

## RESEARCH ARTICLE

# Application of pollution indices to quantify the pollution status of shallow sediments of the Bolgoda Lake, Sri Lanka

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**Abstract:** The present study was conducted to assess the pollution status of the shallow sediments of the Bolgoda Lake in Sri Lanka using sediment pollution indices. Shallow sediment samples were collected as replicates from five sites with different land uses in the monsoonal and non-monsoonal seasons in 2013. The samples were acid digested and analysed for Cd, Cr, Cu, Ni, Fe and Zn. The heavy metal concentrations were used to calculate: (1) contamination factor ( $C_f$ ); (2) degree of contamination ( $C_d$ ); (3) pollution loading index (PLI); (4) enrichment ratio (ER); (5) geoaccumulation index ( $I_{geo}$ ) and (6) ecological risk factor ( $Er^i$ ) of the shallow sediment samples. In addition, the quality of the sediments were also assessed by comparing with the numerical sediment quality guidelines (SQGs) and consensus-based sediment quality guidelines (CBSQGs).

Significant spatial variations of element concentrations and sediment quality indices were identified in the study area. The pollution level of the study sites ranged from unpolluted to heavily polluted due to heavy metals. The contamination factors for all the heavy metals except Zn indicated moderate, considerable or very high level of pollution in both sampling sessions. The potential ecological risk factor for the heavy metals ranked as  $Cd > Ni > Cr > Cu > Zn$  for both sampling sessions indicating the highest potential ecological risk from Cd. The pollution load index for all the study sites except site E in both sampling sessions showed human associated pollution with a PLI higher than 1. All the samples were categorised into class 1 (unpolluted to moderately polluted status) with respect to Cr, Ni, Cu and Zn and to class 0 (unpolluted status) with respect to Cd.

The concentrations of Zn and Cd in the present study were lower than the threshold effect concentration (TEC) level of CBSQGs and therefore, was indicated as unlikely to be causing toxicity to benthic organisms. The concentrations of Cr and Ni were higher than the probable effect concentration

(PEC) level of CBSQGs and indicated a probable toxicity to benthic organisms.

**Keywords:** Bolgoda Lake, sediment quality guidelines, sediment quality indices, Sri Lanka.

## INTRODUCTION

Heavy metals are natural constituents in the environment and trace levels of heavy metals play vital roles in maintaining the natural balance of the aquatic ecosystems on earth. But at higher concentrations heavy metals are pollutants of high environmental concern because they are non degradable, toxic and persistent in the aquatic environment. Unacceptably high concentrations of heavy metals in the aquatic environment can cause serious ecological changes in the environment (Jumbe & Nandini, 2009; Katip *et al.*, 2012). In the aquatic environment, heavy metals are distributed between the dissolved phase, colloids, suspended matter and the sedimentary phases. Sediments have a high storage capacity for contaminants (Katip *et al.*, 2012). Therefore, sediments may act as sinks and sources of pollutants to the overlying water column and biota. Contaminated sediments can decrease water quality and ecological diversity, ecological functioning, and aesthetic properties of waterbodies (Davis & Fox, 2009). Therefore, identification of contaminants associated with sediments is important in the ecological management of aquatic ecosystems.

Many studies have assessed the heavy metal concentrations in sediments of aquatic ecosystems in many parts of the world (Cahill & Unger, 1993; Bertin & Bourg, 1995; Sin *et al.*, 2001; Zhang & Wang, 2001;

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Beg & Ali, 2008; Cardellicchio *et al.*, 2009). Sediment quality assessment values such as pollution risk indices, and sediment quality guidelines are widely used to compare the risks of metal contamination in sediments of aquatic ecosystems (Covelli & Fontolan, 1997; Peterson & Zelt, 1999; Pekey *et al.*, 2004; Cardellicchio *et al.*, 2009; Chakravarty & Patgiri, 2009; Harikumar *et al.*, 2009). The commonly used pollution indices in pollution quantification studies are, the contamination factor, degree of contamination, ecological risk factor, enrichment ratio, pollution loading index and geoaccumulation index.

The objective of the present study was to use sediment pollution indices for the first time to assess the status of pollution in an inland waterbody, the Bolgoda Lake in Sri Lanka. The Bolgoda Lake is a shallow inland waterbody located in the Wet Zone of the country. Several densely populated townships are located along the boundary of the lake. Although some studies have been carried out in the Bolgoda Lake to assess the effect of aquatic pollution on the biological components and the water quality (Senaratne & Pathiratne, 2007; Gunatilaka & Wijeyaratne, 2009), none of those have assessed how potential pollutants have affected the sediment quality. Furthermore, the pollution indices that are commonly used in other parts of the world have not been widely applied to assess the pollution status of the waterbodies in Sri Lanka. This study was carried out to assess the pollution status of the Bolgoda Lake using commonly adopted pollution indices, and to compare the pollution status values with other highly polluted, moderately polluted and non polluted sediments of aquatic systems in other regions of the world.

## METHODOLOGY

Shallow sediment samples were collected from 5 sampling sites [(A - 6°45'54.12"N, 79°54'37.45"E), (B - 6°45'47.33"N, 79°53'56.07"E), (C - 6°46'11.91"N, 79°54'50.72"E), (D - 6°46'45.91"N, 79°54'52.58"E), (E - 6°46'48.21"N, 79°54'17.51"E)] in the Bolgoda Lake (Figure 1). Sampling site A was located near a vehicle service center and the households in the vicinity of this site were owners of private boats that they use for recreational purposes. Sampling site B was located in a densely populated area that contained several small scale wood processing industries and boat painting industries. Sites C and D were located in densely populated areas, but with less industrial activities. Site E was located in a poorly populated area and it can be considered as the least disturbed site due to domestic and industrial activities. From each site, 25 replicate sediment samples were collected using a Peterson grab sampler

at an approximate depth of 0.5 m. Shallow sediment samples were collected as they are the sediments that initially come into contact with contaminants that enter the waterbody due to non point source and point source pollution. Samples were collected during the monsoonal (April) and non-monsoonal (October) seasons in 2013.

The collected sediment samples were transported to the laboratory of the Department of Zoology and Environmental Management, University of Kelaniya. In the laboratory, the samples were oven dried until they attained a constant weight and the dried sediment samples were homogenised using agate mortar and pestle. The homogenised samples were sieved using a plastic sieve with a 2 mm mesh size to remove large particles. Dried and sieved sediment samples were gently warmed with 10 mL of 0.02 M nitric acid using a Kjeldhal digestion system (Kjeldal-therm digestion system KB 125) as described by Cook *et al.* (1997). The slurry was then filtered into a 100 mL volumetric flask and it was further washed with 10 mL of 0.02 M nitric acid solution. This was then diluted with distilled water to the mark.

The acid digested samples were analysed using an atomic absorption spectrophotometer [Analytic jena (Model novAA 400P)] for iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), chromium (Cr) and cadmium (Cd). Furnance mode was used to analyse Cd and Zn, and flame mode was used to analyse the other elements. The minimum detection limits for the analysed metals were: Fe - 1.6 mg/L; Ni - 6 mg/L; Cu - 0.7 mg/L; Zn - 0.2 µg/L; Cr - 1 mg/L and Cd - 0.7 µg/L. Blanks and certified reference materials (CRM) were included in the digestion and analysis process to verify the accuracy of the methods. Freshwater sediment CRM 016 (Sigma Aldrich, USA) was used as the certified reference material. All the element concentrations were determined on dry weight basis.

The data were log<sub>10</sub> transformed before statistical analyses to obtain normal distribution and homogeneity of variance. The temporal variation of element concentrations were statistically analysed using student t test. The spatial variation of element concentrations at different sites were statistically analysed using one way ANOVA ( $p < 0.05$ ) followed by Tukey's pairwise comparison. Statistical analysis was done using MINITAB 15 statistical software.

The measured element concentrations were used to calculate the following pollution indices: (1) contamination factor ( $C^i$ ); (2) degree of contamination ( $C_d$ ); (3) pollution loading index (PLI); (4) enrichment ratio (ER); (5) geoaccumulation index ( $I_{geo}$ ) and (6) ecological risk factor ( $Er^r$ ).

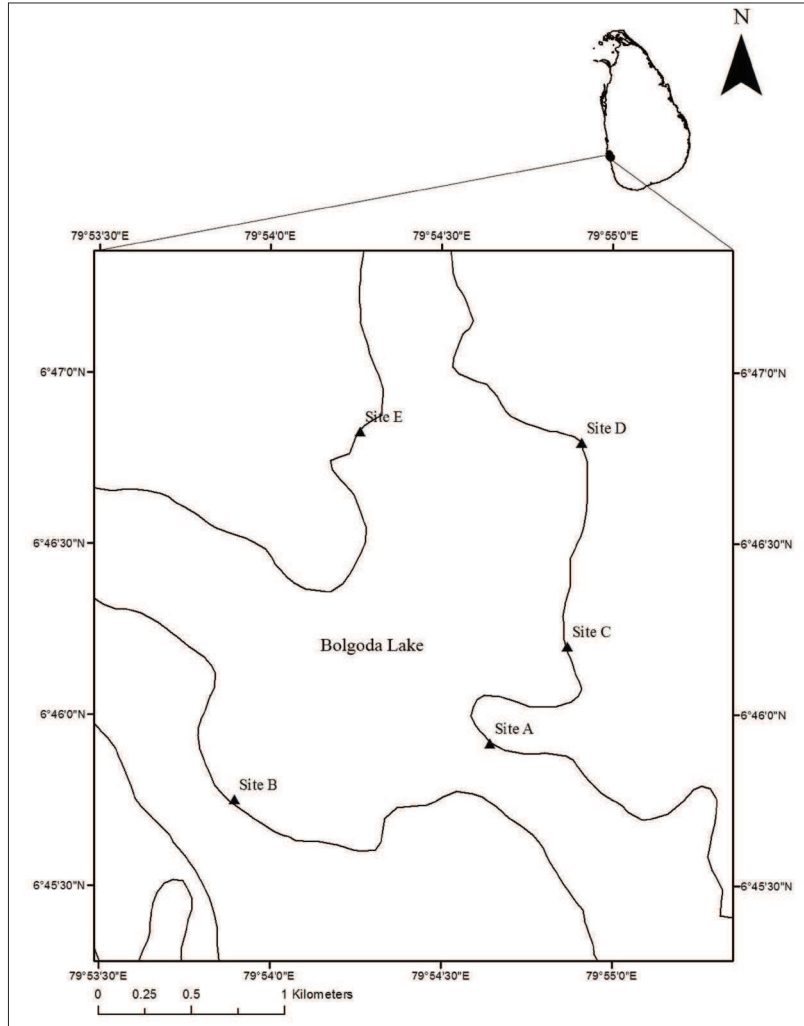


Figure 1: Map of the sampling sites in the Bolgoda Lake

The contamination factor ( $C_f^i$ ) is a measure used to describe the contamination of a given substance in a particular location (Hakanson, 1980), which is calculated as,

$$C_f^i = \frac{C_{0-n}^i}{C_b^i}$$

where,  $C_{0-n}^i$  is the mean concentration of a given element and  $C_b^i$  is the background concentration of the element.

Background concentrations for this study were derived from Martin and Meybeck’s study (Martin & Meybeck, 1979), which has been applied in other studies (Chakravarti & Patgiri, 2009). The background concentrations used for Cd, Cr, Cu, Ni and Zn were 0.2, 71, 32, 49 and 127 mg/kg, respectively (Martin & Meybeck, 1979). The sum of contamination factors of all

the elements is referred to as the degree of contamination ( $C_d$ ) and it describes the contamination of a particular location by all the examined elements.

The pollution load index (PLI) is another simple method to assess the level of pollution in sediments (Tomilson *et al.*, 1980). Sediment pollution load index can be determined from:

$$PLI = (C_{f1} \times C_{f2} \times \dots \times C_{fn})^{1/n}$$

where,  $C_{f1}$  is the contamination factor of element 1,  $C_{f2}$  is the contamination factor of element 2 and  $C_{fn}$  is the contamination factor of element  $n$ , with  $n$  as the total number of elements.

Enrichment ratio (ER) is an index used to assess the level of elements in sediments compared to the

pre-industrial era. This method was proposed by Simex and Helz (1981) and is mathematically expressed as:

$$ER = \frac{(C_x/C_{Fe})_{Sample}}{(C_x/C_{Fe})_{Background}}$$

where,  $C_x$  stands for the concentration of element 'x'. The background value is the element concentration of crust in the pre-industrial era. The world average shale and world average rock element concentrations are the major values used as background concentrations in most of the studies. In the present study, world surface rock average concentrations given by Martin and Meybeck (1979) were used as the background concentrations to calculate ER.

Geoaccumulation index ( $I_{geo}$ ) also measures the metal contamination compared to the pre-industrial era.  $I_{geo}$  can be calculated as follows:

$$I_{geo} = \log_2 \frac{C_i}{1.5 C_b}$$

where,  $C_i$  is the concentration of the element and  $C_b$  is the background concentration. The world surface rock average concentrations given by Martin and Meybeck (1979) were used as the background concentrations to calculate  $I_{geo}$ .

Ecological risk factor ( $Er^i$ ) is used to describe the potential ecological risk of a given element (Hakanson, 1980) and is expressed as:

$$Er^i = Tr^i \cdot C_f^i$$

where,  $Tr^i$  is the toxic response factor of a given element as described by Hakanson (1980) and,  $C_f^i$  is the contamination factor of that element.

The quality of the sediments were also assessed by comparing with the numerical sediment quality guidelines (SQGs) and consensus-based sediment quality guidelines (CBSQGs).

## RESULTS AND DISCUSSION

The mean concentrations of elements at different sites in monsoonal and non monsoonal seasons of 2013 are given in Table 1 and Table 2, respectively. The mean concentration of Cd ranged from 0.1 – 0.6 mg/kg in both sampling sessions. Generally soil Cd concentrations exceeding 0.5 mg/kg are considered to be evidence of soil pollution (McBride, 1994). In this study the concentration of Cd in site A in both sampling sessions showed a concentration of 0.6 mg/kg indicating sediment pollution due to Cd. The mean concentration of Cr ranged from 131.2 – 820 mg/kg indicating a 6 fold variation among the study sites. Cr can be released into the environment due to various small to medium scale industries involving metal plating, painting and wood preserving activities (Emmanuel *et al.*, 2014). The mean concentration of Ni ranged from 90.4 – 317.6 mg/kg. Ni is a commonly used metal in various types of industries including electroplating and electroforming industries. Although metallic nickel is non-carcinogenic to humans, the compounds of nickel containing sulfides, oxides and silicates have carcinogenic properties (Emmanuel *et al.*, 2014).

The mean concentration of Cu ranged from 4.6 – 74.4 mg/kg indicating approximately 10 fold variation among the study sites. Similarly the mean concentration of Zn ranged from 4.8 – 59.8 mg/kg indicating approximately 10 fold variation among the study sites.

The Cd, Cr and Ni concentrations in site A were significantly higher than that of the other sites in both

**Table 1:** Concentration of elements (mg/ kg) in the study sites of the Bolgoda Lake during monsoonal season (2013)

Site	Cd	Cr	Ni	Cu	Zn	Fe
A	0.6 ± 0.06 <sup>a</sup>	820 ± 11.6 <sup>a</sup>	308.8 ± 28.9 <sup>a</sup>	69.6 ± 6.1 <sup>a</sup>	42.8 ± 1.3 <sup>a</sup>	4.66 ± 0.1
B	0.2 ± 0.05 <sup>b</sup>	577.6 ± 13 <sup>b</sup>	138.4 ± 13.4 <sup>b</sup>	8.5 ± 0.1 <sup>b</sup>	36.8 ± 1.4 <sup>a</sup>	4.46 ± 0.4
C	0.4 ± 0.1 <sup>a</sup>	205.6 ± 14 <sup>c</sup>	204 ± 19.4 <sup>c</sup>	62.9 ± 9 <sup>a</sup>	25.1 ± 1.9 <sup>b</sup>	4.59 ± 0.2
D	0.2 ± 0.02 <sup>b</sup>	288.8 ± 18.6 <sup>c</sup>	255.2 ± 7.7 <sup>c</sup>	55.2 ± 5.2 <sup>a</sup>	25 ± 2 <sup>b</sup>	4.63 ± 0.25
E	0.1 ± 0.02 <sup>c</sup>	151.2 ± 15.1 <sup>c</sup>	130.4 ± 12.9 <sup>b</sup>	5.9 ± 1.2 <sup>b</sup>	5.4 ± 1.1 <sup>c</sup>	4.53 ± 0.26

Data are presented as mean ± SD. Different superscripts in each column indicate significantly different concentrations (ANOVA, Tukey's test  $p < 0.05$ )

**Table 2:** Concentration of elements (mg/ kg) in the study sites of the Bolgoda Lake during non-monsoonal season (2013)

Site	Cd	Cr	Ni	Cu	Zn	Fe
A	0.6 ± 0.1 <sup>a</sup>	716 ± 25 <sup>a</sup>	317.6 ± 20.7 <sup>a</sup>	74.4 ± 13.4 <sup>a</sup>	59.8 ± 2.5 <sup>a</sup>	4.6 ± 0.2
B	0.2 ± 0.03 <sup>b</sup>	528 ± 48.5 <sup>b</sup>	140 ± 15.7 <sup>b</sup>	7.6 ± 0.3 <sup>b</sup>	37.9 ± 2 <sup>b</sup>	4.69 ± 0.09
C	0.2 ± 0.03 <sup>b</sup>	199.2 ± 1.8 <sup>c</sup>	218.4 ± 25 <sup>c</sup>	21 ± 1.2 <sup>c</sup>	24.3 ± 2.2 <sup>c</sup>	4.49 ± 0.30
D	0.2 ± 0.02 <sup>b</sup>	258.4 ± 27.1 <sup>c</sup>	213.6 ± 15.3 <sup>c</sup>	43.8 ± 10.3 <sup>c</sup>	28 ± 1.7 <sup>c</sup>	4.69 ± 0.2
E	0.1 ± 0.01 <sup>c</sup>	131.2 ± 7.7 <sup>d</sup>	90.4 ± 14.8 <sup>d</sup>	5.4 ± 0.5 <sup>b</sup>	4.8 ± 1.8 <sup>d</sup>	4.66 ± 0.09

Data are presented as mean ± SD. Different superscripts in each column indicate significantly different concentrations (ANOVA, Tukey's test  $p < 0.05$ )

sampling sessions (ANOVA  $p < 0.05$ ). Site E showed significantly lower concentrations of Cd, Cr, Ni and Zn than the other sites (ANOVA  $p < 0.5$ ). Site B showed significantly lower concentrations of Cu than the other sites in both sampling sessions. The sampling site A was observed to receive runoff from a nearby vehicle service center. In addition, untreated oil was also discharged at the site by the owners of private motor boats who reside around the site. Studies conducted on the assessment of heavy metal concentrations of soil around oil filling and service stations have indicated significant contaminations with Cd, Cr, Pb, Ni and Zn (Afrifa *et al.*, 2013; Emmanuel *et al.*, 2014; Wao *et al.*, 2014). The significantly higher heavy metal concentrations recorded at this site may be the result of prolonged exposure of sediments to oil and other vehicle wastewater runoff. Sampling site B was located in a densely populated area with several small scale wood processing industries and boat painting industries located in the boarder of site B. Storm water from the area is discharged at this site. Site B showed significantly higher concentrations of Cr, Ni and Zn compared to sites C, D and E, which were located in comparatively less industrialised areas. Cr, Cu and Zn are commonly released heavy metals in various types of industries including metal plating, wood processing and painting industries. Therefore, significantly higher concentrations of these metals at site B may indicate the exposure of shallow sediments to untreated outputs of small scale industries located around the site. Sites C and D were located in densely populated but less industrialised areas. A small restaurant and a recreational boat house were located within 50 m from site C. Site E was located in a less populated area and no anthropogenic influences were noted in the surrounding. The significantly lower concentrations of Cd, Cr, Ni and Zn in the sites C, D and E may have been due to the low anthropogenic influences. However, the element concentrations of sediments collected in the monsoonal season were not significantly different from the element concentrations of sediments collected in the non-monsoonal season at 95 % level of significance (student t test,  $p > 0.05$ ).

The concentrations of Cd, Cr, Cu, Ni and Zn were used to calculate the pollution indices. The contamination factors ( $C_f$ ) of these metals, the degree of contamination ( $C_d$ ) and the pollution loading index (PLI) of the study sites in both sampling sessions are given in Table 3.

The contamination factor can categorise the heavy metal pollution in sediments into four classes as follows (Quinjie *et al.*, 2008): low ( $C_f \leq 1$ ), moderate ( $1 < C_f \leq 3$ ), considerable ( $3 < C_f \leq 6$ ) and very high contamination ( $C_f > 6$ ). In the present study, the contamination factors for all the heavy metals except Zn were moderate, considerable or very high in both sampling sessions (Table 3). The contamination factor for Zn was in the low category at all the sites in both sampling sessions. Site A showed a very high contamination of Cr and Ni and a moderate contamination of Cu and Cd in both sampling sessions. Site B showed a high contamination of Cr and a moderate contamination of Ni in both sampling sessions. Cd showed moderate contamination at sites C and D in the monsoonal season and in sites B and C in non-monsoonal season. Cr showed a considerable contamination in site D and moderate contaminations in sites C and E in both sampling sessions. Ni showed considerable contaminations at sites C and D and moderate contaminations at sites B and E in both sampling sessions. Cu showed moderate contaminations in sites A, C and D in monsoonal season and in sites A and D in non-monsoonal season (Table 3).

The pollution quantification scale using  $C_d$  also consists of a four class scale as follows (Edet & Offiong, 2002; Ghadimi & Ghomi, 2013):  $C_d \leq n$ : low;  $n < C_d \leq 2n$ : moderate;  $2n < C_d \leq 3n$ : high;  $C_d > 3n$ : very high, where n is the number of contaminants used in  $C_d$  determination. Since five heavy metal elements were used in the  $C_d$  determination in the present study, the four classes of pollution categorisation are:  $C_d < 5$ : low;  $5 \leq C_d < 10$ : moderate;  $10 \leq C_d < 15$ : high;  $C_d \geq 15$ : very high. The  $C_d$  value in site A in both sampling sessions indicated a very

high degree of contamination with a  $C_d$  value higher than 15 (Table 3). Sites B, C and D in monsoonal season and sites B and D in non-monsoonal season indicated a high degree of contamination and site C in non-monsoonal season indicated a moderate degree of contamination. Site E showed a low degree of contamination in both sampling sessions (Table 3).

A  $PLI > 1$  indicates pollution due to anthropogenic activities and a  $PLI < 1$  indicates no pollution (Harikumar *et al.*, 2009). In the present study, the pollution load index for all the study sites except site E in both sampling sessions showed human associated pollution with a  $PLI$

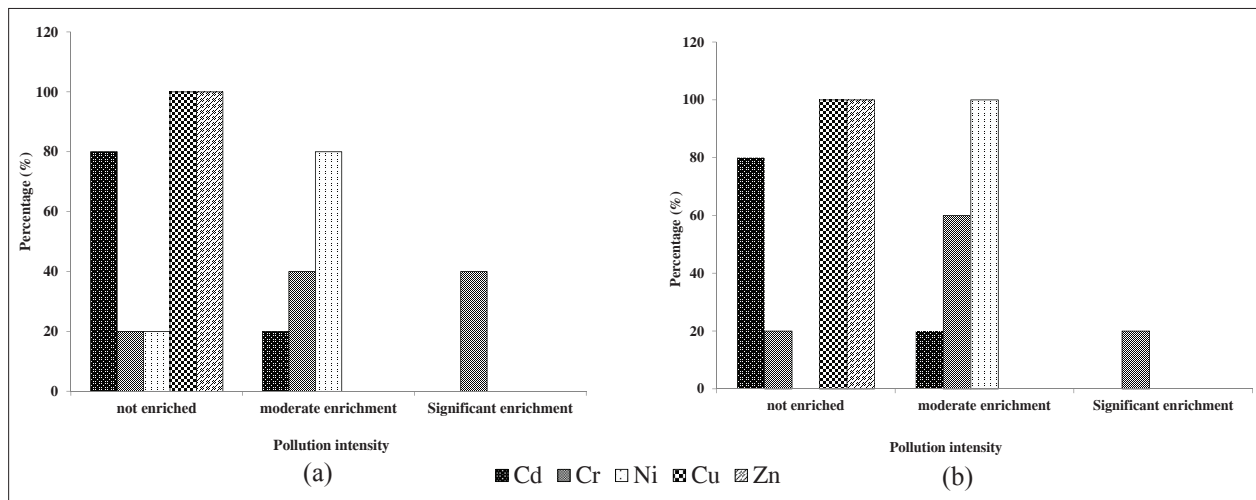
higher than 1. Site E can be considered unpolluted from anthropogenic impacts as it has a  $PLI$  less than 1 in both sampling sessions (Table 3).

Five contamination categories are identified based on the value of the enrichment ratio (ER) (Quinjie *et al.*, 2008):  $ER < 2$ : low enrichment;  $2 \leq ER < 5$ : moderate enrichment;  $5 \leq ER < 20$ : significant enrichment;  $20 \leq ER < 40$ : very high enrichment;  $ER \geq 40$ : extremely high enrichment. The percentage distribution of samples in each pollution category for different metals with respect to ER is given in Figure 2. None of the samples were enriched with Zn and Cu in both sampling sessions.

**Table 3:** Contamination factor ( $C_f$ ) of elements at each site, degree of contamination ( $C_d$ ) and pollution loading index (PLI) of sites in each sampling session of the Bolgoda Lake sediments

Site	Sampling session	Contamination factor					$C_d$	PLI
		Cd	Cr	Ni	Cu	Zn		
A	Monsoonal season 2013	3.1 *	11.5 <sup>▲</sup>	6.3 <sup>▲</sup>	2.2 *	0.3	23.5 <sup>VH</sup>	2.8
B		0.8	8.1 <sup>▲</sup>	2.8 *	0.3	0.3	12.4 <sup>H</sup>	1.1
C		1.9 *	2.9 *	4.2 *	2.0 *	0.2	11.1 <sup>H</sup>	1.6
D		1.2 *	4.1 *	5.2 *	1.7 *	0.2	12.4 <sup>H</sup>	1.5
E		0.6	2.1 *	2.7 *	0.2	0.04	2.9	0.5
A	Non-monsoonal season 2013	3.0 *	10.1 <sup>▲</sup>	6.5 <sup>▲</sup>	2.3 *	0.5	22.3 <sup>VH</sup>	2.9
B		1.0 *	7.4 <sup>▲</sup>	2.9 *	0.2	0.3	12.1 <sup>H</sup>	1.2
C		1.2 *	2.8 *	4.5 *	0.6	0.2	9.3 <sup>M</sup>	1.1
D		0.9	3.6 *	4.4 *	1.4 *	0.2	10.4 <sup>H</sup>	1.3
E		0.4	1.8 *	1.8 *	0.2	0.04	4.3	0.4

<sup>▲</sup> Very high contamination; \* considerable contamination; \* moderate contamination with respect to  $C_f$ ; <sup>VH</sup> very high contamination; <sup>H</sup> high contamination; <sup>M</sup> moderate contamination with respect to  $C_d$



**Figure 2:** Percentage distribution of study sites in each pollution category for heavy metals with respect to enrichment ratio (a) monsoonal season 2013; (b) non-monsoonal season 2013

20 % of the samples showed a moderate enrichment of Cd and a significant enrichment of Cr. The enrichment ratio of Ni showed 80 % moderate enrichment in the monsoonal season and 100 % moderate enrichment in the non-monsoonal season. None of the samples showed very high or extremely high enrichment for any of the elements (Figure 2).

The  $I_{geo}$  scale consists of seven different grades (Quinjie *et al.*, 2008; Chakravarty & Patgiri, 2009) and according to this grade classification, the level of pollution ranges from unpolluted to highly polluted (Table 4).

The percentage of samples in pollution status categories for  $I_{geo}$  of this study is given in Figure 3. In the present study, 100 % of the samples were in unpolluted status (Class 0) with respect to Cd. The samples showed

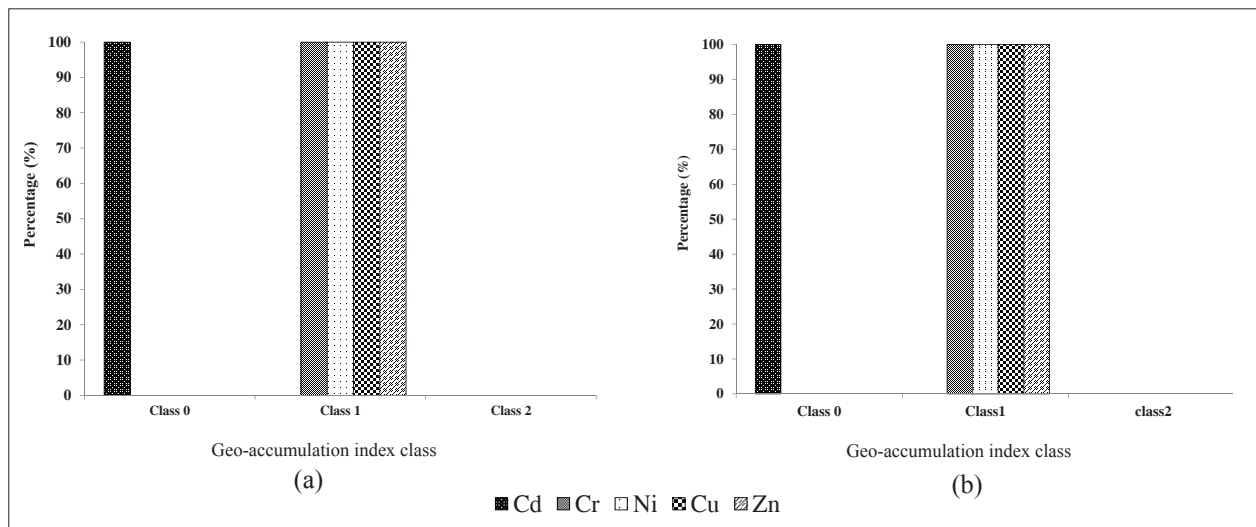
unpolluted to moderately polluted status (Class 1) with respect to Cr, Ni, Cu and Zn (Figure 3).

The ecological risk factor ( $Er^i$ ) scale consists of five grades ranging from low potential ecological risk to very high potential ecological risk:  $Er^i < 40$ : low potential ecological risk;  $40 \leq Er^i < 80$ : moderate potential ecological risk;  $80 \leq Er^i < 160$ : considerable potential ecological risk;  $160 \leq Er^i < 320$ : high potential ecological risk;  $320 \leq Er^i < \infty$ : very high potential ecological risk (Quinjie *et al.*, 2008). Variation of the ecological risk factor for different elements in the sampling sessions is given in Figure 4. All the samples showed a low potential ecological risk for the elements Cr, Ni, Cu and Zn, while the potential ecological risk for Cd ranged from low to high potential ecological risk (Figure 4). The potential ecological risk factor of a particular element is proportional to the contamination factor and the toxic response factor. The toxic response factors proposed by Hakanson (1980) for Cd, Cr, Cu, Ni and Zn are 30, 2, 5, 5 and 1, respectively (Quinjie *et al.*, 2008). In this study the potential ecological risk factors for the heavy metals ranked as  $Cd > Ni > Cr > Cu > Zn$  for both sampling sessions indicating a high potential ecological risk from Cd.

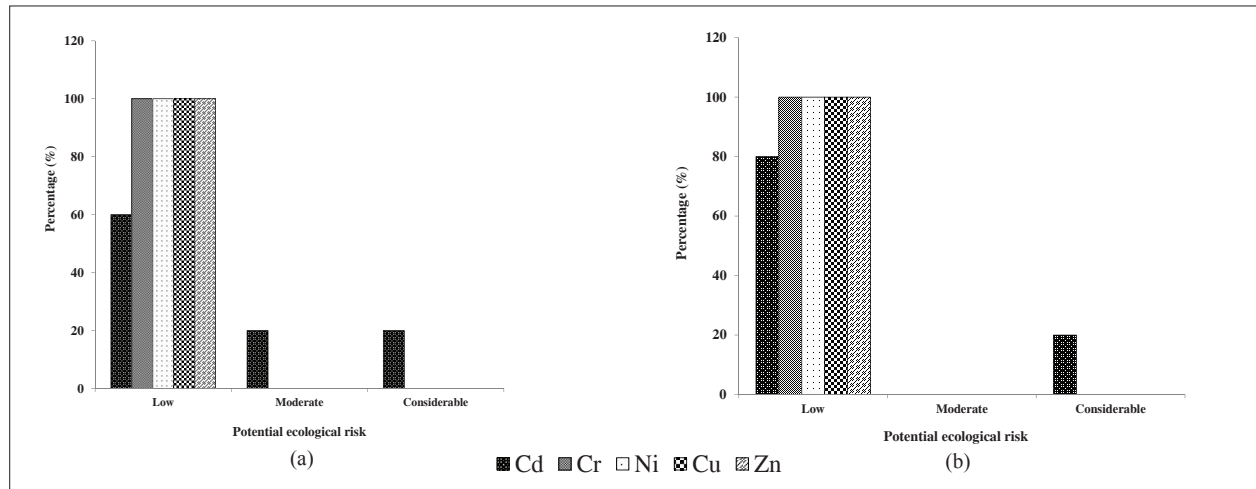
The results of ER,  $I_{geo}$  and  $Er^i$  revealed some contradictions in the concentration profiles of metals in the Bolgoda Lake. The results of ER and  $I_{geo}$  showed that shallow sediments are unpolluted due to Cd and

**Table 4:** Categorisation of sediments based on geoaccumulation index ( $I_{geo}$ ).

Value for $I_{geo}$	Class	Level of pollution
$I_{geo} \leq 0$	0	Unpolluted
$0 < I_{geo} < 1$	1	Unpolluted to moderately polluted
$1 < I_{geo} < 2$	2	Moderately polluted
$2 < I_{geo} < 3$	3	Moderately to strongly polluted
$3 < I_{geo} < 4$	4	Strongly polluted
$4 < I_{geo} < 5$	5	Strongly to extremely polluted
$5 < I_{geo}$	6	Extremely polluted



**Figure 3:** Percentage distribution of samples in each pollution category for heavy metals with respect to geoaccumulation index (a) monsoonal season 2013; (b) non-monsoonal season 2013



**Figure 4:** The percentage distribution of samples in each pollution category for heavy metals with respect to potential ecological risk factor  
(a) monsoonal season 2013; (b) non-monsoonal season 2013

moderately polluted due to Cr and Ni. However, the potential ecological risk for Cd is higher compared to the potential ecological risk for Cr and Ni. The reason for this is related to the high toxic response factor of Cd in comparison with Cr and Zn. The high toxic response factor of Cd indicates that it can cause serious ecological damages due to high toxicity even at low concentrations.

Numerical sediment quality guidelines (SQGs) proposed by the United States Environment Protection Agency (USEPA) were also used to assess the quality of the shallow sediments of the Bolgoda Lake. These sediment quality guidelines have been developed for various organic and inorganic pollutants of concern. The sediments can be classified as non-polluted,

moderately polluted and heavily polluted based on the element concentrations established by the USEPA (Perin *et al.*, 1997; Pekey *et al.*, 2004; Harikumar *et al.*, 2009). The classification of the level of pollution using SQGs based on different element concentrations is given in Table 5. According to the numerical sediment quality guidelines the sediments of the Bolgoda Lake are heavily polluted due to Cr and Ni and non polluted to highly polluted due to Cu. However, the sediments are non polluted due to Zn (Table 5).

The consensus-based SQGs (CBSQGs) developed by MacDonald *et al.* (2000) is used to categorise element concentrations in sediments based on the toxicity to benthic organisms. CBSQGs consist of lower (threshold

**Table 5:** Comparison of concentration range (mg/ kg) of the elements measured in the present study with numerical sediment quality guidelines (SQG) and consensus-based SQGs (CBSQGs)

Element	SQG*			CBSQGs**		Concentration (mg/kg) in present study
	Non polluted	Moderately polluted	Heavily polluted	TEC	PEC	
Cd	–	–	> 7	0.99	5	0.07 – 0.7
Cr	< 25	25 – 75	> 75	43	110	124 – 980
Ni	< 20	20 – 50	> 50	23	49	72 – 356
Cu	< 25	25 – 50	> 50	32	150	4.4 – 224
Zn	< 90	90 – 200	> 200	120	460	4.1 – 63.1

\* Numerical sediment quality guidelines of USEPA (Perin *et al.*, 1997, Ahdy & Khaled, 2009)

\*\* Consensus-based SQGs proposed by MacDonald *et al.* (2000)

TEC – threshold effect concentration; PEC – probable effect concentration



effect concentration - TEC) and upper (probable effect concentration - PEC) effect levels indicating the level of toxicity to benthic organisms associated with those sediments. If the element concentration is equal or less than TEC the toxicity of that element to benthic-dwelling organisms are predicted to be unlikely. If the element concentration is at or above PEC, it indicates a probable toxicity to benthic-dwelling organisms. There is an incremental increase in toxicity as the contaminant concentrations increase between the TEC and PEC (MacDonald *et al.*, 2000). The classification of sediments according to CBSQGs is given in Table 5. The concentrations of Zn (4.1 – 63.1 mg/kg) and Cd (0.07 – 0.7 mg/kg) in the present study were lower than the TEC level of CBSQGs. Therefore, the concentrations of Zn and Cd in the shallow sediments of the Bolgoda Lake are unlikely to be causing toxicity to benthic organisms. The concentrations of Cr (124 – 980 mg/kg) and Ni (72 – 356 mg/kg) recorded in the present study were higher than the PEC level of CBSQGs. Therefore, according to the results of the present study, it can be concluded that the concentrations of Cr and Ni in the shallow sediments of the Bolgoda Lake may cause probable toxicity to the benthic organisms. The concentration of Cu in the present study varied from 4.4 – 224 mg/kg and it ranged between the TEC and PEC levels of CBSQGs. Therefore, the concentration of Cu in the shallow sediments of the Bolgoda Lake may cause unlikely to probable levels of increasing toxicity to the benthic organisms.

A temporal variation of heavy metal concentrations was not identified in the present study. However, there was a spatial variation in the concentrations and  $C_f^i$  of heavy metals. The  $C_d$ , PLI, ER,  $I_{geo}$  and  $Er^i$  also showed spatial variations in the shallow sediments of the Bolgoda Lake. When contamination by heavy metal elements are considered, the shallow sediments of the Bolgoda Lake ranged from unpolluted to polluted status. None of the study sites showed extremely high pollution due to any of the heavy metals studied. The potential ecological risk from contamination of Cr, Cu, Zn and Ni was low while that of Cd ranged from low to high. Only a few studies have been carried out to assess the heavy metal concentrations in the Bolgoda Lake (Ileperuma, 2000; Senaratne & Pathiratne, 2007; Gunathilake & Wijerathne, 2009). From these studies only Senaratne and Pathiratne (2007) have assessed the heavy metal concentrations of the sediments; however they have not used sediment pollution indices in their assessments of the pollution status. The evaluation of sediment quality using pollution indices indicates that the sediments of the

shallow areas of the Bolgoda Lake can not be considered as extremely contaminated due to anthropogenic input of heavy metals. Therefore, the values of sediment quality indices recorded in the present study provides baseline information on the sediment quality of the shallow sediments of the Bolgoda Lake.

Senaratne and Pathiratne (2007) recorded the heavy metals in the sediments of the Bolgoda Lake to be, Cd: 0.8 – 4.2, Cr: 22.6 – 214.8, Cu: 13.2 – 135.5, Zn: 58.2 – 227.6 mg/kg. The concentration ranges of the elements from the present study were; Cd: 0.07 – 0.7; Cr: 124 – 980; Cu: 4.4 – 224; Zn: 4.1 – 63.1 mg/kg. The concentration of Cr is considerably higher and the concentrations of Cd, Cu and Zn are considerably lower in the present study compared to the results of Senaratne and Pathiratne (2007). Chromium is present in alloys and is discharged from diffuse sources and products such as wood preservatives, dyes, vehicle oil discharges and tanning activities (Mukherjee, 1998). The field observations indicated that many small scale dyeing, tanning and boat painting activities are carried out in the watershed by individuals as a livelihood. Therefore, the increase of Cr in the shallow sediments of the Bolgoda Lake may be due to the increase of anthropogenic activities that adds excess Cr and Cr containing compounds to the Bolgoda Lake. The decrease of other heavy metals in the present study when compared to Senaratne and Pathiratne (2007) may be due to the improved public awareness about metal input to aquatic environment, adherence to the environmental regulations by the industries, and using proper treatment methods before discharging industrial wastewater.

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## CONCLUSION

The quantified pollution status values of the present study can be used as baseline information when monitoring the pollution status of the Bolgoda Lake watershed. In addition, the element concentrations and values of pollution indices recorded in the present study can be considered as reference values in assessing the heavy metal pollution of sediments in other inland waterbodies in Sri Lanka.

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