographical regions of the world. *Journal of Food Composition and Analysis, 19*(5), 420-433.

Shinn, C., Dauba, F., Grenouillet, G., Guenard, G., & Lek, S. (2009). Temporal variation of heavy metal contamination in fish of the river lot in southern France. *Ecotoxicology and Environmental Safety, 72*(7), 1957-1965.

Sivaperumal, P., Sankar, T. V., & Nair, P. V. (2007). Heavy metal concentrations in fish, shellfish and fish products from internal markets of India vis-a-vis international standards. *Food Chemistry, 102*(3), 612-620.

Stead-Dexter, K., & Ward, N. I. (2004). Mobility of heavy metals within freshwater sediments affected by motorway stormwater. *Science of the Total Environment, 334*, 271-277.

Stephansen, D. A., Nielsen, A. H., Hvitved-Jacobsen, T., & Vollertsen, J. (2012). Bioaccumulation of heavy metals in fauna from wet detention ponds for stormwater runoff. In S. Rauch, & G. M. Morrison, *Urban Environment* (pp. 329-338). Dordrecht: Springer.

Taghipour, V, & Azizi, S. N. (2010). Determination of trace elements on canned kilka fish marketed in Islamic Republic of Iran. *World Applied Sciences Journal, 9*(6), 704-707.

Tuzen, M., & Soylak, M. (2007). Determination of trace metals in canned fish marketed in Turkey. *Food Chemistry, 101*(4), 1378-1382.

United States Environmental Protection Agency. (2017). National Recommended Aquatic Life Criteria table, Retrieved May 4, 2018, from https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

Vos, J. H., & Janssen, M. P. M. (2009). *EU-wide control measures to reduce pollution from wfd relevant substances: Copper and zinc in the Netherlands*. Nairobi, Kenya: United Nations Environment Programme.

Yap, C. K., Ismail, A., Tan, S. G., & Omar, H. (2002). Correlations between speciation of Cd, Cu, Pb and Zn in sediment and their concentrations in total soft tissue of green-lipped mussel *Perna viridis* from the west coast of Peninsular Malaysia. *Environment International, 28*(1), 117-126.

Yap, C. K., Jusoh, A., Leong, W. J., Karami, A., & Ong, G. H. (2015). Potential human health risk assessment of heavy metals via the consumption of tilapia *Oreochromis mossambicus* collected from contaminated and uncontaminated ponds. *Environmental Monitoring and Assessment, 187*(9), 584.

Yılmaz, F., Özdemir, N., Demirak, A., & Tuna, A. L. (2007). Heavy metal levels in two fish species Leuciscus cephalus and Lepomis gibbosus. *Food Chemistry, 100*(2), 830-835.