Spatial Distribution of Heavy Metals in Sediments of the Negombo Lagoon, Sri Lanka

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Abstract

Heavy metals accumulate in the sediments of aquatic environments due to poor water solubility. Their toxic effect poses a significant threat to living organisms. Negombo Lagoon, a vital aquatic ecosystem in Sri Lanka, has become vulnerable to heavy metals mainly from urbanization-related anthropogenic activities. Previous research in this respect has sampling points restricted to the boundary area. Since the heavy metal concentration is a static parameter, continuous research needs to keep the data updated. This study aims to investigate the spatial distribution of several heavy metals (Cr, Ni, Co, Cu, As, Cd, and Pb) in the surficial sediment of the Negombo Lagoon. Fifteen grab sediment samples were collected from the lagoon and analyzed for heavy metal concentration and grain size. The highest and the lowest concentrations are Ni (1076.64 mg/kg) Cd (0.30 mg/kg) respectively. Heavy metal concentrations and sediment grain sizes show significant spatial variation over the Negambo Lagoon area. Heavy metals were highly concentrated in locations, where finer sediments are accumulated (i.e., towards the eastern and southern part of the lagoon). Heavy metal concentrations were found to be increased with the decreasing grain size. High heavy metal concentrations are also found at places where there is a river discharge.

Keywords: Anthropogenic activities, Aquatic, Concentration, Grain size, Spatial distribution

1. Introduction

Aquatic ecosystems are often polluted by different types of contaminants, at different levels and from diverse sources. Among them, heavy metals occupy a prominent place due to some unique characteristics such as their abundance, high toxicity, and non-biodegradability[1]. There are many food chains and food webs associated with the lagoonal environments. Thus, the non-biodegradability of heavy metals causes them to be biologically enriched within consumers at higher levels in food chains. There is a detrimental impact of heavy metals on the ecosystems and their individual components, including human beings. Heavy metals enter the lagoonal environments in diverse ways.

Cadmium (Cd), zinc (Zn), lead (Pb), copper (Cu), manganese (Mn), ferrous (Fe), magnesium (Mg), mercury (Hg), arsenic (As) and barium (Ba) are the heavy metals commonly found in the aquatic environments in measurable quantities [2]. Since many heavy metals are toxic even at lesser concentrations, estimating the distribution of heavy metals in aquatic ecosystems is a vital and primary step to assess their ecological impact.

The poor water solubility of heavy metals causes them to get attached to the suspended particulate material. With time, these suspended solids get settled as sediments. Therefore, sediments from aquatic environments serve as a reservoir for heavy metals [3], [4]. Selecting sediments for the analysis of heavy metals, out of many components in the aquatic environment such as sediment, water, organisms, etc., is a good approach due to this reason.

Heavy metal accumulation in sediments of aquatic systems can occur due to diverse sources. They are mainly from anthropogenic activities such as disposal of industrial waste and wastewater generated in mining, metal fabrication, foundry, paper production, dye work, tannery, laundry, etc., dumping of municipal and domestic waste, agricultural runoff, and burning of fossil fuels [5]. Occasionally there can be natural sources such as geological weathering of heavy metal-bearing rocks as well as volcanic eruptions[6].

Lagoon ecosystems in Sri Lanka have been identified to contain high levels of heavy metals. For example, six lagoons in the western and north-western coast of Sri Lanka, namely Gembarandiya, Chilaw, Muthupanthiya, Mundal, Puttlam and Negombo have been detected to be affected by anthropogenic inputs of heavy metals [7]. Out of them Negombo Lagoon is identified as one of the most sensitive but productive ecosystems in Sri Lanka. Local communities of the Negombo Lagoon area depend on the ecological, economic, and social benefits from the lagoon including lagoonal fishing, tourism, crab, and prawn rearing etc. Thus, a proper assessment of heavy metal distribution in an ecologically sensitive area like Negombo Lagoon is important for pollution control in the coastal environments and evaluation of present and future socioeconomic impacts.

Based on the previous literature, a high concentration of Cd (1.04 ± 0.28 mg/kg) was found in the tissues of Gray Mullet (*Mugil cephalus*), a commercially important edible fish species from Negombo Lagoon [8]. Cd level in liver tissues of *E. suratensis* and *A. commersoni* fish from the Negombo Lagoon exceeded recommended safe levels for human consumption by the European Union [9]. Elevated levels of Cd and Pb were found in water as well as sediment samples collected from the northern and eastern regions of the Negombo Lagoon [10]. As (>20mg/kg), Cd (>2.0mg/kg), Cr (>30mg/kg), Pb (>15mg/kg) and Hg (>0.4mg/kg) were identified at high concentrations in one or more tested biotic (bark and leaves of *Bruguiera gymnorhiza*, and fauna of several selected taxa) and abiotic components (sediment, and soil) from Negombo Lagoon [11]. Cd (6.90 ppb) and Pb (83.80 ppb) levels were found to be high in water from Negombo Lagoon and Hamilton Canal which is a feeder canal for the lagoon [12].

Although high concentrations of heavy metals are found in the Negombo Lagoon, the distribution of heavy metals present in the lagoon shows significant temporal variations. Therefore, it highlights the need for further research on the lagoon, in order to keep the database up to date. Also, updated data on the heavy metal distribution is vital to trace the point and non-point heavy metal sources associated with the lagoon. In the previous studies, sampling was limited to the lagoon boundary. Hence, there is a lack of detailed studies on the spatial distribution of heavy metals in sediments from the lagoon, especially in the central area.

Therefore, this study is an attempt made to find the spatial distribution of heavy metal contaminants in the surficial sediments of the Negombo Lagoon and to identify the possible causes of the anomalies detected. Further, this research will create an updated database for decision-making and as a reference for future research while helping to bridge the gaps in the scientific literature of this domain.

2. Methodology

2.1 Study Area

Negombo Lagoon is a shallow basin estuary located approximately 20 km north to the city of Colombo in Gampaha District, in western Sri Lanka. This lagoon covers an area of about 32km^2 and extends approximately 12km in length with 3.75 km at its widest point. It receives dispersed freshwater inputs from Dandugam Oya, Ja-Ela, and Hamilton Canal. The northern part of the lagoon is connected to the Indian Ocean, by a set of narrow channels due to the presence of several islands at the sea mouth [13]. The Muthurajawela peatland is at the southern extension of the lagoon. This lagoon holds about 22.5 million cubic meters of water and has an average water depth of about 1.2 m. The area mainly receives rainfall from the southwest monsoon from May to September. Convectional showers occur during the remaining months of the year. The temperature of the lagoon varies from 24 °C to 30 °C [7], [12], [14].

2.3 Materials and Method

Figure 1: Surficial sediment sampling locations in the Negombo Lagoon.

In this research, fifteen surficial sediment samples were collected from the Negombo Lagoon as shown in the ***Figure 1*** using the "Van Veen" Grab Sampler. Judgmental sampling was followed to choose the sampling locations. It is based on the available information about heavy metal distribution within the sampling area.

All sediment samples were oven-dried at a temperature of 105 °C for 24 hours. The dried samples were then powdered by means of a mortar and a pestle. The powdered samples were sieved through a 63µm sieve and cone, and quartering was carried out to obtain representative samples. 0.5 g of each sediment sample was digested with aqua regia, and hydrogen peroxide mixed in the ratio HCl: HNO_3: H_2O_2 – 3: 1: 1, for 3 hours at 120˚C. The digested solutions were filtered using 45µm syringe filters and finally topped up to 100 ml with distilled water. The samples were then analyzed by the Inductively Coupled Plasma Mass Spectrometer (ICP-MS) to find the concentrations of Cr, Ni, Co, Cu, As, Cd and Pb. The abundance of heavy metals was expressed in mg/kg (as ppm values).

The oven-dried samples were wet sieved using 1.18mm sieve. The representative samples with particle size less than 1.18mm, were then fed into the laser particle analyzer to determine the sediment grain size.

3. Results

The heavy metal concentration values obtained from the ICP-MS analysis and the average particle size obtained from the laser particle size analysis are shown in ***Table 1***

The spatial distributions of each heavy metal concentration and average particle size plotted using the ArcMap software are shown in ***Figure 2*** and ***Figure 3***.

The heavy metal concentration for each metal was plotted against the average particle size to observe a general trend. The resulted graph is shown in ***Figure 4***.

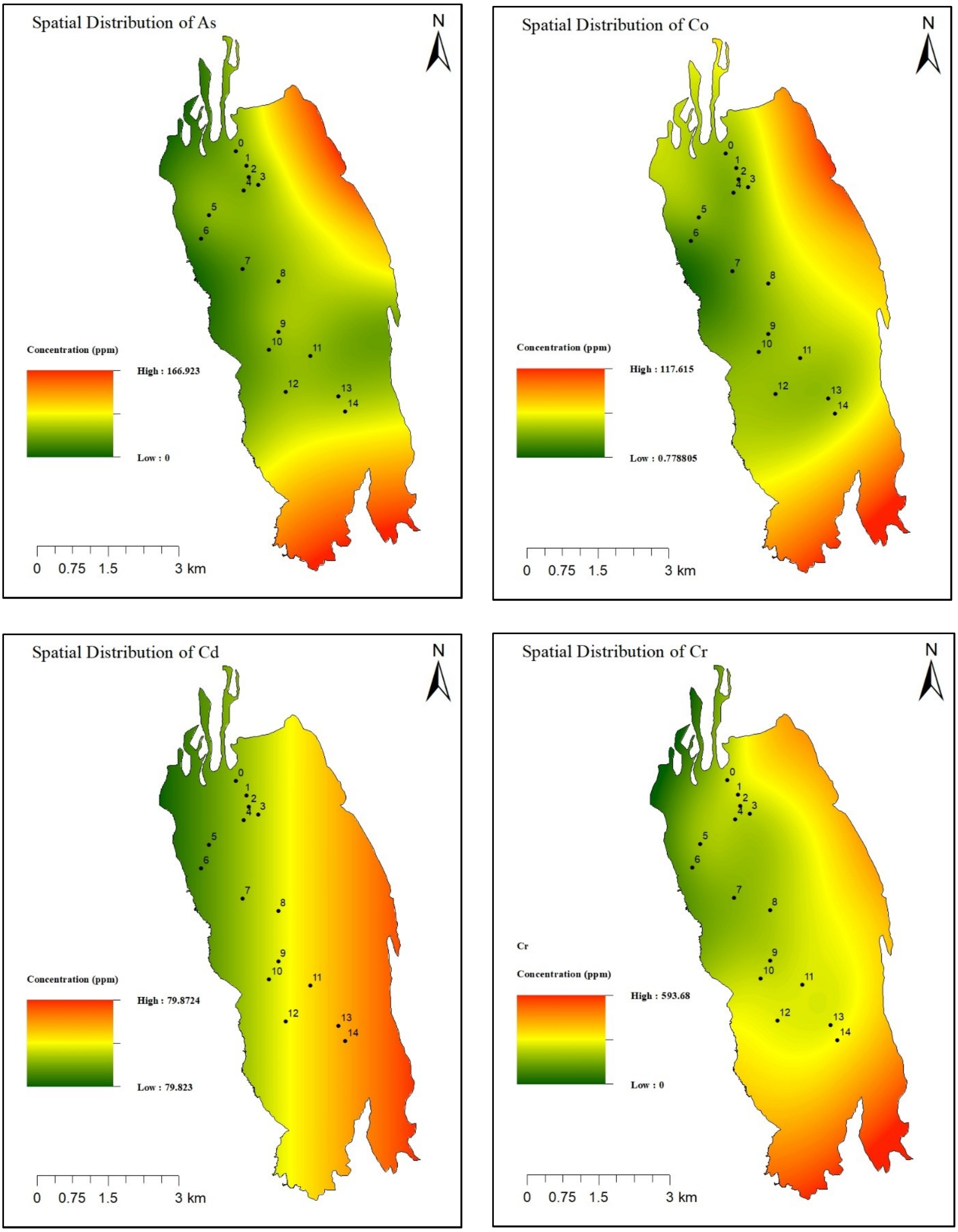

Figure 2: Spatial distribution of heavy metal concentration (Top left: As, Top right: Co, Bottom left: Cd and Bottom right: Cr)

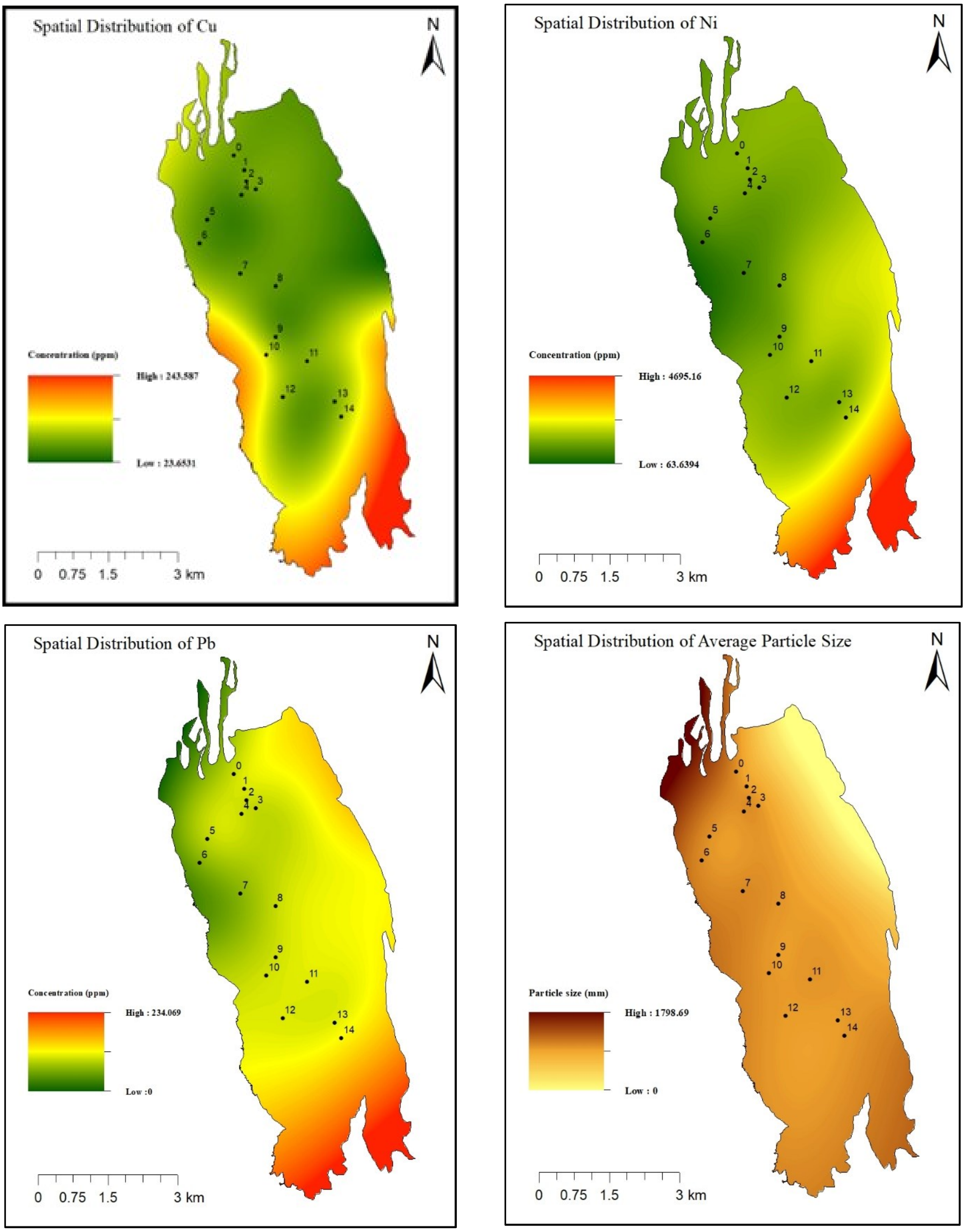

Figure 3: Spatial distribution of heavy metal concentration and sediment grain size (Top left: Cu, Top right: Ni, Bottom left: Pb and Bottom right: Average Particle Size)

Table 1: Heavy metal concentration and average particle size at selected sampling locations.

Locations	Concentration (ppm)							Average particle size (µm)
	Cr	Ni	Co	Cu	As	Cd	Pb	
GS01	157.16	856.34	29.34	55.79	36.80	0.67	47.94	150
GS02	172.44	843.25	29.23	54.78	40.74	0.56	54.07	39
GS03	155.75	791.35	28.38	55.36	37.34	1.40	48.89	132
GS04	146.13	724.84	32.07	55.06	41.85	0.67	45.05	98
GS05	140.93	727.45	25.28	47.97	35.52	0.71	48.98	144
GS06	116.73	634.95	27.39	46.10	36.92	0.88	42.40	134
GS07	78.07	376.70	15.88	50.69	20.17	0.32	16.57	185
GS08	91.52	416.08	18.37	53.88	23.48	0.30	19.65	195
GS09	129.39	731.54	32.52	50.83	41.34	0.73	45.76	99
GS10	147.41	750.50	28.97	56.43	43.51	0.71	49.82	47
GS11	165.45	798.82	28.89	85.37	34.89	0.41	50.55	91
GS12	182.92	1049.52	32.84	61.72	40.45	1.08	56.90	104
GS13	193.55	853.83	30.47	66.99	43.02	0.73	55.22	51
GS14	194.95	852.67	30.90	60.66	45.28	0.71	58.19	44
GS15	222.68	1076.64	36.78	71.96	55.61	1.14	70.98	67

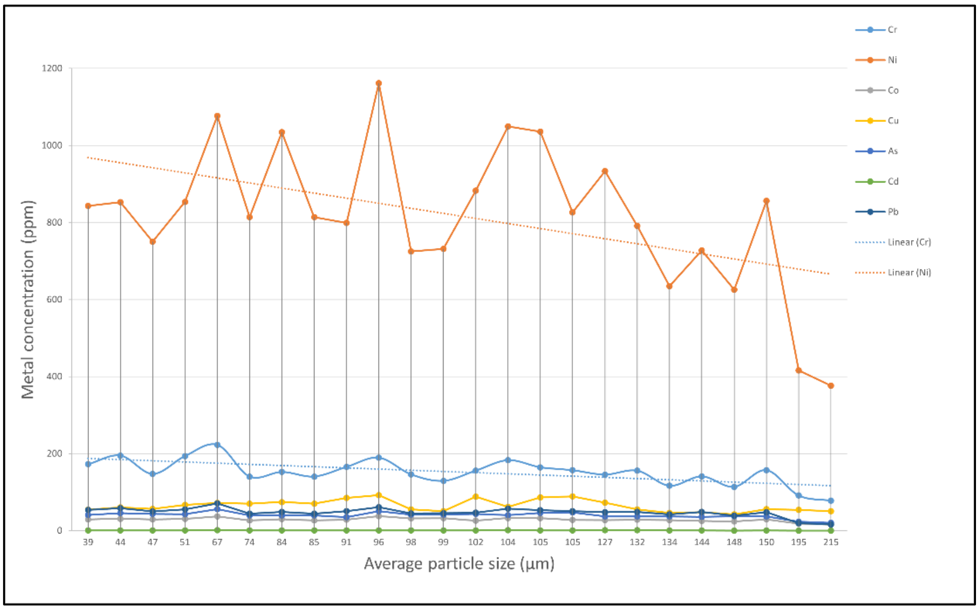

Figure 4: Relationship between the heavy metal concentration and average sediment grain size

4. Discussion

According to the spatial distribution of heavy metals in the surficial sediments (***Figure 2***, ***Figure 3***), a high concentration is found at the eastern and the southern sections of the lagoon. Also, ***Figure 3*** shows that the finer sediments are accumulated mainly in the eastern and southern regions of the lagoon. Relatively coarser particles are present at western and northern part of the lagoon. This can be explained considering the sea water currents as well as the other hydrodynamic related phenomena. Sea water entering eastern part of the lagoon is restricted by the presence of islands at the sea mouth. Due to this, the sea water easily enters the western part of the lagoon compared to the eastern part of the lagoon. Thus, the finer particles are carried to the eastern and southern regions whereas the coarser particles remain at the northern and western sections.

According to the variation of heavy metal concentration with the sediment grain size, the concentrations increase as the particle size drops (***Figure 4***). When particle size of sediments decreases their surface area increases and therefore there is a greater possibility for the heavy metals to get attached. This explains why the heavy metal concentration is reduced with the increasing sediment particle sizes.

Dutch Canal, Ja- Ela, and Aththanagalu Oya enter the Negombo Lagoon from the southern part. Thus, it is a high possibility that these rivers carry heavy metals into the lagoon. Among the sources of heavy metals in the Negombo Lagoon, urbanization related anthropogenic activities such as municipal waste disposal, industrial waste from Ekala industrial zone and Katunayake export processing zone, development of Colombo-Katunayake Expressway, fishing, and naval activities as well as tourism could be prominent.

As a preventive measure for the entering of heavy metals to the lagoonal environment in large quantities, point sources such as industrial waste disposals need to be identified in vicinity to the Negombo Lagoon and proper industrial waste treatment facilities should be implemented. Lagoonal dredging to remove contaminated sediments and removal of accumulated sand bars to facilitate proper flushing are also identified as suitable remedial measures [15]. Lagoonal dredging will also help to restore and maintain lagoons capacity, to improve the appearance of the lagoon as well as to eliminate the odor, sludge, and muck. The contaminated sediments can be treated using the conventional methods such as in-situ capping, sea-dumping, and landfill disposal. However, these methods are found to be not sustainable for a long duration as there is a potential mobility for the treated sediments. Therefore, at present research are focused on incorporating in-situ chemical, biological and thermal treatments for the sediment treatment. It is highly recommended to adhere to such newly developed advanced techniques. Heavy metals can be selectively removed from the aquatic environments using algae. Heavy metals such as Cd, Pb, Ni, and Cu can be hyperaccumulated using Phormidium - blue-green alga. Similarly, As is hyper absorbent and hyper accumulative in Chlorophyta and Cyanophyta. Nanomaterials can be used as a catalyst in contamination remediation techniques can produce effective results. For example, some researchers have discovered that the nanostructured materials can be used as adsorbents or catalysts to remove dangerous, toxic chemicals from soil, wastewater, and air [16].

5. Conclusions

It can be that there is a significant spatial variation in the concentration of each heavy metal within the lagoon. High heavy metal concentrations are found in association with fine sediment accumulations. Fine sediments have a higher surface area to adsorb the heavy metals and thus they can become good pollutant carriers.

The places where there the river discharge flows to the lagoon also have elevated heavy metal concentrations. Therefore, river discharge should have carried heavy metal contaminants from diverse sources around the lagoon. Since there are no natural heavy metal sources such as the heavy metal bearing rocks and volcanoes in association with the lagoon, the major input must be from anthropogenic activities.

Acknowledgement

The authors are thankful to the Department of Earth Resources Engineering, University of Moratuwa for providing laboratory facilities and technical support to complete this research successfully.

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