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Heavy metal distribution and contamination in wetland sediments: A review

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ABSTRACT

Wetlands are an integral part of the watershed ecosystems, and consists of shallow water. These wetlands contain high levels of nutrients and primary productivity which is ideal for the development of organisms that form the base of the food web and feed many species of fish, amphibians, shellfish, and insects. At the same time, due to extensive use and exploited by mankind civilization, heavy mental pollution has an important impact on wetland ecosystems. Heavy metals are released into the environment from a variety of natural and anthropogenic sources. Assessing heavy metals concentration in wetland sediments, their distribution, sources and potential ecological risk on aquatic organisms are crucial steps for the protection and sustainable utilization of wetland resources. Several studies have been performed on the distribution of heavy metal on wetland and the factor affecting the concentration and the risk caused by heavy metal pollution in aquatic ecosystems. This paper is primarily focused to provide a profound and brief review on present status of heavy metal contamination, their source, assessment and their impacts through sedimentary analysis.

INTRODUCTION

Heavy metals accumulation in aquatic environments *viz.*, river, lake, wetland and estuary is a primary concern all over the world. Metals are inorganic persistent elements, variable source, toxic at low concentration and high affinity to accumulate on sediments and its associate environment (Li et al., 2013; Jahan and Strezov, 2018). There are mainly two pathways of metal input on aquatic environment, natural and anthropogenic activities. Natural processes such as rock weathering and erosion release heavy metals which enter into the water streams by transport media (e.g. air, water flow, soil or sediment) (El-Sayed et al., 2015; Naifar et al., 2018). However, nowadays the major sources of heavy metals are human activities. For example, industrial development, agriculture, urban development or waste discharge with socio-economic development (Effendi et al., 2016; Khodami et al., 2017). Besides this, ecotourism in the wetland areas imposed serious threats due to tourism related land development and changes in the landscape. In some instance, construction of boardwalks, destruction of vegetation, development of road and disposal of solid waste which alter water hydrology of wetland areas due to sedimentation and erosion (Tavares et al., 2012). Results in such excessive heavy metals inputs lead to heavy metal pollution at the particular areas (Anbuselvan et al., 2018; Dai et al., 2018; Mohd et al., 2018). Metals such as zinc, copper and chromium are essential elements for living organisms to function well. However, the excessive intake of these metals will bring out harmful impacts (Nobi et al., 2010; Sandilyan and Kathiresan, 2014). Due to the bioaccumulation and bio-magnification factors of toxic metals, toxic levels will increase from low trophic levels to higher ones. For instance, a benthic organism which lives on or within the contaminated sediments and proceeds with its cycle by passing lethal substance to higher trophic levels through nourishment web (Sandilyan and Kathiresan, 2014; Abuduwaili et al., 2015; Le et al., 2017). Thus, the health of organisms on higher trophic levels in aquatic (e.g. dolphins) and terrestrial (*e.g.* humans) ecosystem will be affected. Indeed, aquatic ecosystems act as protein sources for humans (Sanyet al., 2013; Shaari et al.,

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2016). The toxicity of heavy metals effects both acute and chronic on human health including increasing the risk factor of the cancer, failure of the reproductive system and also impacts on the central nervous system (Jaishankar et al., 2014). Thus, the accumulation of heavy metals is an important environmental issue throughout the world and especially in developed countries.

The high concentrations of metals in the water mainly causing from metals input into the aquatic environment through water column. These metals are absorbed by surfaces of sediments particles and become suspended contaminants (Ding et al., 2018; Liang et al., 2018; Naifar et al., 2018). Some physicochemical properties such as grain size of sediment, Fe/Mn oxides, sulphides and organic matter content play a significant role in the absorption and retention capacity of sediments, distribution pattern across the ecosystem (Islam et al., 2015; Khodami et al., 2017; Ding et al., 2018; Jahan and Strezov, 2018). Therefore, surface sediments of river and estuarine environments are the reservoir of metals which reflects the present pollution due to human activities. In addition, surface sediments also act as a sink of metals due to releasing behaviour of absorbed metals in aquatic environment through remobilization process in respect of environment changes (Kadhum et al., 2015; Islam et al., 2018). Thus, surface sediments are the source and sink of potential heavy metal contaminants as well as environmental indicator to give the status of pollution history and ecological changes over time.

Distribution, source and impacts of heavy metals in aquatic environments

Heavy metals in the sediments

Heavy metals are group of metals which are more abundant in the earth crust and their density is greater than water (Jaishankar et al., 2014). These metals have adverse effects on environment and living components (Jaishankar et al., 2014; Abuduwaili et al., 2015; Effendi et al., 2016). Heavy metals enter into aquatic environment are accumulated to the surface sediments through sorption process and bind with sediment particles. Again, sediment released the heavy metals on to water column in order to changes of physicochemical properties in sediment. Thus surface sediment act as a source and sink of heavy metals in aquatic environment (Yuan et al., 2015; Pradit et al., 2016; Khodami et al., 2017; Wang et al., 2017).

Physicochemical properties such as organic matter content (Yuan et al., 2015; Kadhum et al., 2015; Pradit et al., 2016; Wang et al., 2017; Zhu et al., 2017; Jahan and Strezov, 2018; Liang et al., 2018), sediment pH (Islam et al., 2015; Kadhum et al., 2015), grain size distribution (Nobi et al., 2010; Pradit et al., 2016; Khodami et al., 2017; Jahan and Strezov, 2018; Liang et al., 2018), oxides of Fe and Mn, redox reaction and electrical conductivity of sediments (Islam et al., 2015; Kadhum et al., 2015) influence the accumulation of heavy metals in aquatic environment. For example, Nobi et al. (2010) reported that concentration of heavy metal was increased with fine grain size of particles and organic matter content on the sediments of Andaman Island, India. The result indicates that, metals accumulated to finer particle higher compared to large particles and organic matter allow the sediments to absorb higher amount of heavy metals.

Source of heavy metals

The heavy metals input into aquatic environment through various transport media such as soil, sediments, air and water(Li et al., 2013; Jahan and Strezov, 2018). Heavy metal pollution into aquatic environment occurs mainly two ways which are anthropogenic activities and natural processes. The natural processes which contribute heavy metal pollution in aquatic environment include rocks weathering, mining and soil erosion (Nobi et al., 2010; Li et al., 2013; Baharim et al., 2015; El-Amier et al., 2017; Zhu et al., 2017; Liang et al., 2018). Out of natural processes, there is wide range of sources of heavy metal contamination into environment due to anthropogenic activities. Untreated waste from manufacturing and food processing industries, sewage sludge, fertilizer and pesticide used for agricultural activities, aquaculture and fishing activities, house hold waste discharge and land development for recreational purposes are few examples of anthropogenic activities which might be caused heavy metal contamination (Nobi et al., 2010; Li et al., 2013; Baharim et al., 2015; Islam et al., 2015; Yuan et al., 2015, El-Amier et al., 2017; Khodami et al., 2017; Zhu et al., 2017; Mohd et al., 2018; Liang et al., 2018; Jahan and Strezov, 2018). Thus, anthropogenic activities might be contributing soil and water contamination and pollution and increased ecological risk of living organisms due to lack of proper management of ecosystems.

Heavy metals pollution in wetland

A vast number of peoples are living in coastal areas (total population is around 32 million out of which 26 million people lived in coastal area) (World Bank, 2013). Coastal areas have been greatly used for industry and artificial farm development (Pradit et al., 2016; Mohd et al., 2018). Besides this, wetland and mangrove area situated in coastal areas are also used for recreation and tourism activities (Kamaruzzaman et al., 2008; Sandilyan and Kathiresan, 2014; Jamilah et al., 2015). In last few years, mangrove trees are cut down to develop road, small houses and board walk; and coastal plains converted to pond for shrimp and aquaculture activities (Sandilyan and Kathiresan, 2014; Pradit et al., 2016). Thus, anthropogenic activities along the coastal areas had a negative effect on aquatic environment. The contamination of heavy metals on sediments of aquatic environment was increases due to land exploitation, sewage discharge from industries and household areas, mining and aquaculture activities (Sany et al., 2013; Baharim et al., 2015; Mohd et al., 2018).

Khodami et al. (2017) reported that metal pollution on sediments of Bayan Lepas area due to industrial development. Similar results also found by Wang et al.(2017) on the sediments of Kelantan river. In coastal areas of Selangor, the heavy metals pollution was found to be associated with industrial waste water and anthropogenic activities in port areas (Sany et al., 2013).

Hazardous effect of heavy metals

A number of methods and approaches applied to determine the heavy metal pollution and their adverse biological effects to aquatic environment through soil (Yuan et al., 2015; Liang et al., 2018), water (Islam et al., 2015; Suratman et al., 2016)or tissue of organisms (Kamaruzzaman et al., 2009; Le et al., 2017) as parameter of ecosystem health. Heavy metals on the environment enter into food web from soil and sediments which create adverse impact to the biota from lower trophic level to higher level (Rainbow, 2006; Le et al., 2017). The hazardous effect of metals to the aquatic organisms is based on the level and type of heavy metals present in a particular area (Jaishankar et al., 2014). Based on the type of heavy metals they are categorized as essential, borderline and non-essential (Walker and Sibly, 2012) (Table 1). Essential heavy metals are micronutrients required for various biological and physiological functions in biota while non-essential heavy metals have no recognized functions in biota (Walker and Sibly, 2012; Jaishankar et al., 2014). The essential metals become toxic to the biota when high amount to be present in environment, but non-essential heavy metals become toxic al low level of exposures in environment.

Table 1: Classification of heavy metals

Essential	Borderline	Non-essential
Calcium (Ca)	Zinc (Zn)	Cadmium (Cd)
Magnesium (Mg)	Chromium (Cr)	Lead (Pb)
Manganese (Mn)	Iron (Fe)	Mercury (Hg)
Sodium (Na)	Cobalt (Co)	Arsenic (As)
Potassium (K)	Nickel (Ni)	Silver (Ag)
Strontium (Sr)	Vanadium (V)	

Source: Adapted from (Walker and Sibly, 2012)

Heavy metal accumulation from aquatic organism towards higher trophic level via bioaccumulation and biomagnifications process, the accumulated metals exceed the tolerable level of heavy metals at a definite stage of living organisms (Kamaruzzaman et al., 2009; Jaishankar et al., 2014; Le et al., 2017). The excess heavy metal accumulation into plant and animals leads to acute and chronic impacts to biota in environment (Walker and Sibly, 2012). Cadmium is one of the toxic metals at low dose and longtime exposure of Cd causes kidney failure, restrict growth and development of living organisms and other physiological problems. Consumption of chromium above safety level will cause anemia and malfunction of kidney and liver as well as lung cancer. Other than Cd and Cr, exposure of Cu will lead to acute and chronic health problems. The acute health problems are stomachache and erythrocytes while chronic effects liver and kidney damages of human and restrict the growth rate of animals. In addition, excessive intake of as will cause skin cancer, facilitate cancer development and problems with inhalation. Moreover, Pb poisoning occurs at low dose of Pb intake and can leads to physiological and neurobiological system disturbance. Beside this, Pb poisoning is serious to children compared to adult and Pb toxicity will give negative effect to brains and nervous systems of children (Walker and Sibly, 2012; Jaishankar et al., 2014).

Assessment of sediment quality

The concentration of heavy metal on sediment of aquatic environment has received great importance. Several approaches and indices: Sediment Quality Guidelines (SGQs), Enrichment Factor (EF), Geo-accumulation Index (I_{geo}), Contamination factor (CF), Pollution Load Index (PLI), Potential Ecological Risk (E_r^i) and Risk Index (RI) are used to measure the quality of sediments and the status of heavy metal. These procedures determine the environmental risk of heavy metals on the ecosystem.

Sediment quality guidelines (SGQs) compared the metals content on the sediment sample with the values of metal described in sediment quality guidelines for aquatic environment. The levels of metal contents on the sediment sample define their adverse biological effects to aquatic organisms based on Consensus-Based Sediment Quality Guidelines of Wisconsin CBSQG (CBQG) (Li et al., 2013; Pradit et al., 2016). The EF value used to differentiate the source of heavy metal either natural or anthropogenic or both (Khodami et al., 2017; El-Amier et al., 2017; Anbuselvan et al., 2018; Liang et al., 2018; Islam et al., 2018). The level of heavy metal contamination on the sediment sample can be measured by Contamination Factor (CF) and Geo-accumulation Index (I_{geo}) (Khodami et al., 2017; El-Amier et al., 2017; Anbuselvan et al., 2018; Liang et al., 2018; Islam et al., 2018). PLI value used to determine the amount of pollution caused by heavy metals in aquatic environment (Kadhum et al., 2015; El-Amier et al., 2017). Moreover, the ecological risk of individual metal and multiple metals on the sediment sample can be determined by using E_r^i and RI, respectively (Khodami et al., 2017; Liang et al., 2018; Islam et al., 2018). Thus, results of these methods give further information for future management of a particular study area.

Multivariate statistical analysis

Multivariate statistical analysis: Pearson's correlation analysis, principal component analysis (PCA) and cluster analysis (CA) are used widely to determine the source of heavy metals and the factors which influence the distribution of metals on the sediment of aquatic environment (Nobi et al., 2010; Li et al., 2013; Yuan et al., 2015; Baharim et al., 2015; Islam et al., 2018; Liang et al., 2018). Pearson correlation analysis is used to determine the correlation between different metals along with their physicochemical properties of sediment (Kadhum et al., 2015; Wang et al., 2017; Jahan and Strezov, 2018; Mohd et al., 2018). Anbuselvan et al. (2018) reported that, Zn had strong positive correlation with Pb and Cu; and their abundance also associated with grain size and organic matter content of sediment samples in Coromandel Coast of India. Also, Li et al. (2013), Pearson correlation analysis was applied to the concentration of heavy metals on the sediment of Dongting lake, China. He found that, metal content Cr-Cu and Cu-Pb had a strong correlation with each other, respectively. To find the relationship between natural and anthropogenic sources of heavy metals to determine the potential source of metals and physicochemical properties which influence the metal content on the sediments Factor Analysis is applied by different researcher (Abuduwaili et al., 2015; Effendi et al., 2016; Jahan and Strezov, 2018). For instance, Kadhum et al. (2015) was applied PCA to find the relationship between heavy metals and their physicochemical properties on the sediment sample in Langat river basin, Malaysia. The result reveals that, Cr and Ni were come from anthropogenic activities and their distribution was linked with total organic carbon, pH and salinity of studied sediment sample. Moreover, hierarchical cluster analysis (CA) is used to group the variables according to their interrelationship and correlation. Cluster analysis was performed along with FA to examine the analysis results and to makes the cluster of heavy metals and the elements which influence the quality of sediment in a particular area. Dendrogram was developed form variables and parameters reflect the similarities among metals, physicochemical properties or both (Baharim et al., 2015; Jahan and Strezov, 2018). According to Li et al. (2013), cluster analysis was performed to identify the similarities on the metal contents in Dongting lake China. The results suggest that cluster 1 includes Cd, As and Hg which indicate the high level of contamination by those metal while, cluster 3 include Zn with low level of contamination.

CONCLUSION

The wetland systems directly received runoff and contamination from land. Based on the review high concentration of heavy metals in the sediment coming from direct flow create stress on aquatic organisms. As a result, systems may suffer from both acute and chronic effects from pollutants. Harvesting or utilization of wetland biomass such as fish, crabs or benthic organism will transfer the heavy metal into environment with the potential risk of the metal become available in the food chain. To prevent future challenges, heavy metal pollution in wetland ecosystems must be considered. The author suggests using environmental quality assessment to combat the widespread problem of metal contamination to ecosystems.

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