Feature Article

An overview of heavy metal contamination in coastal sediments of Sri Lanka

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Abstract

Coastal sediments are often subjected to heavy metal contamination as they reside at the marginal environments of anthropological water releases. These sediments provide the habitat for marine aquatic life of seafood. Therefore, heavy metal contamination in coastal sediments is one of the major environmental concerns. The coastal belt of Sri Lanka is highly urbanized with high population (59% of Sri Lankan population) and is mostly depend on the sea. Therefore, anthropogenic inputs of pollutants in to the marine environments have been increased during last decades. Heavy metal contamination of the coastal sediments of Sri Lanka has been discussed by several studies, focusing on selected coastal regions. In this article, previous studies have been reviewed in order to understand the contamination status and ecological risks due to heavy metal accumulations.Despite the sampling location, the elemental distribution of coastal lagoonalsediments shows similar trend indicating the dominance of natural elemental sources rather the anthropogenic influences. The concentrations of As and Cr in sediments are high compared to the upper continental crust values which is a characteristic feature in possible source rocks, soils and sediments of Sri Lanka. Theresults of the previous studies indicate thatcoastal sediments are low to moderately contaminated but notat ecological risk. However, anthropogenic activities are highly variable across the coastal regions. Since limited results of the previous studies is not enough to get an overview of the heavy metal concentrationsaround the island, urgent need for a spatial and temporal geochemical database for coastal sediments of Sri Lanka is emphasized.

Keywords: contamination, coastal, metals and sediments

1. Introduction

Environmental contaminants are in three categories:(a) stable trace elements (b) organic substances and (c) radionuclides (Tornero andd'Alcalà, 2014). United States Environmental Protection Agency (USEPA) has chosen the following trace elements including heavy metalssuch as Ag, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se and Zn that is toxic in desired excessive concentrations. The list has expanded later by several authors (McBridge, 1995; Chen and Ma, 1998).

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When a substance is above the level of background it is said to be as “contaminated”.When it is adversely affected on biological communities, it is said to be as“polluted” (Chapman, 2007). Heavy metal contamination in natural environments is a severe environmental problem due to their natural toxicity, persistence, vast sources and non-degradability (Wang et al., 2013). Heavy metals get into natural environments from effluents of industries, agriculture and aquaculture practices, and municipal and domestic wastes (Tornero andd'Alcalà, 2014). Marineand coastal environments have been paid more attention because they are the ultimate settings of heavy metal accumulationsand human concern for seafood (Wang et al., 2005).Bioaccumulation, bio-magnification by food chains, destruction to organisms and ecological systems and consequently damage to ecological goods and services are the adverse effects of heavy metal contaminations (Newton et al., 2013; Tornero andd'Alcalà, 2014). Therefore, it is essential to monitor the present contamination status in marine and coastal environments.

Sri Lankan coastline is about 1,920 km long and encompasses about 50% of the Bay of Bengal (Katupotha, 1989).Different coastal features such as lagoons, estuaries, sediment bars and spits, dunes, wave cuts, arches and cliffs which are characterized by erosional and depositional processes are presentaround the island (Katupotha, 2007). The origin and evolution of coastal landforms of the country was activated during the Quaternary period and the sea level reaches its present status about 3000 year BP (Ranasinghe et al., 2013). Several studies on different coastal landforms of Sri Lanka have been reviewed in this article to summarize the current status of coastal sediment contamination.This article reviews the existing literature on the concentrations of selected trace elements in the coastal regions of Sri Lanka and risk of contamination of the coastal ecosystems by them.

2. Coastal environment of Sri Lanka

The climate of Sri Lanka is tropical with diversified rainfalls from both southwest (SW) and northeast (NE) monsoons. In general, high rainfall is recorded during May to September due to SW monsoons and low rainfall during November to February due to NE monsoons. Altogether 103 main rivers are flowing to the coastal low lands from the central part of the country. The river discharges are timely changed with monsoonal rainfall effect. Huge sediment loads are carried through the river channels, and hence river channels are the basic sediment supplier for the coastal zones. Large scale storm or cyclone has not been recorded during past decades except the tsunami occurred in 2004. The temperature ranges from 16° C to 32°C across the country. The lowest temperature recorded in the central highlands and highest temperatures are recorded in constantly southeastern and eastern coastal areas. The tidal effect of the island is micro-scale and hence no considerable effect on sedimentation in coastal zones except the regionally developing sea currents.

Many of the coastal zones of Sri Lanka are densely populated due to clear and shallow beaches, corals and hot sun. About 59% of the total population of Sri Lanka is associated to the coastal regions (Nayanananda, 2007). Most of the industrialized capital cities are located around the coastal margins of the country. Sea around the country receives nutrient rich currents, therefore other than point sources of contaminants non-point source such as storm water and dust can contribute for contamination. Fishing industry is famous in Sri Lanka and fish processing units are established around the coastal areas.Western and southern coastal regions arehighly industrialized and densely populated. Thus,effluents that comes from industries such as petroleum refining, ship repairing, tires and thermal industries other than the huge municipal and domestic leachates are mixed with natural waters are ended up at the sea.Additionally, minor water based industries such as foundry, laundry, tannery, paper industries, service stations and “batik”fabric die work are commonly observed in coastal low lands of Sri Lanka where tourists are attracted.

3. Levels of contaminants

In presentarticle, heavy metals and As concentrations in sediments ofseven main semi-enclosed marginal marine water bodiesand capital city of Sri Lanka are summarized from published data. These recent publications are done by collecting surface sediment fractions of each semi-enclosed body. Sampling locations areTrincomalee bay, Batticaloa lagoon, Hambanthota lagoon, Galle harbor, Hikkaduwa lagoon, Beruwala harbor, Muthurajawela peat deposit and surface sediments of Colombo city (Dissanayake, 1987; Jayawardana et al., 2012; Young et al., 2014; Silva, 2015; Heath et al., 2016; Adikaram et al., 2017).Geographical distribution of the concentrations of the selected heavy metals of Sri Lanka is shown in Figure 1 (Dissanayake, 1987; Jayawardana et al., 2012; Young et al., 2014; Silva, 2015; Heath et al., 2016; Adikaram et al., 2017).Concentrations of Zn and Cr are significant in all natural lagoonal systems including Muthurajawela peat deposit with compared to the other elements. The two harbors show high Pb concentrations. Substantial enrichments of Zn and Cu are observed in the city sediments of the Colombo region.

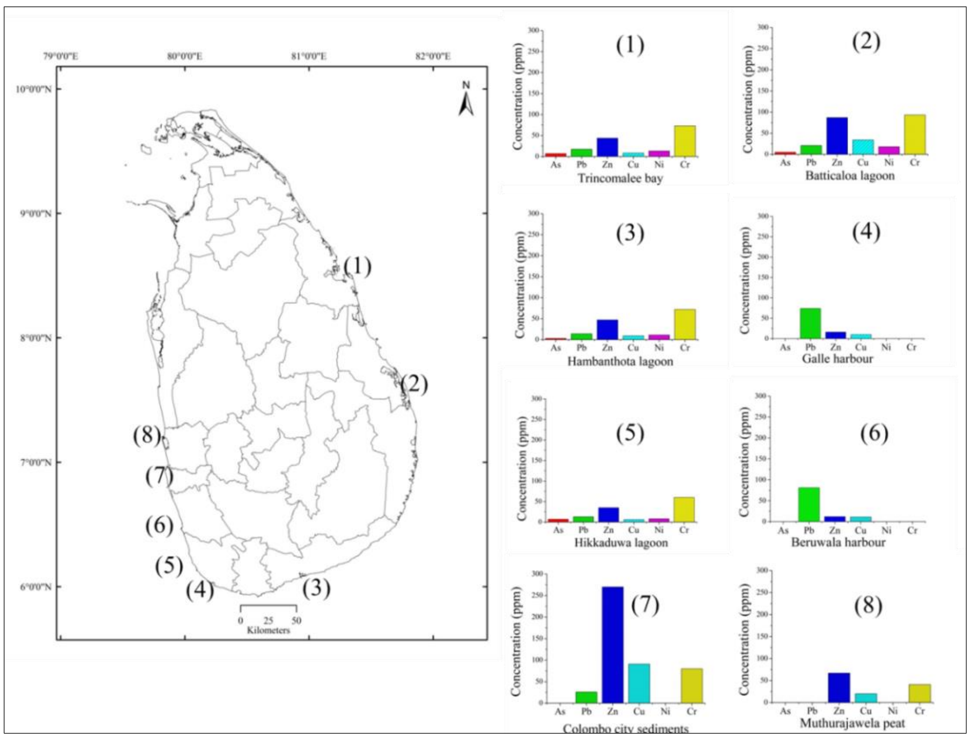

Figure 1: Geographical distribution of heavy metal concentrations in coastal sediments of Sri Lanka.(After Dissanayake, 1987; Jayawardana et al., 2012; Young et al., 2014; Silva, 2015; Herath et al., 2016; Adikaram et al., 2017).

Average concentrations of As, Pb, Zn, Cu, Ni and Cr of the semi-enclosed water bodies of Sri Lanka, other published data in different regions of the world and international standards are summarized in Table1. It is noted that the sediments of Sri Lankan coastal zones are not contaminated with compared to other compared marine environments of the world.

Table 1: Concentrations of heavy metals and As in coastal sediments of Sri Lanka and comparison with other coasts.

Country	Location	Concentration (ppm)						
		As	Pb	Zn	Cu	Ni	Cr	
Sri Lanka	Batticaloa lagoon	5 (3-10)*	21 (14-26)	87 (21-155)	34 (6-216)	18 (7-41)	93 (52-146)	Adikaram et al., 2017
	Trincomalee, inner harbour	7 (3-19)	23 (3-103)	49 (21-152)	13 (2-41)	16 (3-57)	73 (26-192)	Young et al., 2014
	Trincomalee, Thambalagam bay	10 (2-43)	14 (8-20)	31 (9-79)	6 (0-23)	11 (4-46)	50 (11-181)	Young et al., 2014
	Trincomalee, Koddiyar bay	4 (2-9)	15 (9-20)	51 (6-181)	6 (2-14)	13 (0-27)	96 (7-356)	Young et al., 2014
	Hikkaduwa lagoon	7 (3-11)	13 (8-17)	35 (8-55)	6 (2-9)	8 (0-20)	60 (45-84)	Jayawardana et al., 2012
	Hambanthota lagoon	3 (3-4)	14 (14-15)	47 (38-72)	9 (5-12)	11 (10-17)	72 (61-78)	Jayawardana et al., 2012
	Galle fishery harbour	nd	74 (61-87)	16 (1-68)	10 (7-16)	nd	nd	Silva (2015)
	Beruwala fishery harbour	nd	80 (37-102)	12 (0-50)	11 (5-15)	nd	nd	Silva (2015)
	Muthurajawela peat	nd	nd	67 (26-262)	20 (12-37)	nd	41 (20-84)	Dissanayake (1987)
	Colombo city dust	nd	26 (0-76)	270 (53-625)	91 (28-319)	nd	80 (47-152)	Herath et al., (2016)
India	Gulf of Mannar	nd	16	73	57	24	177	Jonathan et al.,2009
	Kalpakkam	nd	22	119	nd	53	118	Selvaraj et al., 2004
	Pondicherry	nd	33	52	48	20	334	Solali et al, 2013
	Gange's estuary	nd	29	71	26	32	67	Subramanian et al., 1988
	Krishna Estuary	nd	4	1482	59	149	174	Ramesh and Subramanium, 1988
	West Bengal	nd	17	74	36	34	37	Sarkar et al., 2004
Bangladesh	Chittagong coast,	nd	18	355	189	33	658	Hasan et al., 2013
Tunisia	Mediterrnian sea	(13-36)	(65-152)	(47-546)	(8-29)	(9-31)	nd	Zohra and Habib, 2016
China	Bhohai bay	nd	(21-66)	(55-457)	(20-63)	(23-53)	(60-224)	Gao and Chen, 2012
SQG	TEC	10	36	121	32	23	43	McDonald et al., 1996
	PEC	33	128	459	149	49	111	McDonald et al., 1997

SQG: sediment quality guidelines, TEC: threshold effect level, PEC: probable effect level

The concentration of As and Cr in coastal sediments of Sri Lanka is high with compared to the upper continental crust (UCC) values (Figure. 1; Taylor and McLennan, 1985). The possible source country rock types are characterized in high concentrations of As and Cr and this might be the reason for the enrichments of such elements (Young et al., 2014).

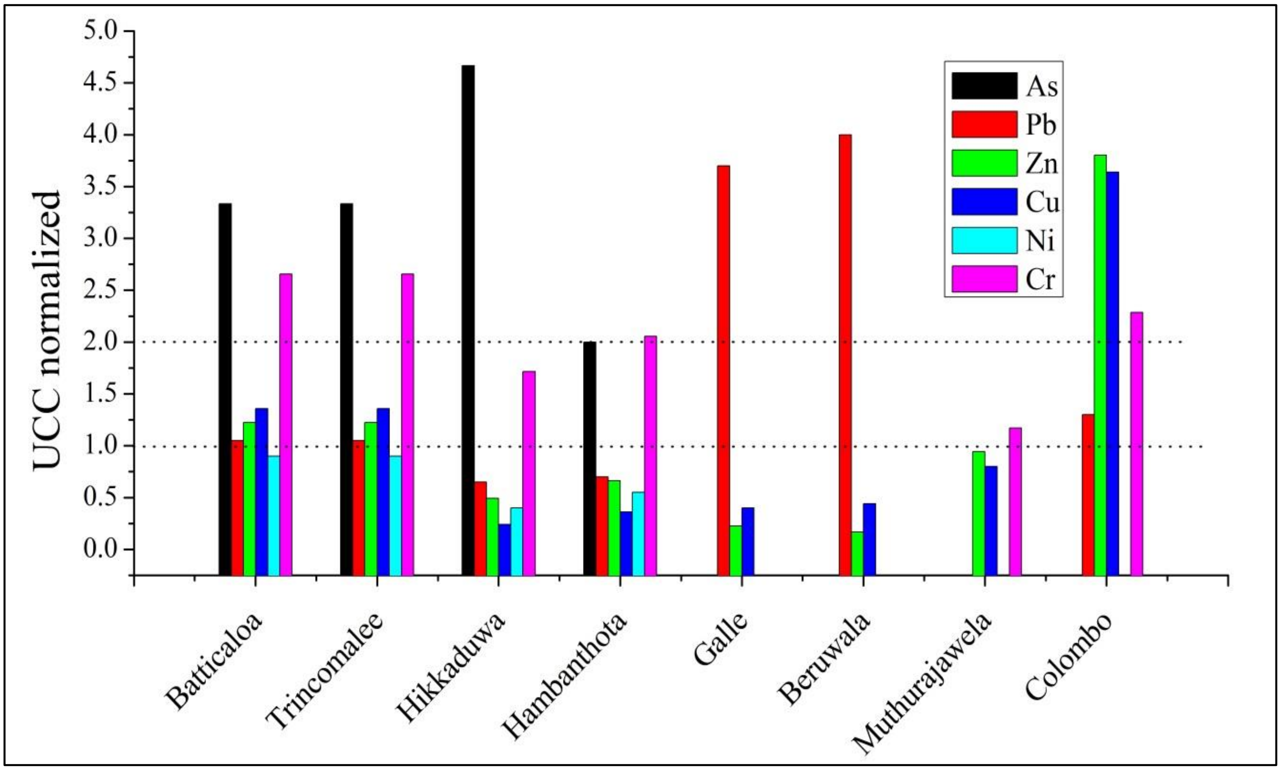

Figure 2: UCC normalized elemental concentrations in coastal sediments of Sri Lanka (After Dissanayake, 1987; Jayawardana et al., 2012; Young et al., 2014; Silva, 2015; Heath et al., 2016; Adikaram et al., 2017).

4. Environmental and ecological risk assessment of coastal sediments

Average concentrations of six trace elements of coastal sediments of Sri Lanka are compared with reference values of Threshold Effect Concentration (TEC) and Probable Effect Concentrations (PEC) of consensus-based freshwater ecosystem Sediment Quality Guidelines (Table 1; MacDonald et al., 1996). Values in between TEC and PEC are rarely or occasionally make adverse effects on organisms whereas values above PEC make adverse effects on a wide range of organisms (MacDonald et al., 1996). The average concentrations of As of Sri Lankan coasts are below the threshold values of sediment quality guidelines. In addition, Beruwala and Galle harbors shows above Pbvalues for TEC. The concentrations of Zn, Cu and Cr of Colombo city sediments show higher values for TEC. Except Muthurajawela peaty sediments, all sediment types have exceeded the TEC values for Cr. However, average concentrations of all sediment types of Sri Lankan coasts are below the PEC values suggesting the level of contamination is not much considerable.

Contamination factor (CF) is an elemental ratio of concentration of each metal in the sediment with concentration of those particular metals in the background (Hakanson, 1980). The contamination levels may be classified based on their intensities on a scale ranging from 1 to 6 (0=none, 1=none to medium, 2

=moderate, 3=moderately to strong, 4=strongly polluted, 5=strong to very strong, 6=very strong (Muller, 1969).

$$CF = \frac{CM_{Sediment}}{CM_{background}} \quad (1)$$

Where:

CM= metal concentration.

The pollution load index (PLI) is calculated using the CF values that provide comparative means to measure the level of pollution in different locations (Tomlinson et al., 1980).

$$PLI = \sqrt[n]{CF_1 x\ CF_2 x\ CF_3 x \ldots .xCF_n} \quad (2)$$

Where:

CF =contamination factor and n is the number of elements.

If sediments are polluted PLI > 1 and for non-polluted PLI<1 (Tomlinson et al., 1980).

The CF values and PLI values for average concentrations of semi-enclosed coastal bodies of Sri Lanka are given in Table 2. Contamination factor also indicates enrichments of As and Cr in Sri Lanka coasts. According to the PLI values, Colombo city sediments are significantly polluted. Additionally,Batticaloa lagoon and Trincomalee bay shows slightly polluted sediments whereas other locations are unpolluted with the global references. This is basically due to the high concentrations of Cr and As which is controlled by the country rocks.

Table 2: Contamination factor, pollution load index and potential ecological risk index of coastal sediments, Sri Lanka.

Location	Contamination factor						PLI	PERI
	As	Pb	Zn	Cu	Ni	Cr		
Batticaloa lagoon	3.3	1.1	1.2	1.4	0.9	2.7	1.6	56
Trincomalee bay	3.3	1.1	1.2	1.4	0.9	2.7	1.6	56
Hikkaduwa lagoon	4.7	0.7	0.5	0.2	0.4	1.7	0.8	57
Hambanthota lagoon	2.0	0.7	0.7	0.4	0.6	2.1	0.9	33
Galle harbour	nd	3.7	0.2	0.4	nd	nd	0.7	21
Beruwalaharbour	nd	4.0	0.2	0.4	nd	nd	0.7	22
Muthurajawela peat	nd	nd	0.9	0.8	nd	1.2	1.0	7
Colombo city	nd	1.3	3.8	3.6	nd	2.3	2.5	33

PLI: pollution load index

PERI: potential ecological risk index

High metal concentrations in sediments create adverse biological effects which can be measured by several defined approaches. To evaluate the adverse biological effect a simple method introduced by Hakanson (1980) was used. The potential ecological risk index (PERI) is specially proposed to assess the contamination levels of coastal sediments with respect to toxicity of some selected contaminants (Hakanson, 1980).

$$PERI = \sum E_r \quad (3)$$

$$E_r = T_r \ x\ CF \quad (4)$$

Where:

E_r= ecological risk factor
T_r= toxic response factor
CF= contamination factor

The standard values for T_r are As, Pb, Zn, Cu, Ni and Cr are 10, 5, 1, 5, 5 and 2 respectively. The PERI < 90 is low potential ecological risk; 90 < PERI < 190 is moderate ecological risk; 190 < PERI < 380 is considerable ecological risk and PERI > 380 is a very high ecological risk. According to the calculated PERI values with published data, it can be suggested that the Sri Lankan coastal sediments have low potential ecological risk (Table 2).

5. Summery

In summary, based on the available data of Sri Lankan coastal sediments, it can be concluded that the sediments are slightly polluted and that level is not adversely affected to the ecological systems. The selection of geochemical background values in contamination status evaluations might be a reason for the pollution status of the present article which is basically depends on the possible source rocks. Regional trace metal concentrations are affected by the rock types, geomorphological conditions and geographical locations which are altered by physical and chemical weathering processes. Therefore, to determine the anthropogenic influences more accurately, a baseline for the sediment trace metal concentrations should be determined regionally. This will help to identify the anthropogenic causes of pollution and take necessary actions to control pollution to prevent the present coastal sediments.

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