

Abstract of thesis presented to the Senate of Universiti Malaysia Terengganu in fulfilment of the requirements for the Degree of Doctor of Philosophy

**HEAVY METALS ACCUMULATION IN TROPICAL FRESHWATER EELS
(*Anguilla bicolor bicolor*, McClelland 1844 AND *Anguilla bengalensis bengalensis*, Gray 1831) FROM PENANG, PERAK AND KEDAH (Malaysia)
WITH THE HUMAN HEALTH RISK ASSESSMENT**

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Concentrations of heavy metals (Cd, Pb, Cu, Zn, Se, Fe, As, Ni and Hg) in muscle, gill and liver of tropical freshwater eel (*Anguilla bicolor bicolor* and *Anguilla bengalensis bengalensis*) from the northern states of west coast Peninsular Malaysia were measured and the relationship between fish size with gonad maturation stage and metal concentrations in different tissues were investigated by correlation analysis. Potential human health risk due to metals from the consumption of the tropical freshwater eels was assessed. Most of the studied rivers in Penang Island were enriched with Cu, Zn, Cd, Pb, As, Ni, and Hg with high enrichment factors (EF). However, according to I_{geo} index, these rivers are moderately (I_{geo} index of 2) polluted and some moderately to heavily polluted (I_{geo} index of 3) with Zn, Pb and As. Although the measured metal concentrations were very low in the river water and the levels of anthropogenic metals in sediment were high, bioaccumulation factors (BAF) in the *Anguilla* spp. indicated a higher rate of accumulation was via from both water and sediment. Metal concentrations were (in the pattern of essential metals > non-essential metal) highest in the liver, except for

Hg which was higher in the muscle > liver or gills and this shows a size-dependent factor during the juvenile stage. The highest concentrations (in $\mu\text{g/g}$ dry wt.) measured in *Anguilla bicolor bicolor* were 339.9(Fe), 44.6(Ni), 13.8(Zn), 32.1(As), 10.7(Se), 0.8(Cd), 16.8(Pb) and 2.8(Hg) while in *Anguilla bengalensis bengalensis* the highest metals concentration (in $\mu\text{g/g}$ dry wt.) measured were 149.0(Fe), 19.3(Ni), 109.0(Cu), 183.2(Zn), 66.2(As), 8.3(Se), 1.4(Cd), 17.6(Pb) and 5.2(Hg). Significant correlations ($P < 0.01$, $P < 0.05$) between the anthropogenic metals, Ni, Zn, Cd, Pb, and Hg were frequently found in the gill, liver and muscle of *Anguilla* spp. indicating similarities in bioavailability and occurrence of these metals in the aquatic environments studied. The bioaccumulation patterns of anthropogenic metals in organs of both *Anguilla* spp. suggest that it may be a good biomonitoring species for anthropogenic metals in rivers. In a few cases, significant negative relationships ($P < 0.01$, $P < 0.05$) between these metals and gonadal maturation stage were found. The observed Pb, Ni and Cd accumulation in the muscle of *Anguilla* spp. were within the reported range of *Anguilla* sp. from Malaysia while Zn, Fe, and Pb concentrations were higher compared to previously reported studies. Heavy metals such as Pb, As, Ni and Cd exceeded the upper tolerable daily intake limit (EDI) or the reference nutrient intake (RNI) for both adult and child as suggested by USEPA 2009. As for the other metals, the tolerable daily intake was not violated. Daily consumption of *Anguilla bengalensis bengalensis* from Sg. Perak may pose a health risk from As in both adult and child, while the consumption of *Anguilla bengalensis bengalensis* from Sg. Titi Serong would pose a health risk from Cd as the EDI value was above the suggested metal limit intake by FAO (1999) and WHO (2003). This study also revealed that the total THQ values (HI) of metals (As, Cd, Fe, Pb, Ni, Se, Cu, Hg, and Zn) were higher in adult compared to a child but were under of no risk effect ($\text{THQ} < 1$) as recommended by USEPA 2009 and JECFA 2000, suggesting consumers are not at any potential health risk from the dietary intake of *Anguilla* sp.

**Abstrak tesis yang dikemukakan kepada Senat Universiti Malaysia Terengganu
sebagai memenuhi keperluan untuk peringkat Doktor Falsafah**

**PENUMPUKAN LOGAM BERAT DALAM IKAN LINANG (*Anguilla bicolor
bicolor*, McClelland 1844 DAN *Anguilla bengalensis bengalensis*, Gray, 1831)
DARI PULAU PINANG, PERAK DAN KEDAH (Malaysia) SERTA
PENILAIAN RISIKO KESIHATAN**

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Purata kepekatan berat logam (Cd, Pb, Cu, Zn, Se, Fe, As, Ni dan Hg) dalam otot, insang dan hati ikan linang (*Anguilla bicolor bicolor* dan *Anguilla bengalensis bengalensis*) dari negeri pantai barat Semenanjung Malaysia diukur dan hubungan di antara saiz ikan serta peringkat matang gonad dengan kepekatan logam dalam tisu dikaji melalui analisis korelasi. Penilaian risiko kesihatan manusia ke atas ikan linang yang terdedah kepada logam berat juga dikaji. Kebanyakan sungai yang dikaji di Pulau Pinang menunjukkan peningkatan faktor pengkayaan (EF) terhadap logam berat Cu, Zn, Cd, Pb, Ni dan Hg. Mengikut penilaian Indeks Geo-akumulasi (I_{geo}), kebanyakan sungai yang dikaji mengalami pencemaran antara peringkat sederhana (I_{geo} paras indeks 2) dan hampir tercemar (I_{geo} paras indeks 3) oleh kehadiran Zn, Pb, dan As. Walaupun kepekatan logam berat dalam air sungai adalah rendah dan kepekatan logam antropogenik dalam sedimen sungai adalah tinggi, faktor bioakumulasi (BAF) logam berat dalam *Anguilla* spp. menunjukkan bioakumulasi logam berat disumbangkan melalui air dan sedimen sungai di kawasan kajian tersebut. Kepekatan logam (mengikut turutan logam perlu > logam tidak perlu) mencatat rekod tertinggi di hati, kecuali Hg yang lebih tinggi dalam otot > hati atau

insang serta menunjukkan biokumulasi bergantung kepada saiz di peringkat juvena. Kepekatan ($\mu\text{g/g}$ berat kering) tertinggi yang dicatat oleh *Anguilla bicolor bicolor* ialah 339.9(Fe), 44.6(Ni), 13.8(Zn), 32.1(As), 10.7(Se), 0.8(Cd), 16.8(Pb) dan 2.8(Hg) manakala kepekatan logam yang tertinggi dicatat oleh *Anguilla bengalensis bengalensis* adalah 149.0(Fe), 19.3(Ni), 109.0(Cu), 183.2(Zn), 66.2(As), 8.3(Se), 1.4(Cd), 17.6(Pb) and 5.2(Hg). Terdapat hubungan signifikan ($P < 0.01$, $P < 0.05$) antara logam antropogenik, Ni, Zn, Cd, Pb dan Hg sering ditemui di insang, hati dan otot *Anguilla* spp. yang menunjukkan terdapat hubungan antara logam-logam berat dalam persekitaran akuatik kawasan kajian. Corak bioakumulasi logam berat dalam organ-organ *Anguilla* spp. menyarankan ikan linang berkemungkinan adalah spesies biomonitor yang sesuai bagi logam antropogenik di dalam sungai. Dalam beberapa kes terpencil, hubungan negatif yang signifikan ($P < 0.01$, $P < 0.05$) antara logam berat dan peringkat matang gonad dikesan. Akumulasi Pb, Ni dan Cd dalam otot *Anguilla* sp. berada dalam lingkungan *Anguilla* yang dilaporkan dari Malaysia manakala kepekatan Zn, Fe, dan Pb adalah lebih tinggi berbanding dengan kajian sebelum ini. Logam berat Pb, As, Ni dan Cd dalam *Anguilla* spp. juga didapati melebihi had bagi pengambilan nutrien harian (EDI) / nutrien rujukan (RNI) untuk dewasa dan kanak-kanak seperti yang dicadangkan oleh USEPA 2009. Manakala logam berat selebihnya berada bawah paras selamat seperti yang ditetapkan. Pengambilan harian *Anguilla bengalensis bengalensis* (Sg. Perak) bagi dewasa dan kanak-kanak boleh menyebabkan terdedah kepada risiko kesihatan. Pengambilan *Anguilla bengalensis bengalensis* dari Sg. Titi Serong juga boleh menimbulkan risiko kesihatan kerana nilai EDI melebihi had pengambilan Cd yang dicadangkan oleh FAO (1999) dan WHO (2003). Kajian ini juga mendedahkan bahawa jumlah nilai keseluruhan (HI) logam berat dalam *Anguilla* spp. dari kawasan kajian adalah tinggi bagi seorang dewasa berbanding kanak-kanak namun begitu para pengguna tidaklah terdedah kepada risiko kesihatan kerana nilai THQ adalah < 1 seperti yang disyorkan oleh USEPA 2009 dan JECFA 2000. Target Hazard Quotient (THQ) dan Hazard Index (HI) serta penilaian risiko kesihatan manusia menunjukkan ikan linang dari lokasi kajian adalah selamat untuk dimakan dan tidak berisiko serta berada bawah paras pengambilan diet / nutrien yang dibenarkan.