UNIVERSITI PUTRA MALAYSIA

BIOMONITORING, DISTRIBUTION AND RISK ASSESSMENT OF HEAVY METALS AND POLYCYCLIC AROMATIC HYDROCARBONS IN Asystasia gangetica (L.) T. ANDERSON AND SURROUNDING TOPSOIL FROM PENINSULAR MALAYSIA

CHEW WEIYUN

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By

CHEW WEIYUN

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Chairman: Yap Chee Kong, PhD
Faculty: Science

In this study, the invasive weed *Asystasia gangetica* with their surrounding topsoil (0 - 10cm) were collected at 23 sites from Peninsular Malaysia. Samples were collected throughout Peninsular Malaysia during the period of 8th June 2011 to 17th January 2012. The plants (leaves, stems, and roots) and topsoil samples were determined for heavy metals (Cd, Cu, Fe, Ni, Pb and Zn) and 16 polycyclic aromatic hydrocarbons (PAHs). The ranges of the heavy metals in the plant (µg/g, dry weight) of this study for the respective metals are Cd: 0.01 – 5.11 µg/g, Cu: 4.05 – 139.03 µg/g, Fe: 18.10 – 2537.01 µg/g, Ni: 0.03-8.28 µg/g, Pb: 0.01 -31.59 µg/g, and Zn: 9.84 – 299.96 µg/g, while the ranges of PAHs concentrations (ng/g, wet weight) in the plant were 2 – 3 rings PAHs: 6.64 – 64.91 ng/g, 4 rings PAHs: 3.32 – 27.26 ng/g, and 5 – 6 rings PAHs: 1.42 – 226.37 ng/g. Topsoil from Sg. Kembung (S7), Juru (S18) and Kuala Terengganu (S21) have high concentrations of heavy metals and PAHs. Topsoil from these locations have high enrichment of heavy metals (EF > 20) and posed very strong ecological risk (ERI > 600). Furthermore, topsoil from these locations also can affected human health adversely. Present study determined highest toxicity equivalency factors (TEF) from S7 (34.28 ng/g), S18 (151.57 ng/g), and S21 (67.33 ng/g). The three sites also posed non-carcinogenic risk (HI > 1) and carcinogenic risk (Total Risk > 1×10^{-6}) to adult and children in the area. Chemometric studies revealed that the three sites received significant input of mix sources of anthropogenic sources (heavy metals and PAHs). However, determination on the origin of anthropogenic sources was not possible due to lack of data. As for accumulation of contaminant in *A. gangetica*, plants sampled from Sg. Lembing (S13) and Juru (S18) generally accumulated higher heavy metals concentrations than other sites. Whereas, plant samples from Bidor (S4), Sepang (S6), Sg. Kembung (S7), and Kuala Krai (S11) generally contain higher PAHs than other sites. Accumulation behaviours of heavy metals in plants were generally consistent, however, increase of heavy metals in their habitat will induce changed in accumulations behaviours. Present study revealed that *A. gangetica* have higher uptake of Cu and Zn from topsoil to roots while having low translocations of Cu, Fe, and Zn. However, it was revealed that leaves and roots of the plant have similar accumulations behaviours of heavy metals. As for accumulations behaviours of PAHs, leaves usually accumulated more PAHs than other parts. Roots accumulated higher concentrations of 2-3 rings PAHs than 5-6 rings PAHs from topsoil. Translocations of PAHs in plants were low. Principal component analysis (PCA) and correlation suggested that there were no relationships of the pollutants between plants and topsoil. Present study suggested that *A. gangetica* can be a potential biomonitor, however, further studies are needed.

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

PEMONITORAN BIOLOGI, PENILAIAN PENGAGIHAN DAN PENILAIAN RISIKO LOGAM BERAT DAN HIDROKARBON AROMATIC POLISIKLIK PADA *Asystasia gangetica* (L.) T. ANDERSON BERSERTA DENGAN TANAH LAPISAN ATAS PERSEKITARANNYA DARI SEMENANJUNG MALAYSIA.

Oleh

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Di dalam kajian ini, sampel – sampel rumpai invasif *Asystasia gangetica* berserta dengan tanah lapisan atas (0 – 10cm) di Semenanjung Malaysia telah dikumpulkan. Cd, Cu Fe, Ni, Pb, and Zn dan 16 jenis hidrokarbon aromatik polisiklik (PAHs) yang terdapat di dalam sampel-sampel berikutnya telah dianalisakan, termasuk bahagian-bahagian (daun, batang, dan akar) *A. gangetica* dan tanah lapisan atas. Sampel-sampel telah dikumpul daripada 23 lokasi di Semenanjung Malaysia bermula daripada 8 Jun 2011 sehingga 17 Januari 2012. Kepekatan logam berat di dalam sampel tumbuhan (keberatan kering) berjulat di antara Cd: 0.01 – 5.11 µg/g, Cu: 4.05 – 139.03 µg/g, Fe: 18.10 – 2537.01 µg/g, Ni: 0.03-8.28 µg/g, Pb: 0.01 -31.59 µg/g, dan Zn: 9.84 – 299.96 µg/g. Kepekatan PAHs di dalam sampel tumbuhan berjulat di antara 2 – 3 cincin PAHs: 6.64 – 64.91 ng/g, 4 cincin PAHs: 3.32 – 27.26 ng/g, dan 5 – 6 cincin PAHs: 1.42 – 226.37 ng/g. Sampel tanah dari Sg. Kembung, Juru, dan Kuala Terengganu mempunyai kepekatan logam berat dan PAHs yang lebih tinggi apabila dibandingkan dengan lokasi lain-lain. Sampel tanah dari lokasi-lokasi tersebut terdapat kepekayaan logam berat yang tinggi (EF > 20) dan dapat menimbulkan risiko ekologi yang tinggi (ERI > 600). Selain itu, lokasi-lokasi tersebut juga memberi kesan-kesan buruk kepada kesihatan manusia. Penyelidikan ini mendapati bahawa S7 (34.28 ng/g), S18 (151.57 ng/g), and S21 (67.33 ng/g) mempunyai 'Toxicity equivalency factors (TEF)' yang lebih tinggi apabila dibandingkan dengan lokasi lain-lain. Selain itu, lokasi-lokasi tersebut didapati mempunyai risiko secara bukan karsinogenik (HI >1) dan risiko secara karsinogenik (Jumlah Risiko > 1 x 10^{-6}) yang tinggi kepada dewasa and kanak-kanak. Kajian 'chemometric' mendedahkan bahawa tiga lokasi tersebut menerima input sumber antropogenik tercampur untuk logam berat and PAHs. Kajian ini tidak dapat menentukan sumber asal antropogenik di lokasi-lokasi tersebut kerana kekurangan data yang diperlukan. Secara umumnya, sampel-sampel tumbuhan yang dikumpulkan dari Sg. Lembing (S13) dan Juru (S18) mempunyai kepekatan logam berat yang lebih tinggi

apabila dibandingkan dengan lokasi lain-lain. Sampel-sampel tumbuhan dari Bidor (S4), Sepang (S6), Sg. Kembung (S7), dan Kuala Krai (S11) mempunyai kepekatan PAHs yang lebih tinggi apabila dibandingkan dengan lokasi lain-lain. Secara umumnya, tingkah-laku pengumpulan logam berat di dalam tumbuhan adalah konsisten, akan tetapi, peningkatan logam berat di sekeliling menyebabkan perubahan pada tingkah-laku pengumpulan logam berat. Kajian ini mendapati bahawa *A. gangetica* mempunyai pengumpulan Cu dan Zn yang lebih tinggi dari tanah ke dalam akarnya dan, pada masa yang sama, Cu, Fe, dan Zn mempunyai translokasi yang rendah. Tumbuhan-tumbuhan ini juga mempunyai tingkah-laku pengumpulan logam berat yang serupa pada daun-daun and akar-akar tumbuhan. Bagi tingkah-laku pengumpulan PAHs, daun-daun biasanya mempunyai PAHs lebih tinggi daripada bahagian-bahagian tumbuhan lain. Akar-akar pula terkumpul 2-3 rings PAHs yang lebih tinggi berbandingkan dengan 5-6 rings PAHs dari tanah. Analisis komponen prinsipal (PCA) menentukan bahawa bahan-bahan pencemar di dalam kedua-dua tanah dan bahagian-bahagian tumbuhan adalah tidak berkaitan antara satu sama lain. Kajian ini mendapati bahawa *A. gangetica* adalah potensi ‘biomonitor’, tetapi, kajian-kajian perlu dilanjutkan untuk mengesahkan potensi tumbuhan tersebut sebagai ‘biomonitor’.

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I certify that a Thesis Examination Committee has met on 21 December 2016 to conduct the final examination of Chew Weiyun on his thesis entitled "Biomonitoring, Distribution and Risk Assessment of Heavy Metals and Polycyclic Aromatic Hydrocarbons in *Asystasia gangetica* (L.) T.Anderson and Surrounding Topsoil from Peninsular Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

AC	Accumulation coefficient
ACY	Acenaphthylene
ACP	Acenapthene
ANT	Anthracene
BaA	Benzo[*a*]anthracene
BaP	Benzo[*a*]pyrene
BbF	Benzo[*b*]fluoranthene
BghiP	Benzo[*g*,*h*,*i*]perylene
BkF	Benzo[*k*]fluoranthene
Cd	Cadmium
CHR	Chrysene
CRM	Certified reference materials
Cu	Copper
DahA	Dibenzo[*a*,*h*]antharacene
ERI	Ecological Risk Index
EF	Enrichment factor
FLT	Fluoranthene
FLR	Fluorene
Igeo	Geoaccumulation index
HI	Hazard Index
HMW PAHs	High molecular weight Polycyclic Aromatic Hydrocarbons
IcdP	Indeno[*1*,*2*,*3-cd*]pyrene
Fe	Iron

Pb	Lead
LMW PAHs	Low molecular weight Polycyclic Aromatic Hydrocarbons
NAP	Naphthalene
Ni	Nickel
PHE	Phenanthrene
PCA	Principal Component analysis
PYR	Pyrene
TEF	Toxic Equivalency Factor
TF	Translocation Factor
TOC	Total Organic Carbon
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 Background of study

Malaysia is a fast developing country with increasing traffic and industrial activities accompanying the modern lifestyle of today's society (DOE, 2015). However, the fast paced development of Malaysia has increased the output of anthropogenic sources (such as heavy metals and polycyclic aromatic hydrocarbons (PAHs) into its ambient environments. Coal burning, transportation, industrial, mining and agricultural activities and landfill emissions are a few examples which contributes to the anthropogenic heavy metals pollution in urban areas (Zakaria et al., 2005; Yap et al., 2011). In Peninsular Malaysia, numerous studies have already reported the occurrences of heavy metals and PAHs pollutions in coastal areas, estuarine rivers, mangroves, urban areas, lakes and etc. due to increasing urban activities (Zakaria et al., 2000; Zakaria et al., 2002; Yap et al., 2006; Omar et al., 2007; Maimon et al., 2009; Yap et al., 2009; Ahmad et al., 2010; Ashraf et al., 2011). However, limited studies have been focussed on terrestrial pollution in Malaysia.

It has been reported that heavy metals and polycyclic aromatic hydrocarbons (PAHs) are capable of disrupting the ecosystems of a living environment (Wolfe et al., 2007). Furthermore, long term exposure to these pollutants is toxic to human health (Akagi et al., 1995; Xue and Warshawsky, 2004).

Monitoring these anthropogenic sources is crucial to avoid unwanted toxicity on human and the environment. Generally, chemicals in the environment were measured using a few techniques, namely biological, exposure, emission, environmental, and process monitoring (Becher and Bjorseth, 1987). Each monitoring system has its own usage and target. As the amount of anthropogenic substances is rising in Malaysia, suitable biomonitorings are required to monitor the changes of anthropogenic substances. Monitoring antropegenic substances is imperative to not only ensure a healthy environment but also public health throughout time. Biomonitor which utilizes an organism as a chemical monitoring agent, allows study of contaminants within an organism. It enables the measurement of a long term effects of pollutants/xenobiotics in an organism (Siddig et al., 2016).

As Malaysia moves into achieving an industrialized nation in 2020, the blooming of industries is significantly causing a major public health issue in our country. It is inevitable that the cumulative amount of heavy metals and PAHs in the air is increasing. Currently in Malaysia, lichens (Samdudin et al., 2013), tree bark (Ameran et al., 2014), mud crab (*Scylla serrata*) (Ong et al., 2015) and green mussels *Perna viridis* (Shahbazi et al., 2010; Yap and Al-Barwani, 2012) were proposed as a few biomonitors for heavy metals and PAHs. One of the suggested agent, (*Scylla serrata*) capable of accumulating anthropogenic substances *in situ* as they are localized. Mussels (*Perna* viridis) are well known great biomonitor in aquatic environment and capable of accumulating various chemicals. However, mussels are limited to aquatic biomonitoring. Meanwhile, using tree bark as a biomonitor does not give a uniform result as accumulation of compounds varies with species. Lichens however, are geographically diverse, abundance and can accumulate high levels of pollutants without dying; making them a great biomonitor (Bargagli, 2005). Monitoring pollutants with only proposed species is definitely insufficient and with lichen being the only feasible agent for terrestrial conditions. Hence, it is crucial to search for more holistic terrestrial biomonitors to ensure that the monitoring of pollutants in Malaysia could be done efficiently.

Therefore, present study investigated the potentials of *Asystasia gangetica* as a biomonitor of heavy metals and PAHs pollution in Malaysia. This species is proposed as a biomonitor due to the fact that it is vastly distributed and abundance (high specificity and fidelity) in unattended open areas such as roadside, palm oil plantations, and riverbank (Wiart, 2000). Being in an abundance and vastly distributed, the plant is a good ecological indicator and is able to provide information on pollutants for various site locations in Malaysia. In addition, the plant is a herbaceous plant which is consumed by the locals as a traditional medicine. Therefore, it is even more important to study this plant thoroughly which in case if the plant stores a high concentration of pollutant, it could affect the public health by consuming it. In the early 1960s, *A. gangetica* is used as a cover crop in plantation sites, especially in oil palm plantations (Samedani et al., 2015).

As the amount of pollutants is undoubtfully increasing in Malaysia, the current study attempts to determine the accumulation of heavy metals and PAHs in *A. gangetica* collected from various sites and locations in Peninsula Malaysia. Areas with high traffic, industries, and agriculture and horticulture areas are known to accumulate high antropogenic sources (Wuana and Okieimen, 2011). However, this does not mean that rural and non-highly agricultural areas have low anthropogenic sources (Davis et al., 2009). Hence, in the current study, various sampling sites including landfill, industrial, residential, rubbish heap, ex-mining, and plantation were investigated in the study area. In the present study, *A. gangetica* plant (divided into leaves, stems and roots) and the habitat topsoil were collected from these sites. Anthropogenic sources were determined from the different parts of the plant and topsoil using established methods such as sequential extraction technique (SET) and atomic absorption spectroscopy (AAS) for heavy metal and gas chromatography-mass spectrum (GCMS) for PAHs.

At present, no plant species that respond to a wide range of heavy metals as biomonitors are known (Mertens et al., 2005). Various biomonitors are required so that pollution monitoring in this developing country could be well monitored. Since *A. gangetica* fulfill the criteria as a potential biomonitor, this plant is chosen as the subject in the present study.

1.2 Objectives of the study

1) To study the concentrations of the heavy metals (Cd, Cu, Hg, Fe, Ni, Pb, and Zn) in *A. gangetica* (leaves, stems, and roots) and their habitat topsoil.

2) To study the concentrations of the polycyclic aromatic hydrocarons (PAHs) in *A. gangetica* (leaves, stems, and roots) and their habitat topsoil.

3) To study the relationships of *A. gangetica* and their habitat topsoil.

4) To assess the human health risk (non-cancerous and cancerous) posed by the heavy metals and PAHs pollutants found in the habitat topsoil of *A. gangetica*.

REFERENCES

Abdullah, M., Fasola, M., Muhammad, A., Malik, S. A., Bostan, N., Bokhari, H., … Eqani, S. A. M. A. S. (2015). Avian feathers as a non-destructive bio-monitoring tool of trace metals signatures: A case study from severely contaminated areas. *Chemosphere*, *119*: 553–561.

Adeyemi, O. O., Algbe, F. R., and Uyaiabasi, N. G. (2011). Analgesic and anti-inflammatory activities of the aqueous stem and leaf extract of *Asystasia gangetica* (Linn) T. Anderson. *Nigerian Quarterly Journal of Hospital Medicine, 21*(2): 129-134.

Agarwal, T., Khillare, P. S., Shridhar, V., and Ray, S. (2009). Pattern, sources and toxic potential of PAHs in the agricultural soils of Delhi, India. *Journal of Hazardous Materials*, *163*(2-3): 1033–1039.

Ahmad, A. K., Shuhaimi-Othman, M., and Hoon, L. P. (2010). Heavy metal concentrations in Fanworth (*Cabomba furcata*) from Lake Chini, Malaysia. *World Academy of Science, Engineering and Technology*. *65*:106-109.

Akagi, H., Malm, O., Branches, F. J. P., Kinjo, Y., Kashima, Y., Guimaraes, J. R. D., Oliveira, R. B., Haraguchi, K. Pfeiffer, W. C., Takizawa, Y., and Kato, H. (1995). Human exposure to mercury due to gold mining in the Tapajos River basin, Amazon, Brazil: Speciation of mercury in human hair, blood and urine. *Water, Air, and Soil Pollution, 80*(1): 85-94.

Akah, P. A. Ezike, A. C. Nwafor, S. V. Okoli, C. O. and Enwerem, N. M. (2003). Evaluation of the anti-asthmatic property of *Asystasia gangetica* leaf extracts. *Journal of Ethnopharmacology*, *89*: 25–36.

Akguc, N., Ozyigit, I. I., and Yarci, C. (2008). *Pyracantha coccinea* Roem. (Rosaceae) as a biomonitor for Cd, Pb, and Zn in Mugla province (Turkey). *Pakistan Journal of Botany, 40*(4):1767-1776.

Aksoy, A. and Sahin, U. (1999) *Elaeagnus angustifoli* L. as a biomonitor of heavy metal pollution. *Turkish Journal of Botany, 23*: 83-87.

Aksoy, A., and Demirezen, D. (2006). *Fraxinus excelsior* as a Biomonitor of Heavy Metal Pollution. *Polish Journal of Environmental Studies*, *15*(1):27-33.

Al-Farraj, A. S., Al-Wabel, M. I., Al-Shahrani, T. S., El-Maghraby, S. E., and Al-Sewailem, M. A. S. (2010). Accumulation coefficient and translocation factor of heavy metals through Rhazya stricta grown in the mining area of Mahad AD'Dahab, Saudi Arabia. *Waste Management and the Environment, V*: 325-336.

Alloway, B. J. (1995). *Heavy metals in soils* (pp. 354). Blackie Academic and Professional, London.

Ameran, M. F., Yusoff, Z., Masdar, N. D., Salmi, M. D. H., Kamal, M. L. and Hamzah, Z. (2014). Tree barks as bioindicator for organic and inorganic pollutants: A preliminary study. *Jurnal Intelek*, *9*(1): 16-22.

Antisari, L. V., Carbone, S., Ferronato, C., Simoni, A., and Vianello, G. (2011). Characterization of heavy metals atmospheric deposition for assessment of urban environmental quality in the Bologna City (Italy). *EQA – International Journal of Environmental Quality, 7*: 49-63.

Ashraf, M. a, Maah, M. J., and Yusoff, I. (2011). Heavy metals accumulation in plants growing in ex tin mining catchment. *International Journal of Environmental Science and Technology*, *8*(2): 401–416.

Ashraf, M. A., Maah, M. J., and Yusoff, I. (2011). Heavy metals accumulation in plants growing in ex tin mining catchment. *International Journal of Environmental Science and Tecnology, 8*(2): 401-416.

Samedani, B., Juraimi, A.S., Rafii, M.Y., Sheikh Awadz, S.A., Anwar, M.P., and Anuar, A.R. (2015). Effect of Cover Crops on Weed Suppression in Oil Palm Plantation. *International Journal of Agriculture and Biology*, *17*: 251–260.

Badri, M. A., and Aston, S. R. (1983). Observations on heavy metal geochemical associations in polluted and non-polluted estuarine sediments. *Environmental Pollution Series B: Chemical and Physical*, *6*(3): 181–193.

Baker, A. J. M. (1981). Accumulators and excluders – strategies in the response of plants to heavy metals. *Journal of Plant Nutrition*, *3*: 643-654.

Baker, A. J. M. and Brooks, R. R. (1989). Terrestrial higher plants which hyperaccumulate metallic elements – a review of their distribution, ecology and phytochemistry. *Biorecovery*, *1*: 81-126.

Bargagli, R. (1998). The emission of dispersal of atmospheric trace elements. In R. Bargagli (Ed.), *Trace Elements in Terrestrial Plants: an Ecophysiological Approach to Biomonitoring and Biorecovery* (pp. 49-77). Berlin: Springer-Verlag and R.G. Landes Company.

Bargagli, R. (2005). *Antarctic Ecosystems: Environmental Contamination, Climate Change, and Human Impact* (pp. 397). Berlin, Germany: Springer.

Becher, G and Bjerseth, A. (1987). Monitoring of Environmental. In V. B. Vouk, G. C. Butler, A. C. Upton, D. V. Parke and S. C. Asher (Eds) *Methods For Assessing the Effects of Mixtures of Chemicals* (pp. 225-248). Great Britain, UK: John Wiley and Sons.

Boehm, P. D. (2006). Polycyclic Aromatic Hydrocarbons (PAHs). In R.D. Morrison and B.L. Murphy (Ed.), *Environmental Forensics Contaminant Specific Guide* (pp. 313 – 337). Burlington, MA: Elsevier, Academic Press.

Bonanno, G. 2013. Comparative performance of trace element bioaccumulation and biomonitoring in the plant species *Typha domingensis*, *Phragmitesaustralis* and *Arundo donax. Ecotoxicology and Environmental Safety*, *97*: 124-130.

Calzoni, G. L., Antognoni, F., Pari, E., Fonti, P., Gnes, A., and Speranza, A. (2007). Active biomonitoring of heavy metal pollution using *Rosa rugosa* plants. *Environmental Pollution, 149*(2): 239-245.

Calzoni, G. L., Antognoni, F., Pari, E., Fonti, P., Gnes, A., and Speranza, A. (2007). Active biomonitoring of heavy metal pollution using *Rosa rugosa* plants. *Environmental Pollution*, *149*: 239-245.

Chakrabortty, S. and Paratkar, G. T. (2006). Biomonitoring of trace element air pollution using mosses. *Aerosol and Air Quality Research, 6*(3): 247-258.

Chen, H., Teng, Y., and Wang, J. (2012). Source appointment of polycyclic aromatic hydrocarbons (PAHs) in surface sediments of the Rizhao coastal area (China) using diagnostic ratios and factor analysis with nonnegative constrains. *Science of Total Environment, 414*: 293-400.

Cheng, S. (2003). Effects of Heavy metals on plants and resistance mechanisms. Environmental Science and Pollution *Research, 10*(4): 256-264.

Chiarantini, L., Rimondi, V., Benvenuti, M., Beutel, M.W., Costagliola, P., Gonnelli, C., Lattanzi, P., and Paolieri, M. (2016). Black pine (*Pinus nigra*) barks as biomonitors of airborne mercury pollution. *Science of the Total Environment*, *569-570*: 105-113.

Da Silva, E.T., Ridd, M. and Klumpp, D. (2005). Can body burden in the barnacle *Balanus amphitrite* indicate seasonal variation in cadmium concentrations? *Estuarine, Coastal 9 and Shelf Science*, *65*: 159-171.

Da Silva, F. B. V., do Nascimento, C. W. A., Araújo, P. R. M., da Silva, F. L., and Lima, L. H. V. (2016). Soil contamination by metals with high ecological risk in urban and rural areas. *International Journal of Environmental Science and Technology*, *14*: 553–562.

Dalvand, A., Jahangiri, A., and Iranmanesh, J. (2016). Introduce lichen *Lepraria incana* as biomonitor of Cesium-137 from Ramsar, northern Iran. *Journal of Environmental Radioactivity*, *160*: 36-41.

Daso, A. P., Akortia, E., and Okonkwo, J. O. (2016). Concentration profiles, source apportionment and risk assessment of polycyclic aromatic hydrocarbons (PAHs) in dumpsite soils from Agbogbloshie e-waste dismantling site, Accra, Ghana. *Environmental Science and Pollution Research*, *23*(11): 10883–10894.

Dauwe, T., Jaspers, V., Covaci, A., Schepens, P., and Eens, M. (2005). Feathers As a Nondestructive Biomonitor for Persistent Organic Pollutants. *Environmental Toxicology and Chemistry*, *24*(2): 442.

Davis, H. T., Aelion, C. M., McDermott, S., and Lawson, A. B. (2009). Identifying natural and anthropogenic sources of metals in urban and rural soils using GIS-based data, PCA, and spatial interpolation. *Environmental Pollution*, *157*(8-9): 2378–2385.

De Nicola, F., Maisto, G. Prati, M. V., and Alfani, A. (2008). Leaf accumulation of trace elements and polycyclic aromatic hydrocarbons (PAHs) in *Quercus ilex* L. *Environmental Pollution*, *153*: 376-383.

De Paula, P. H. M., Mateus, V. L., Araripe, D. R., Duyck, C. B., Pierre, T. D. S., and Gioda, A. (2015). Biomonitoring of metals for air pollution assessment using a hemiepiphyte herb (*Struthanthus flexicaulis*). *Chemosphere*, *138*: 429-437.

DHHS (2011). The 12th Report on Carcinogens. National Institutes of Health, National Toxicology Program. Retrieved 12th July 2016.

Diami, S. M., Kusin, F. M., and Madzin, Z. (2016). Potential ecological and human health risks of heavy metals in surface soils associated with iron ore mining in Pahang, Malaysia. *Environmental Science and Pollution Research*, *23*: 21086-21097.

Ding, J., Li, J., Chen, J., Chen, H., Ouyang, W., Zhang, R., Xue, C., Zhang, D., Amin, S., Desai, D., and Huang, C. (2006). Effects of Polycyclic Aromatic Hydrocarbons (PAHs) on Vascular Endothelial Growth Factor Induction through Phosphatidylinositol 3-Kinase/AP-1-dependent, HIF-1α-independent Pathway. *The Journal of Biological Chemistry*, *281*: 9093-9100.

DOE (2015). *Malaysia Environmental Quality Report 2014,* Department of Environment, Malaysia.

Douglas, G. S., Emsbo-Mattingly, S. D., Stout, S.A., Uhler, A.D., and McCarthy, K. J. (2007). Chemical Fingerprinting Methods. In B. L. Murphy and R. D. Morrison. (Ed.), *Introduction to Environmental Forensics, 2nd edition* (pp.311-454).. Elsevier, New York, NY: Elsevier.

Douibi, C., Ramdani, M., Khelfi1, A., Benharket, R., Lograda, T., and Chalard, P. (2015). Biomonitoring of heavy metals by lichens in Setif area (East of Algeria). *Unified Journal of Environmental Science and Toxicology*, *1*(1): 1- 13.

Ergin, M., Saydam, C., Bastuk, O., Erdem, E., and Yoruk, R. (1991). Heavy metal concentrations in surface sediments from the two coastal inlets (Goldern Horn Estuary and Izmit Bay) of the northeastern Sea of Marmara. *Chemical Geology*, *91*: 269-285.

Ernst, W. H. O., and Leloup, S. (1987). Perennial hers as monitor for moderate levels of metal fallout. *Chemosphere, 16*: 233-238.

Ezike, A. C., Akah, P. A., and Okoli, C. O. (2008). Bronchospasmolytic activity of the extract and fractions of *Asystasia gangetica* leaves. *International Journal of Applied Research in Natural Products*, *1*(3): 8-12.

Fadzil, M. F., Tahir, N. M., Mohd, W., Wan, K., and Zin, M. (2008). Concentration and distribution of polycylic aromatic hydrocarbons (PAHs) in the town of Kota Bahru. *The Malaysian Journal of Analytical Sciences, 12*(3): 609–618.

Fang, G., Chang, K., Lu, C., and Bai, H. (2004). Estimation of PAHs dry deposition and BaP toxic equivalency factors (TEFs) study at urban, Industry Park and rural sampling sites in central Taiwan, Taichung. *Chemosphere*, *55*(6): 787-796.

Gao, Y. Z. and Zhu, L. Z. (2004). Plant uptake, accumulation and translocation of phenanthrene and pyrene in soils. *Chemosphere*, *55*(9): 1169-1178.

Hakanson, L. (1980). An Ecological Risk Index for Aquatic Pollution Control: A sedimentological approach. *Water Research, 14*: 975-1001.

Hamid, A. A., Aiyelaagbe, O. O., Ahmed, R. N., Usman, L. A., and Adebayo, S. A. (2011). Preliminary phytochemistry, antibacterial and antifungal properties of extracts of *Asystasia gangetica* Linn T. Anderson grown in Nigeria. *Advances in Applied Science Research, 2*(3): 219-226.

Hao, X., Li, J., and Yao, Z. (2016). Changes in PAHs levels in edible oils during deep-frying process. *Food Control*, *66*(835): 233–240.

Haritash, A. K. and Kaushik, C. P. (2016). Degradation of low molecular weight Polycyclic Aromatic Hydrocarbons by microorganisms isolated from contaminated soil. *International Journal of Environmental Sciences, 6*(5): 646-656.

Hartmann, P. C., Quinn, J. G., King, J. W., Tsutumi, 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.

Hoodaji, M., Tahmourespour, A., and Amini, H. (2010). Assessment of copper, cobalt and zinc contaminations in soils and plants of industrial area in Esfahan city (in Iran). *Environmental Earth Sciences, 61*(7): 1353-1360.

Hu, X., Zhang, Y., Ding, Z. H., Wang, T. J., Lian, H. Z., Sun, Y. Y., and Wu, J. (2012). Bioaccessibility and health risk of arsenic and heavy metals (Cd, Co, Cr, Cu, Ni, Pb, Zn, and Mn) in the TSP and PM2.5 in Nanjing, China. *Atmospheric Environment, 57*: 146-52.

Hussar, E., Richards, S., Lin, Z., Dixon, R. P., and Johnson, K. A. (2012). Human health risk assessment of 16 Priority Polycyclic Aromatic Hydrocarbons in soils of Chattanooga, Tennessee, USA. *Water, Air, and Soil Pollution, 223*(9): 5535-5548.

IRIS, Integrated Risk Information System, US Environmental Protection Agency, USA. Retrieved 18th June 2016.

Jung, M. C. (2008). Heavy metal concentrations in soils and factors affecting metal uptake by plants in the vicinity of a Korean Cu-W Mine. *Sensors, 8*: 2413-2423.

Divan, A. M. Jr., de Oliveira, P. L., Perry, C. T., Atz, V. L., Azzarini-Rostirola, L. N., and Raya-Rodriguez, M. T. (2009). Using wild plant species as indicators for the accumulation of emissions from a thermal power plant, Candiota, South Brazil. *Ecological Indicators*, *9*(6):1156-1162.

Kamaruzzaman, B. Y., Akbar John, B., Maryam, B. Z., Jalal, K. C. A., and Shahbuddin, S. (2012). Bioaccumulation of heavy metals (Cd, Pb, Cu and Zn) in *Scylla serrata* (Forsskal 1775) Collected from Sungai Penor, Pahang, Malaysia. *Pertanika Journal of Tropical Agricultural Science*, *35*(1): 183 – 190.

Khalili, N. R., Scheff, P. A., and Holsen, T. M. (1995). PAH source fingerprints for coke ovens, diesel and, gasoline engines, highway tunnels, and wood combustion emissions. *Atmospheric Environment*, 29(4): 533–542.

Khan, S., Aijun, L., Zhang, S., Hu, Q., and Zhu, Y. (2008). Accumulation of polycyclic aromatic hydrocarbons and heavy metals in lettuce grown in the soils contaminated with long-term wastewater irrigation. *Journal of Hazardous Materials*, *152*: 506-515.

Kiew, R., and Vollesen, K. (1997). Asystasia (Acanthaceae) in Malaysia. *Kew Bulletin, 52*(4): 965-971.

Kim, Y. J., and Osako, M. (2003). Leaching characteristics of polycyclic aromatic hydrocarbons (PAHs) from spiked sandy soil. *Chemosphere*, *51*(5): 387–395.

Komp, P, and Mclachlen, M. S. (1997). Interspecies variability of the plant/air partitioning of polychlorinated biphenyls. *Environmental Science and Technology, 31*: 2944-2948.

Krishna, A. K., and Mohan, K. R. (2016). Distribution, correlation, ecological and health risk assessment of heavy metal contamination in surface soils around an industrial area, Hyderabad, India. *Environmental Earth Sciences*, *75*(5): 1–17.

Kumar, B., Tyagi, J., Verma, V. K., Gaur, R., and Sharma, C. S. (2014). Concentrations, source identification and health risk of selected priority polycyclic aromatic hydrocarbons in residential street soils. *Pelagia research library*, *5*(3): 130–139.

Kumar, V., Kothiyal, N. C., Saruchi, Mehra, R., Parkash, A., Sinha, R. R., … Gaba, R. (2014). Determination of some carcinogenic PAHs with toxic equivalency factor along roadside soil within a fast developing northern city of India. *Journal of Earth System Science*, *123*(3): 479–489.

Kuppusamy, A.K., Muthusamy, U., Shanmugam, S. S., Thirumalaisamy, I. A., Varadharajan, S., and Ramanathan, A. (2010). Antidiabetic, hypolipidemic and antioxidant properties of *Asystasia gangetica* in streptozotocin-nicotinamide-induced type 2 diabetes mellitus (NIDDM) in rats. *Journal of Pharmacy Research*, *3*(10): 2516-2520.

Kylin, H., Grimvall, E. and Ostman, C. (1994). Environmental monitoring of polychlorinated biphenyls using pine needles as passive samples. *Environmental Science and Technology, 28*: 1320-1324.

Lau, E. Von, Gan, S., and Ng, H. K. (2012). Distribution and source apportionment of polycyclic aromatic hydrocarbons (pahs) in surface soils from five different locations in Klang Valley, Malaysia. *Bulletin of Environmental Contamination and Toxicology*, *88*(5): 741–746.

Li, J., Shang, X., Zhao, Z., Tanguay, R. L., Dong, Q., and Huang, C. (2010). Polycyclic aromatic hydrocarbons in water, sediment, soil, and plants of Aojiang River waterway in Wenzhou, China. *Journal of Hazardous Materials, 173*: 75-81.

Li, Q., Li, Y., Zhu, L., Xing, B., and Chen, B. (2017). Dependence of Plant Uptake and Diffusion of Polycyclic Aromatic Hydrocarbons on the Leaf Surface Morphology and Micro-structures of Cuticular Waxes. *Scientific Reports*, *7*(November 2016), 46235.

Li, Y. T., Li, F. B., Chen, J. J., Yang, G. Y., Wan, H. F., Zhang, T. B., Zeng, X. D., and Liu, J. M. (2008). The concentrations, distribution and sources of PAHs in agricultural soils and vegetables from Shunde, Guangdong, China. *Environmental Monitoring and Assessment, 139*: 61-76.

Li, Z., Ma, Z., van der Kuijp, T. J., Yuan, Z., and Huang, L. (2014). A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. *Science of the Total Environment*, *468–469*: 843–853.

Lin, D., Zhu, L., He, W., and Tu, Y. (2006). Tea plant uptake and translocation of Polycyclic Aromatic Hydrocarbons from water and around air. *Journal of Agricultural and Food Chemistry, 54*:3658-3662.

Loppi, S., Pozo, K., Estellano, V. H., Corsolini, S., Sardella, G., and Paoli, L. (2015). Accumulation of polycyclic aromatic hydrocarbons by lichen transplants: Comparison with gas-phase passive air samplers. *Chemosphere*, *134*(April): 39–43.

Lu, S., Teng, Y., Wang, Y., Wu, J., and Wang, J. (2015). Research on the ecological risk of heavy metals in the soil around a Pb-Zn mine in the Huize County, China. *Chinese Journal of Geochemistry*, *34*(4): 540–549.

Maimon, A., Khairiah, J., Mahir Ahmand, R., Aminah, A., and Ismail. B. S. (2009). Comparative assumulation of heavy metals in selected vegetables, their availability and correlation in lithogenic and nonlithogenic fractions of soils from some agricultural areas in Malaysia. *Advances in Environmental Biology, 3*(3): 314-321.

Maisto, G., Alfani, A. Baldantoni, D., De Marco, A., and De Santo, A.V. (2004). Trace metals in the soil and in *Quercus ilex* L. leaves at anthropic and remote sites of the Campania Region of Italy. *Geoderma*, *122*: 269-279.

Malawska, M., Bojakowska, I., and Wiłkomirski, B. (2002). Polycyclic aromatic hydrocarbons (PAHs) in peat and plants from selected peat-bogs in the north-east of Poland. *Journal of Plant Nutrition and Soil Science*, *165*(6): 686–691.

Malik, R. N., Husain, S. Z., and Nazir, I. (2010). Heavy metal contamination and accumulation in soil and wild plant species from industrial area of Islamabad, Pakistan. *Pakistan Journal of Botany*, *42*(1): 291–301.

Mehes-Smith, M., Nkongolo, K. K., Narendrula, R., and Cholewa, E. (2014). Mobility of heavy metals in plants and soil: A case study from a mining region in Canada. *American Journal of Environmental Sciences*, *9*(6): 483–493.

Memon, A.R., Aktoprakligil, D., Ozdemir, A., and Vertii, A. (2001). Heavy metal accumulation and detoxification mechanisms in plants. *Turkish Journal of Botany, 25*: 111-121.

Meng, F. and Li, G. (1998). The effects of acid rain on chemical activities of elements in soil. *J. Central South Forestry University*, *18*(1): 27-34.

Meniconi, G., and Gabardo, T. (2002). Brazilian Oil Spills Chemical Characterization—Case Studies. *Environmental Forensics, 3*: 303–321.

Mertens, J., Luyssaert, S., and Verheyen, K. (2005). Use and abuse of trace metal concentrations in plant tissue for biomonitoring and phytoextraction. *Environmental Pollution*, *138*(1): 1-4.

Mo, C., Cai, Q., Tang, S., Zeng, Q., and Wu, Q. (2009). Polycyclic Aromatic Hydrocarbons and Phthalic Acid Esters in vegetables from nine farms of the Pearl River Delta, South China. *Archives of Environmental Contamination and Toxicology, 56*: 181-189.

Morillo, J., Usero, J., and El Bakouri, H. (2008). Biomonitoring of heavy metals in the coastal waters of two industrialised bays in southern Spain using the barnacle *Balanus Amphitrite. Chemical Speciation and Bioavailability*, *20*(4): 227-237.

Moya, J., Bearer, C. F., and Etzel, R.A. (2004). Various Life Stages. *Pediatrics, 113*(4): 996–1006.

Müller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. *GeoJournal, 2*: 108-118.

Murphy, Jr., C.B. (1981). Bioaccumulation and toxicity of heavy metals and related trace elements. *Journal of the Water Pollution Control Federation, 53*(6): 993.

Nadal, M., Schuhmacher, M., and Domingo, J.L., (2004). Levels of PAHs in soil and vegetation samples from Tarragona County, *Spain Environmental Pollution*, *132*: 1–11.

Nasher, E., Heng, L.Y., Zakaria, Z., and Surif, S. (2013). Assessing the Ecological Risk of Polycyclic Aromatic Hydrocarbons in sediments at Langkawi Island, Malaysia. *The Scientific World Journal, 2013*:1-13. DOI: 10.1155/2013/858309

NCEA, National Center for Environment Assessment/EPA provisional Value, US Environmental Protection Agency, USA. Retrieved 18th June 2016.

Nelson, D.W., and L.E. Sommers. (1982). Total carbon, organic carbon, and organic matter. In A.L. Page (Ed.), *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. 2nd Edition* (pp. 539-579). Madison, WI: American Society of Agronomy.

Nicola, F. De, Baldantoni, D., Sessa, L., Monaci, F., Bargagli, R., and Alfani, A. (2015). Distribution of heavy metals and polycyclic aromatic hydrocarbons in holm oak plant–soil system evaluated along urbanization gradients. *Chemosphere*, *134*: 91–97.

Nieboer, E. and Richardson, D. H. S. (1980). The replacement of the nondescript term "heavy metals" by a biologically and chemically significant classification of metal ions. *Environmental Pollution Series, B*: 1-3.

Nisbet C, and LaGoy P. (1992). Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs). *Regulatory Toxicology and Pharmacology*, *16*: 290–300.

Odhav, B., Beekrum, S., Akula, U., and Baijnath, H. (2007). Preliminary assessment of nutritional value of traditional leafy vegetables in KwaZulu-Natal, South Africa. *Journal of Food Composition and Analysis, 20*: 430–435.

Ojiako, O. A., Chikezie, P. C., and Ogbuji, A. C. (2015). Comparative hypoglycaemic activities of aqueous and ethanolic extracts of four medicinal plants (*Acanthus montanus, Asystasia gangetica, Emilia coccinea* and *Hibiscus rosasinensis*) in type 1 diabetic rats. *Journal of Intercultural Ethnopharmacology, 4*(3): 228-233.

Omar, N. Y. M .J., Abas, M. R., Rahman, N. A., Tahir, N. M., Rushdi, A. I., and Simoneit, B. R. T. (2007). Levels and distributions of organic source tracers in air and roadside dust particles of Kuala Lumpur, Malaysia. *Environmental Geology, 52*: 1485-1500.

Ong M. C., Tan Y. F., Khoo X. Y. and Yong J. C. (2015). Heavy metals and polycyclic aromatic hydrocarbons (PAHs) concentration in mud crab (*Scylla Serrata*) from UMT mangrove, Terengganu, Malaysia. *Advances in Environmental Biology*, *9*(21): 66-73.

Ong, G. H., Wong, L. S., Tan, A. L., and Yap, C. K. (2016). Effects of metal-contaminated soils on the accumulation of heavy metals in gotu kola (Centella asiatica) and the potential health risks: a study in Peninsular Malaysia. *Environmental Monitoring and Assessment*, *188*(1): 40.

Parrish, Z. D., White, J. C., Isleyen, M., Gent, M. P. N., Iannucci-Berger, W., Eitzer, B. D., Kelsey, J. W., and Mattina, M. I. (2006). Accumulation of weathered polycyclic aromatic hydrocarbons (PAHs) by plant and earthworm species. *Chemosphere*, *64*: 609-618.

Peng, C., Ouyang, Z., Wang, M., Chen, W., and Jiao, W. (2012). Vegetative cover and PAHs accumulation in soils of urban green space. *Environmental Pollution*, *161*: 36–42.

Peralta-Videa, J. R., Lopez, M. L., Narayan, M., Saupe, G., and Gardea-Torresdey, J. (2009). The biochemistry of environmental heavy metal uptake by plants: Implications for the food chain. *The International Journal of Biochemistry and Cell Biology*, *41*: 1665-1677.

Prasad, A. G. D., Shyma, T. B., and Raghavendra, M. P. (2013). Plants used by the tribes for the treatment of digestive system disorders in Wayanad district, Kerala. *Journal of Applied Pharmaceutical Science*, *3*(08): 171-175.

Praveena, S. M., Ismail, S. N. S., and Aris, A. Z. (2015). Health risk assessment of heavy metal exposure in urban soil from Seri Kembangan (Malaysia). *Arabian Journal of Geosciences*, *8*(11): 9753–9761.

Qiao, M., Cai, C., Huang, Y., Liu, Y., Lin, A., and Zheng, Y. (2010). Characterization of PAHs contamination in soils from metropolitan region of Northern China. *The Bulletin of Environmental Contamination and Toxicology, 85*: 190-194.

Rainbow, P. S. and Phillips, D. J. H. (1993). Cosmopolitan biomonitors of trace metals. *Marine Pollution Bulletin*, *26*(11): 593-601.

Ramesar, S., Baijnath, H., Govender, T., and Mackraj, I. (2008). Angiotensin I-converting enzyme inhibitor activity of nutritive plants in KwaZulu-Natal. *Journal Medicinal Food*, *11*(2):331–336.

Raskin, I, Kumar, P. B. A. N., Dushenkov, S., and Salt, D. (1994). Bioconcentration of heavy metals by plants. *Current Opinion in Biotechnology*, *5*: 285-290.

Rocher, V., Azimi, S., Moilleron, R., and Chebbo, G. (2004). Hydrocarbons and heavy metals in the different sewer deposits in the 'Le Marais' catchment (Paris, France): stocks, distributions and origins. *The Science of the Total Environment, 323*: 107–122.

Sądej, W., and Namiotko, A. (2010). Content of polycyclic aromatic hydrocarbons in soil fertilized with composted Municipal waste. *Polish Journal of Environmental Studies*, *19*(5): 999–1005.

Saha, M., Takada, H., and Bhattacharya, B. (2012). Establishing Criteria of Relative Abundance of Alkyl PAHs for Differentiation of Pyrogenic and Petrogenic PAHs: An Application to Indian Sediment. *Environmental Forensics, 13*(4): 312–331.

Samdudin, M.W., Azahar, H., Abas, A., and Zakaria, Z. (2013). Determination of heavy metals and polycyclic aromatic hydrocarbons (PAH) contents using the lichen *Dirinaria picta* in Universiti Kebangsaan Malaysia. *Journal of Environmental Protection, 4*: 760-765.

Savinov, V. M., Savinova, T. N., Matishov, G. G., Dahle, S., and Næs, K. (2003). Polycyclic aromatic hydrocarbons (PAHs) and organochlorines (OCs) in bottom sediments of the Guba Pechenga, Barents Sea, Russia. *Science of the Total Environment, 306*(1–3): 39–56.

Schi, K. C. and Weisberg, S. B. (1999). Iron as a reference element for determining trace metal enrichment in Southern California coast shelf sediments. *Marine Environmental Research, 48*: 161-176.

Shahbazi, A., Zakaria, M. P., Yap, C. K., Surif, S., Baktiari, A. R., Chandru, K., Bahry, P. S., and Sakari, M. (2010). Spatial distribution and sources of polycyclic aromatic hydrocarbons (PAHs) in green mussels (*Perna viridis*) from coastal areas of Peninsular Malaysia: implications for source identification of perylene. *International Journal of Environmental Analytical Chemistry, 90*(1): 14-30.

Siddig, A. A. H., Ellison, A. M., Ochs, A., Villar-Leeman, C., Lau, M. K. (2016). How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in Ecological Indicators. *Ecological Indicator*, *60*: 223-230.

Slaski, J. J., Archambault, D. J., Li, X., (2000). *Evaluation of polycyclic aromatic hydrocarbon (PAH) accumulation in plants. The potential use of PAH accumulation as a marker of exposure to air emissions from oil and gas flares.* ISBN 0-7785-1228-2. Report prepared for the Air Research Users Group, Alberta Environment, Edmonton, Alberta.

Sousa, A. I., Cacador, I., Lillebø, A. I., and Pardal, M. A. (2008). Heavy metal accumulation in *Halimione portulacoides*: Intra- and extra-cellular metal binding sites. *Chemosphere*, *70*: 850-857.

Sudhakar, M., Rao, Ch. V., Rao, P. M., Raju, D. B., and Venkateswarlu, Y. (2006). Antimicrobial activity of *Caesalpinia pulcherrima*, *Euphorbia hirta* and *Asystasia gangeticum. Fitoterapia, 77*: 378-380.

Suntherland, R. A. (2000). Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. *Environmental Geology, 39*(6): 611-627.

Tang, Y. T., Qiu, R. L., Zeng, X. W., Ying, R. R., Yu, F. M., and Zhou, X. Y. (2009). Lead, zinc, cadmium hyperaccumulation and growth stimulation in Arabis paniculata Franch. *Environmental and Experimental Botany*, *66*(1): 126–134.

Tataruch, F. and Kierdorf, H. (2003). Mammals as biomonitors. In B.A. Markert, A.M. Breure, H.G. Zechmeister, (Eds.), *Bioindicators and biomonitors* (pp 737-772). Amsterdam, Elsevier.

Taur, D.J. and Patil. R.Y. (2011). Some medicinal plants with antiasthmatic potential: a current status. *Asian Pacific Journal of Tropical Biomedicine, 1*(5): 413-418.

Tremolada, P., Burnett, V., Calamari, D. and Jones, K. C. (1996). Spatial distribution of PAHs in U.K. atmosphere using pine needles. *Environmental Science and Technology, 30*: 3570-3577.

Uka, U. N., Chukwuka, K. S., and Afoke, C. (2013). Heavy metal accumulation by Telfairia occidentalis hook, F grown on waste dumpsites in South-eastern Nigeria. *Research Journal of Environmental Toxicology*, *7*(1): 47–53.

USEPA. (1989). Risk assessment guidance for superfund. *Human health evaluation manual, (part A) [R], volume 1*. Washington, DC: Office of emergency and remedial response.

USEPA. (1993). Carcinogenic Polycyclic Aromatic Hydrocarbons; Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons. Retrieved 15th January 2014.

USEPA. (2001). Risk assessment guidance for superfund: volume 3, Part A, Process for conducting probabilistic risk assessment. *Human Health Evaluation Manual, vol. 1*. Washington, DC: U.S. Environmental Protection Agency. Retrieved 2nd July 2016.

USEPA. (2002). Supplemental guidance for developing soil screening levels for superfund sites. Retrieved 2nd July 2016.

USEPA. (2008). Ingestion - dermal exposure pathway soil remediation standards. Washington, DC: U.S. Environmental Protection Agency. Retrieved 2nd July 2016.

USEPA. (2011). Risk Assessment guidance for superfund. Part E, Supplemental Guidance for Dermal Risk Assessment; Part F, Supplemental Guidance for Inhalation Risk Assessment. *Human Health Evaluation Manual, vol. 1*. Washington, DC: U.S. Environmental Protection Agency. Retrieved 3rd July 2016.

Vollenweider, P., Bernasconi, P., Gautschi, H., Menard, T., Frey, B., and Günthardt-Goerg, M. S. (2011). Compartmentation of metals in foliage of *Populus tremula* grown on soils with mixed contamination. II. Zinc binding inside leaf cell organelles. *Environmental Pollution*, *159*: 337-347.

Waltham, N. J., Teasdale, P. R., and Connolly, R. M. (2013). Use of flathead mullet (*Mugil cephalus*) in coastal biomonitor studies: Review and recommendations for future studies. *Marine Pollution Bulletin*, *69*(1–2): 195–205.

Wang, J., Liu, W., Yang, R., Zhang, L., and Ma, J. (2013b). Assessment of the potential ecological risk of heavy metals in reclaimed soils at an opencast coal mine. *Disaster Advances, 6*(S3): 366-377.

Wang, X., Li, L., and Zuo, W. (2013a). Occurrence and Potential Ecological Risk Assessment of Heavy Metals in the Farmland Soil. In W. Du (Ed.), *Informatics and Management Science II* (pp. 191–198). London: Springer London.

Watts, A. W., Ballestero, T. P., and Gardner, K. H. (2008). Soil and atmospheric inputs to PAH concentrations in Salt Marsh Plants. *Water, Air, and Soil Pollution, 189*: 253-263.

Wedepohl, K.H. (2004). The composition of Earth's Upper Crust, Natural Cycles of Elements, Natural Resources. In E. Merian, M. Anke, M. Ihnat, and M. Stoeppler. (Ed.), *Elements and their Compounds in the Environment* (pp. 3-16). Weinheim: Wiley-VCH.

Wiart, C. (2000). *Medicinal Plants of Southeast Asia*. Pelanduk Publications. Subang Jaya, Malaysia

Wilcke, W. (2000). Polycyclic aromatic hydrocarbons (PAHs) in soil: A review. *The Journal of Plant Nutrition and Soil Science (Zeitschrift für Pflanzenernährung und Bodenkunde), 163*: 229–248.

Wittig, R. (1993). General aspects of biomonitoring heavy metals by plants. In: *Plants as biomonitors.* (Ed.): B. Markert, Weinheim VCH Publisher, 3-28.

Wolfe, M. F., Atkeson, T., Bowerman, W., Burger, J., Evers, D. C., Murray, M. W., and Zillioux, E. (2007). Wildlife Indicators. In R. Harris, D. P. Krabbenhoft, R. Mason, M. W. Murray, R. Reash and T. Saltman. (Ed.), *Ecosystem Responses to Mercury Contamination: Indicators of Change* (pp. 123-189). Florida, FL: SETAC Press.

Wolterbeek, B. (2002). Biomonitoring of trace element air pollution: principles, possibilities and perspectives. *Environmental Pollution, 120*: 11–21.

Wuana, R. A and Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *International Scholarly Research Network*, *2011*: 1-20.

Xiao, Y., Tong, F., Kuang, Y., and Chen, B. (2014). Distribution and source apportionment of Polycyclic Aromatic Hydrocarbons (PAHs) in forest soils from urban to rural areas in the Pearl River Delta of Southern China. *Environmental Research and Public Health, 11*: 2642-2656.

Xue, W. L., and Warshawsky, D. (2004). Metabolic activation of polycyclic and heterocyclic aromatic hydrocarbons and DNA damage: A review. *Toxicology and Applied Pharmacology, 206*: 73–93.

Yang, R. Y., Tsou, S. C. S., Lee, T. C., Wu, W. J., Hanson, P. M., Kuo, G., Engle, L. M., and Lai, P. Y. (2006). Distribution of 127 edible plant species for antioxidant activities by two assays. *Journal of the Science of Food and Agriculture, 86*: 2395–2403.

Yap, C. K. and Pang, B. H., (2011). Assessment of Cu, Pb, and Zn contamination in sediment of north western Peninsular Malaysia by using sediment quality values and different geochemical indices. *Environmental Monitoring and Assessment, 183*: 23-39.

Yap, C. K. and Wong, C. H. (2011). Assessment Cu, Ni, and Zn pollution in the surface sediments in the Southern Peninsular Malaysia using cluster analysis, ratios of geochemical nonresistant to resistant fractions, and geochemical indices. *Environment Asia*, *4*(1):53-61.

Yap, C. K., and Al-Barwani, S. M. (2012). A comparative study of condition indices and heavy metals in perna viridis populations at sebatu and muar, Peninsular Malaysia. *Sains Malaysiana*, *41*(9): 1063–1069.

Yap, C. K., Ismail, A., Cheng, W. H., and Tan, S. G. (2006). Crystalline style and tissue redistribution in *Perna viridis* as indicators of Cu and Pb bioavailabilities and contamination in coastal waters. *Ecotoxicology and Environmental Safety, 63*: 413-423.

Yap, C. K., Ismail, A., Tan, S.G., and 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*(1-2):117-126.

Yap, C. K., Noorhaidah, A., Azlan, A., Nor Azwady, A. A., Ismail, A., Ismail, A. R., Siraj, S. S., and Tan, S. G. (2009). *Telescopium telescopium* as potential biomonitors of Cu, Zn, and Pb for the tropical intertidal area. *Ecotoxicology and Environmental Safety*, *72*(2): 496–506.

Yap, C.K., and Al-Barwani, S.M. (2012). A comparative study of condition indices and heavy metals in *Perna viridis* populations at Sebatu and Muar, Peninsular Malaysia. *Sains Malaysiana, 41*(9):1063-1069.

Yap, D. W., Adezrian, J., Khairiah, J., Ismail, B. S., and Ahmad-Mahir, R. (2009). The uptake of heavy metals by Paddy plants (*Oryza sativa*) in Kota Marudu, Sabah, Malaysia. *American-Eurasion Journal of Agricultural and Environmental Science, 6*(1):16-19.

Yenni, A., Yahya, S., Murtilaksono, K., Sudradjat, S., and Sutarta, E.S. (2016). The roles of *Asystasia gangetica* (L.) T. Anderson and ridge terrace in reducing soil erosion and nutrient losses in oil palm plantation in South Lampung, Indonesia. *Journal of Tropical Crop Science*, *3*(2): 49-55.

Yenni, A., Yahya, S., Murtilaksono, K., Sudradjat, S., and Sutarta, E.S. (2015). Study of *Asystasia gangetica* (L.) T. Anderson utilization as cover crop under mature oil palm with different ages. *International Journal of Sciences: Basic and Applied Research, 19*: 137-148.

Yeoh, H. H. and Wong, P. F. M. (1993). Food value of lesser utilized tropical plants. *Food Chemistry, 46*: 239–241.

Yildirim, D., and Sasmaz, A. (2016). Phytoremediation of As, Ag, and Pb in contaminated soils using terrestrial plants grown on Gumuskoy mining area (Kutahya Turkey). *Journal of Geochemical Exploration*. In Press. http://doi.org/https://doi.org/10.1016/j.gexplo.2016.11.005

Yoon, J., Cao, X., Zhou, Q., and Ma, L. Q. (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. *Science of the Total Environment*, *368*(2–3): 456–464.

Zakaria, M. P., Geik, K. H., Lee, W. Y. and Hayet, R. (2005). Landfill leachate as a source of polycyclic aromatic hydrocarbons (PAHs) to Malaysian waters. *Coastal Marine Science, 29*(2): 116-123.

Zakaria, M. P., Horinouchi, A., Tsutsumi, S., Takada, H., Tanabe, S., and Ismail, A. (2000). Oil pollution in the Straits of Malacca, Malaysia: Application of Molecular Markers for source identification. *Environmental Science and Technology, 34*:1189-1196.

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*: 1907-1918.

Zheng, T., Ran, Y., and Chen, L. (2014). Polycyclic aromatic hydrocarbons (PAHs) in rural soils of Dongjiang River Basin: Occurrence, source apportionment, and potential human health risk. *Journal of Soils and Sediments*, *14*(1): 110–120.

Zhu, L. and Shou, X. (1997). Chemical form distribution and plant availability of Cd in plough horizons. *Journal of Hohai University*, 25(3): 50-56.