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Original Paper

Contamination Assessment of Heavy Metals in Sediment Cores from De Montigny Lake around Siscoe-Sullivan Former Mining Sites, Val-d'Or, Canada

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Abstract

Seven sediment cores were collected from De Montigny Lake in order to determine concentrations, and contamination assessment of heavy metals such as Cr, Zn, Ni, Pb, Cu, Co and Cd. The mean concentrations of heavy metals are as follows: 48.3 mg/kg for Cr, 36.4 mg/kg for Zn, 20.6 mg/kg for Ni, 14.7 mg/kg for Pb, 10.2 mg/kg for Cu, 6.7 mg/kg for Co and 0.1 mg/kg for Cd. Based on the sediment quality guidelines, the mean concentration metals such as Cr, Cu and Ni exceeded the US Environmental Protection Agency (USEPA) guideline. However, the concentration of Cr was more than the Canadian Water Quality Guidelines for Protection of Aquatic Life (CCME), and Threshold Effect Level (TEL) guidelines. The metal contamination in the sediments was also evaluated using Enrichment Factor (EF) and geoaccumulation index (Igeo) to assess natural and anthropogenic factors. The results of enrichment factor methods demonstrated that sediments from De Montigny Lake were moderately to high enriched, mainly controlled by through anthropogenic activities. According to Sediment Quality Guidelines (SQGs), the concentrations metals from the core sediment of De Montigny Lake are classified as having moderate impacts with potential adverse biotoxic effects.

Keywords

heavy metals, core sediments, contamination assessment

1. Introduction

Metals and metalloids are hazardous contaminants in the environment. Metal Contamination of sediments may be due to the natural sources (for example processes of alteration and dissolution of minerals in parent rocks and soils), or by anthropogenic activities (for example mining and agricultural activities) (Xuelu & Chen-Tung, 2012; Kalloul et al., 2012; Keshavarzi et al., 2015). Sediments are considered as the final destination of the large proportion of metal contaminants, or the source of metal contamination in aquatic systems (Zahir et Shikazono, 2011; Liu et al., 2013). Furthermore, due to adsorption, desorption, remobilization, hydrolysis, precipitation, diffusion, chemical reactions, biological activity, heavy metals are predominantly dissolved as ions remains in water (Boughriet et al., 2007; Kalnejais et al., 2010; Suresh et al., 2015), and therefore the effective means of monitoring's state of the aquatic ecosystem (Islam et al., 2018. Siscoe-Sullivan former mining sites may contribute to metal contamination of the water and sediments of the De Montigny Lake. In addition, it is recognized that the mining activities are known to be a source of metal contaminants in aquatic system (Riba et al., 2002; Ahn et al., 2005; Kapoor & Singh, 2020). Therefore, it was essential to study the levels of contamination in the sediments from De Montigny Lake by heavy metals (Pb, Zn, Co, Cr, Cu, Ni and Cd), and to define the natural and/or anthropogenic sources of heavy metals. The basic objectives of this study were as follows: (1) determine the vertical spatial distribution of heavy metals in sediments; (2) assess the natural and/or anthropogenic sources by using the Enrichment Factor (EF), the geo-accumulation index (Igeo), CCME SQG guidelines (1999) and the quality of sediment based on Sediment quality guidelines (SQGs) (Smith et al., 1996); (3) define the natural and/or anthropogenic sources of metal contamination by using statistical analyses: Pearson's correlation matrix and Principal Component Analysis (PCA).

2. Materials and Methods

2.1 Study Area

De Montigny Lake is one of the most important lakes in the Milky sub-basin that is included in the Hurricana River basin. The study area is bounded by latitudes (48 ° 6 '15" N to 48 ° 10 '10" N) and longitudes (77 ° 57 '30" W to 77 ° 50 '00" W). De Montigny Lake is located north of Route 117, west-northwest of Val d´Or (Figure 1). Along the De Montigny Lake, we have the Kiena mining complex owned by Wesdome Gold Mines. The climate of the study area is boreal with snow cover on the ground from mid-November to mid-April, with rather dry winters and a short frost season of around 80 days.

2.2 Collection of Sediment Samples

From February 25 to 27, 2014, seven sediment cores (S1: 37.5 cm; S2: 40 cm; S3: 42.5 cm; S4: 36.5 cm; S5: 40 cm; S6: 36.5 cm and S8: 38 cm in length) were collected at seven sites in the De Montigny Lake. The sampling sites are located in Lake De Montigny (S1: 77 ° 56 '15.8 "E, 48 ° 10' 00.8" N; S2: 77 ° 52 '29.0 "E, 48 ° 10' 00.8" N; S3 : 77 ° 56 '15.8 "E, 48 ° 08' 46.8" N; S4: 77 ° 53 '45.7 "E, 48 °

08’ 46.8" N; S5: 77 ° 51 ‘13.3 "E, 48 ° 08’ 46.8 "N; S6: 77 ° 54 ‘58.9" E, 48 ° 07’ 31.0 "N; S7: 77 ° 52 ‘29.0" E, 48 ° 07’ 31.0 "N). The sampling sites are shown in Figure 1 and all sediment cores were collected by using a PVC pipe with a core sampler (internal diameter: 65 mm and length: 1m). During sample collection, sampling sites were localized exactly by GPS (Garmin GPSMAP 62S). The samples were placed in a portable cooler with ice packs and transported to the laboratory under frozen condition (at 4° C) in Val-d’Or, Canada.

2.3 Analysis of Samples

The segments of sediment cores were selected as (0-5 cm, 5-15 cm, 15-25 cm, and 25-40 cm). For the analysis of heavy metals (total), 0.5 g from each sample were treated with aqua regia (HNO3 + 3HCl) in a closed Teflon vessel (100 mL). The samples were digested in the microwave digestion system, and the filtered samples through a 0.45 µm filter, 50 mL of each sample was placed in a tube. Heavy metals in the final solutions were determined using ICP-AES (Inductively Coupled Plasma Atomic Emission Spectroscopy-Optima 3000, Perkin Elmer Inc.).

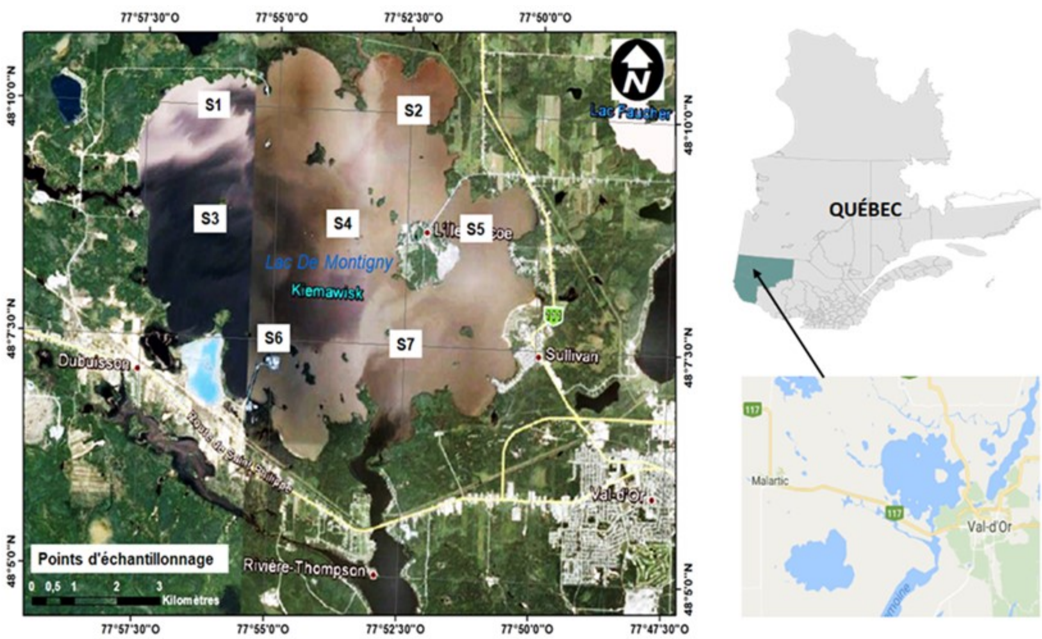

Figure 1. Map Showing Location of Sediment Cores (S1, S2, S3, S4, S5, S6, and S7) Collected from De Montigny Lake

2.4 Assessment of Sediment Contamination

The assessment of contamination is very often based on comparing data with the background references level (Turekian et Wedepohl, 1961; Varol, 2011; Haynes, 2016). To evaluate the contamination extent of sediment cores through heavy metals, Enrichment Factor (EF) and geo-accumulation index (*Igeo*) have been calculated to determine different contamination levels. In addition, Sediment Quality Guidelines (SQGs) were used to assess the ecological effects of the sediment contaminants (Zhuang et al., 2020).

2.4.1 Sediment Quality Guidelines (SQGs)

The Sediment Quality Guidelines (SQGs) were used to assess individual heavy metal substances by comparing the metal concentration with the quality guidelines to evaluate the degree to which the sediment associated chemical status might adversely affect marine organisms (Ke et al., 2017; Maanan et al., 2015). The SQG-based ecological risk assessment index for multiple heavy metals, known as the mean Sediment Quality Guidelines Quotient (SQG-Q), SQG-Q is computed as follows (Long et al., 1998):

$$PEL-Q_i = \frac{C_i}{PEL_i}$$

$$SQG-Q = \frac{\sum_{i=1}^{n}(PEL-Q_i)}{n}$$

where $PEL\text{-}Q_i$ is the Probable Effects Level (PEL) quotient for the *i-th* metal; C_i is the concentration of the *i*-th metal in sediments; PEL_i is the PEL for the *i*-th metal; and n is the number of heavy metals (here 5). The value of the PEL comes from the potential effect concentration/critical effect concentration (PEL/TEL) benchmark proposed by Smith et al. (1996) (Table 2). According to Long at al. (1998), when TEL > C_i unfavourable biotoxic effects rarely occur; when PEL< C_i unfavourable biotic effects occur frequently, and when the heavy metal concentrations are between the TEL and PEL, unfavourable biotic effects occur occasionally. The ecological risk levels of the heavy metals in the sediments based on the values of *SQG-Q* can be categorized as follows: no impact with adverse biotic effects ($SQG – Q \le 0.1$); moderation impact with potential adverse biotic effects ($0.1 < SQG – Q \le 1.0$); and strong impact with extremely strong adverse biotic effects ($SQG – Q > 1.0$).

2.4.2 Enrichment Factor (EF)

The enrichment Factor (EF) is used to differentiate between natural sources and anthropogenic sources in a site, and thus to define the intensity of pollution (Radakovitch et al., 2008; Maanan et al., 2015; Decena et al., 2018; Remeikaite-Nikiene et al., 2018). The enrichment factor (EF) was calculated using Al as an immobile element due to its natural abundance in the earth's crust, and by its concentration which is not altered by anthropogenic causes (Zhang et al., 2018; Maanan et al., 2015). The reference material (Average shale) used is recognized worldwide as the reference background values of unpolluted areas (Turekian & Wedepohl, 1961; Haynes, 2016). The Enrichment Factor (EF) is expressed as follows (Zhuang et al., 2020):

$$EF = \frac{[M]sample/[Al]sample}{[M]background/[Al]background}$$

where [M]sample is the concentration of heavy metal of interest in sediment samples; [Al]sample is the concentration of Al measured in sediment samples; [M]background is the normal background value of heavy metal (World average shale values), and [Al]background is the normal background value Al of average shale. The Enrichment Factor (EF) values less than 1.5, or less than 2 indicate that the heavy metal is entirely crystallized in the sediment while the higher FE values to 1.5 or 2 suggest anthropogenic sources (Garcia et al., 2008; Abreu et al., 2016). According to the EF of an element, Loska et al. (2004) and Guan et al. (2016) classified the enrichment factor (EF) into five levels: no or slight enrichment (EF < 2), moderate enrichment (2 ≤ EF < 5), significant enrichment (5 ≤ EF < 20), high enrichment (20 ≤ EF < 40) and extremely high enrichment (EF > 40).

2.4.3 Geoaccumulation Index (I_{geo})

The geoaccumulation index (Geo) proposed by Müller (1969) is used to determine and define the metal contamination in sediments by comparing a given concentration of the heavy metal versus a value considered as the local background value of metal. The geoaccumulation index (*Igeo*) is expressed as follows:

$$I_{g\acute{e}o_x} = log_2 \left(\frac{C_n}{1{,}5Bg_n}\right)$$

where C_n is the measured concentration of heavy metals in sediments; B_{gn} is the geochemical background value in average shale of element n; 1.5 is the background factor correction used because of variations in the background caused by lithology or natural variation of the geochemical background (Lu et al., 2009; Orani et al., 2019). The geoaccumulation index values (I_{geo}) values for heavy metals is classified in seven classes as follows: Class 0 ($Igeo \leq 0$), uncontaminated; Class 1 ($0 < Igeo \leq 1$), uncontaminated to moderately contaminated; Class 2 ($1 \leq Igeo \leq 2$), moderately contaminated; Class 3 ($2 < Igeo \leq 3$), moderately contaminated to strongly contaminated; Class 4 ($3 < Igeo \leq 4$), strongly contaminated; Class 5 ($4 < Igeo \leq 5$), strongly contaminated to extremely contaminated; and Class 6 ($Igeo > 5$), extremely contaminated (Müller, 1979; Ji et al., 2015; Dai et al., 2018; Liu et al., 2021).

2.5 Statistical and Graphical Analysis

The data were statistically analyzed using XLSTAT version 2020, Excel (2019) and R software, which is free on www.r-project.org (accessed on 27 October 2021). Principal Component Analysis (PCA) correlations using varimax rotation were applied to verify significant relationships among the heavy metals of core sediments, and to identify contamination sources (natural and/or anthropogenic). The Kaiser-Meyer-Olkin (KMO) test (Hutcheson & Sofroniou, 1999) with a > 0.5 KMO (0.5), and the Bartlett sphericity test ($p < 0.0005$) with test significance Bartlett's ($p = 0.000$) were used to measure the sampling adequacy.

3. Results

3.1 Metal Levels in Sediment Core

The concentration of heavy metals measured in sediment cores of De Montigny Lake as well as the World average shale values, CCME SQGs, USEPA SQGs, and Sediment Quality Guidelines (SQGs) for freshwater ecosystems are summarized in Table 1. Overall, the heavy metals mean values in the sediment cores were as follows: 0.1 ± 0.1 mg/kg for Cd, 48.3 ± 9.2 mg/kg for Cr, 10.2 ± 5.1 mg/kg for Cu, 20.6 ± 1.9 mg/kg for Ni, 6.7 ± 0.7 mg/kg for Co, 14.7 ± 12.4 mg/kg for Pb, and 36.4 ± 14.3 mg/kg for Zn. Compared to World average shale values of 0.3 mg/kg for Cd, 90 mg/kg for Cr, 11.2 mg/kg for Cu, 68 mg/kg for Ni, 29 mg/kg for Co, 20 mg/kg for Pb, and 95 mg/kg for Zn. It is noted that all the average concentrations of heavy metals in sediments were less than their corresponding average shale values. The highest Cd and Zn mean concentrations occurred in sediments from core S2, Ni and Pb from core S6, Co from S5, and Cu from S4.

The vertical distribution of metal concentrations along cores collected from the seven sampling sites (S1, S2, S3, S4, S5, S6, and S7) showed different patterns in the concentrations of heavy metals with depth. In the cores S1, S2, S5, and S6, the focus was placed on Cr for which the highest concentrations were observed in the middle layer of sediment cores (depth 25-45 cm). The highest concentrations of Co were observed in the bottom layer (depth 25-45 cm) in cores S1, S2, S4, S5, and S6 ; a relatively high Ni concentrations were found in sediment cores (depth 25-45 cm) in cores S1, S4, and S5. The vertical profiles of Pb from S1, S3, S5, and S6 sediment cores pass through a maximum of 39.4 mg/kg (depth 25-45 cm), while decreased concentrations were observed for Cd, Cu and Zn from top to bottom in cores S1, S2, S3, S4, S5, S6, and S7 (Fig. 2). Higher content of heavy metals in the bottom layer (depth 25-45 cm) in sediment cores denotes historical deposition of Cr, Co, and Ni in the sediment cores. The comparison of heavy metal concentrations between the De Montigny Lake and other lakes showed that the concentrations of heavy metal in the present study were globally lower than other those of other World lakes (Table 2). Although, the concentration of Cr, which present a pollution risk to aquatic environment, was higher than the Karachi Coast (Chaudhary et al., 2021) and Rewalsar Lake (Meena et al., 2017).

Table 1. Descriptive Statistics of Heavy Metal Concentrations pf Samples in Sediment Cores (n = 30) of De Montigny Lake (mg/kg)

	Al	Fe	Cd	Cr	Cu	Ni	Co	Pb	Zn
Min	5757	7959	0.02	28.8	5	16.2	5	0.02	22.7
Max	9914	13577	0.33	66.5	22	24.4	8.3	39.4	86.7
Mean	8070.2	10967.2	0.1	48.3	10.2	20.6	6.7	14.7	36.4
SD	1164.2	1551.8	0.1	9.2	5.1	1.9	0.7	12.4	14.3
CV (%) [a]	14.4	14.1	100	19.1	50.0	9.2	10.4	84.4	39.3
Average shale values[b]	80000	47200	0.3	90	11.2	68	29	20	95
USEPA SQG[c]	-	30	0.6	25	16	16	-	40	110
CCME SQG[d]	-	-	0.6	37.3	35.7	-	-	35	123
Sediment quality guidelines (SQGs)									
TEL[e]	-	-	0.6	37.3	35.7	-	-	35	123
PEL[f]	-	-	3.5	90	197	-	-	91.3	315

[a] Coefficient of variation.

[b] Turekian et Wedepohl (1961)

[c] USEPA SQG (1999);

[d] CCME, 1999

[e] TEL: threshold effect level (Smith et al., 1996).

[f] PEL: probable effect level (Smith et al., 1996).

Table 2. Summaries of Heavy Metal Concentrations in Sediments from Different Lakes (mg/kg)

River/Localisation	Cd	Zn	Cu	Ni	Co	Cr	Pb	References
De Montigny Lake, Canada	0.1	36.4	10.2	20.6	6.7	48.3	14.7	Present study
Karachi Coast, Pakistan	-	132	26	34	30	24	32	Chaudhary et al. (2021)
Red Sea, Saudi Arabia	0.3	-	6.7	21.4	4.6	-	-	Youssef et al. (2020)
Namal Lake, Pakistana	1.4	90.9	30.0	57.3	15.9	75.6	12.4	Javed et al., (2018)
Lagos Coastal, Nigeria	0.5	103.4	15.8	-	-	116.5	24.4	Olaniyi & Popoola (2020)
Rewalsar Lake, India	-	103.9	43.6	35.2	13.8	25.8	24.3	Meena et al. (2017)
Lake Hazar Turkey	0.2	87.8	55.2	126.7	30.8	174.2	18.1	Val et al. (2020)
Typical intertidal zones, China	0.2	78.5	29.2	-	-	72.2	25.8	Zhuang et al. (2020)
World average shale values	0.3	95	45	68	-	90	20	Turekian et Wedpohl (1961)

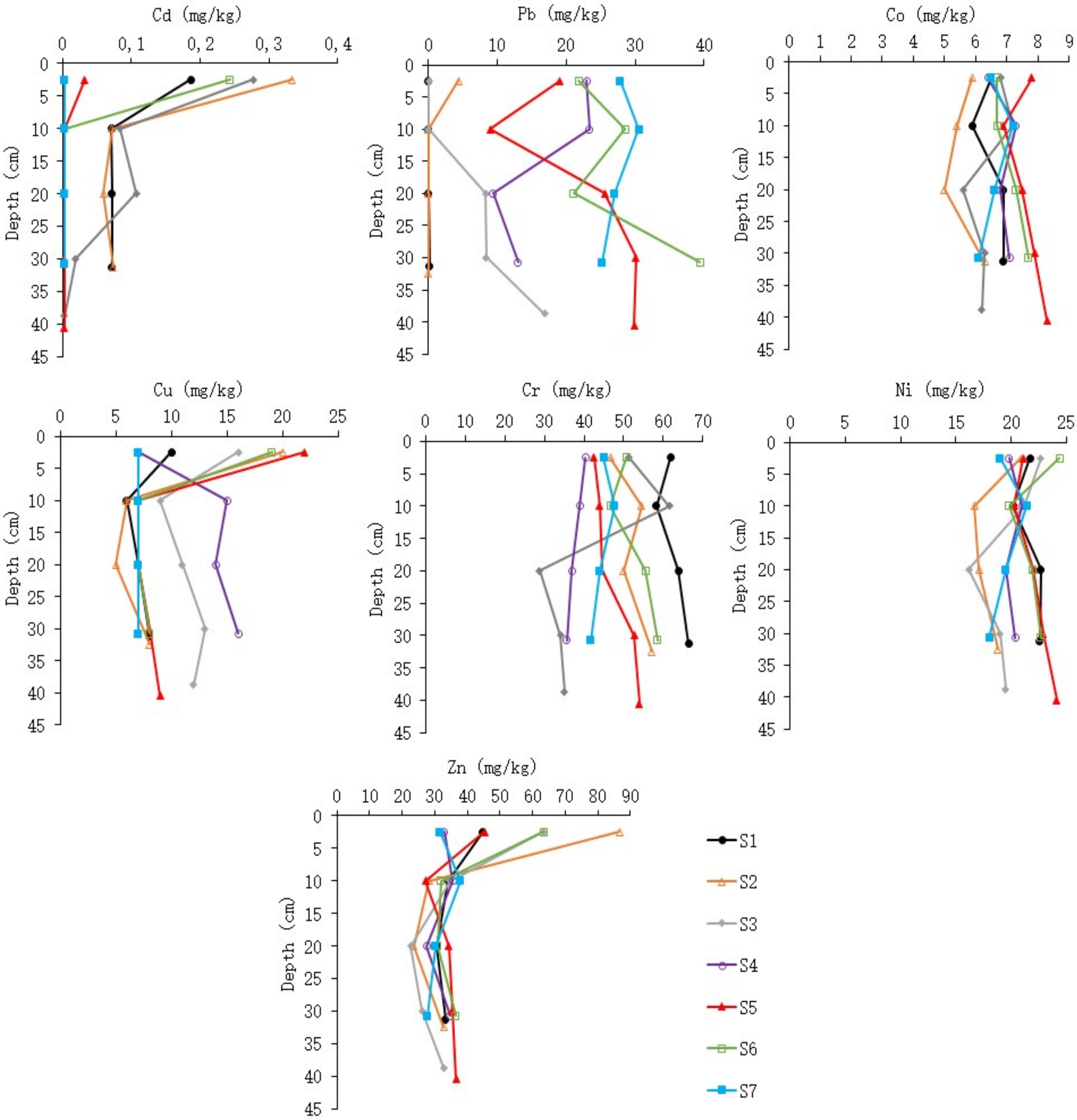

Figure 2. Vertical Variation in Heavy Metal Concentrations in the Sediment Cores

3.2 Index of Heavy Metals Pollution in Sediments

To evaluate the sediment heavy metal contamination degree, we used two parameters: Enrichment Factor (EF) and the Geoaccumulation index (I_{geo}).

3.2.1 Enrichment Factor (EF)

The calculated enrichment factor values of seven investigated heavy metals are illustrated in Figure 3. Significant enrichment was found for Cd, Cr, Cu and Zn especially in the surface sediments samples (depth 0 - 5 cm); Pb showed significant enrichment in all layers of sediment cores S5, S6 and S7.

Sediment cores S1, S2, S3, S4, S5, S6, and S7 showed moderate enrichment with Co, Mn and Ni in all layers of sediment cores. The high values of EF suggest that the De Montigny Lake is polluted mainly by Pb and Cr, which indicates anthropogenic sources in the study area.

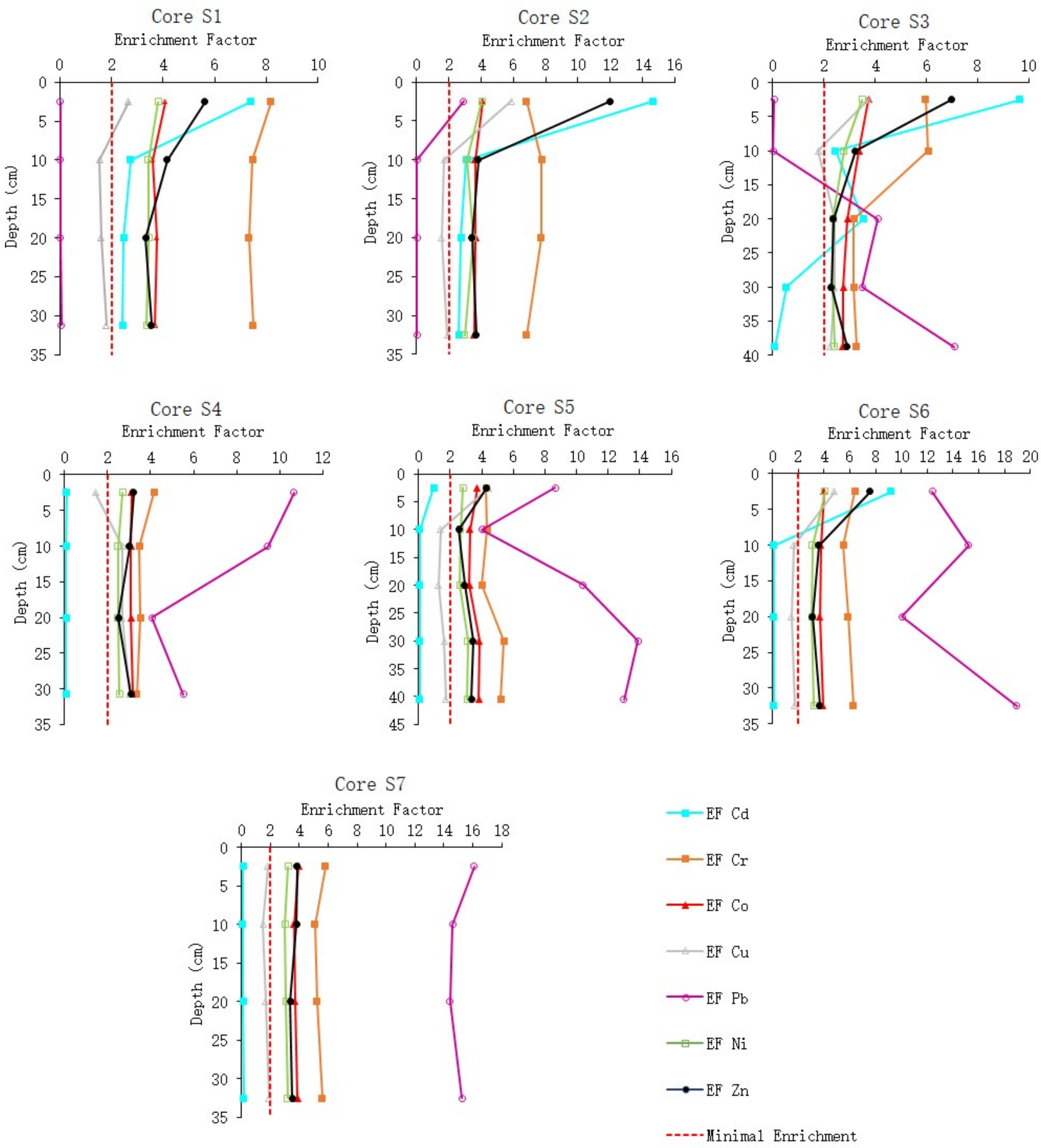

Figure 3. Graphical Representation of Enrichment Factors (EF) Variation with Depth for Heavy Metals in Sediment Cores

3.2.2 Geo-Accumulation (I_{geo})

The calculated I_{geo} of the heavy metals in sediment cores is shown in Figure 5. All the I_{geo} values of Cd, Cr, Co, Cu, Pb, Pb, Ni and Zn in all layers of sediment cores were below zero ($I_{geo}<0$) which means the sediments were not contaminated. The mean average values in sediment cores were ranked as: Cr > Zn > Co > Ni > Cu > Pb > Cd.

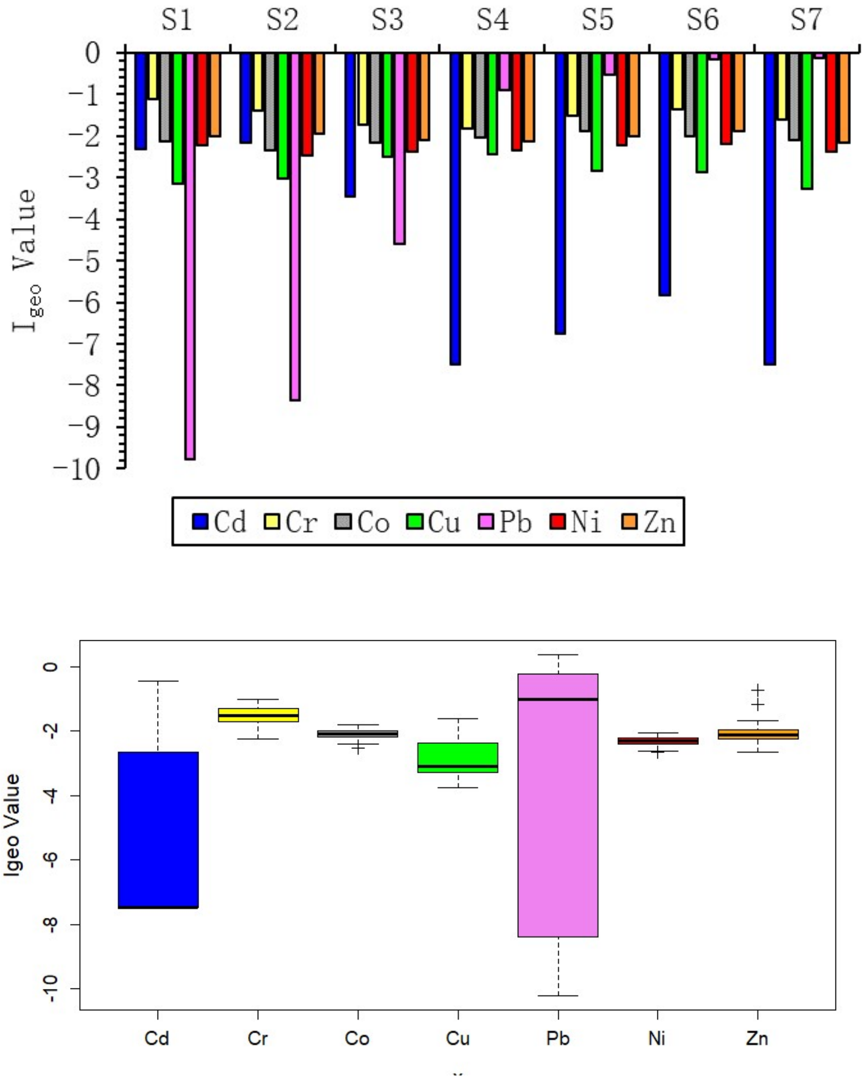

Figure 4. Variation in the I_{geo} Values of Heavy Metals in the Sediment Cores

3.3 Assessment of Sediment Quality

According to Smith et al. (1996), sediment quality guidelines consist of a Probable Effect Level (PEL) and a Threshold Effect Level (TEL) are 3.5 and 0.6 mg/kg for Cd, 90 and 37.3 mg/kg for Cr, 197 and 35.7 mg/kg for Cu, 91.3 and 35 mg/kg for Pb, and 315 and 123 mg/kg for Zn, respectively. The concentration of Cd, Cr, Cu, Pb and Zn were below PEL guidelines in S1, S2, S3, S4, S5, S6, and S7 sampling locations; however, Cd, Cr, Cu, Pb, and Zn were higher than their TEL guidelines in all sampling sites. The calculated PEL – Qi values (0.0002 – 0.7) of seven sampling sites are illustrated in Figure 5, and all sites had moderate impacts with potential adverse biotic effects. The average SQG - Q in the terms of sampling sites were S1 (0.18), S2 (0.16), S3 (0.15), S4 (0.16), S5 (0.19), S6 (0.22), and

S7 (0.19). Based on mean SQG – Q, the seven sampling sites is ranked at moderate impacts with potential adverse biotic effects (Table 5). The CVs of Cd, Cr, Cu, Ni, Co, Pb, and Zn were 100%, 19.1%, 50%, 9.2%, 10.4%, 84,4%, and 39.3%, respectively. According to Vaz et al. (2017), this suggest low variability for Cr, Ni, and Co, while Cd, Cu, Pb, and Zn have very higher variation.

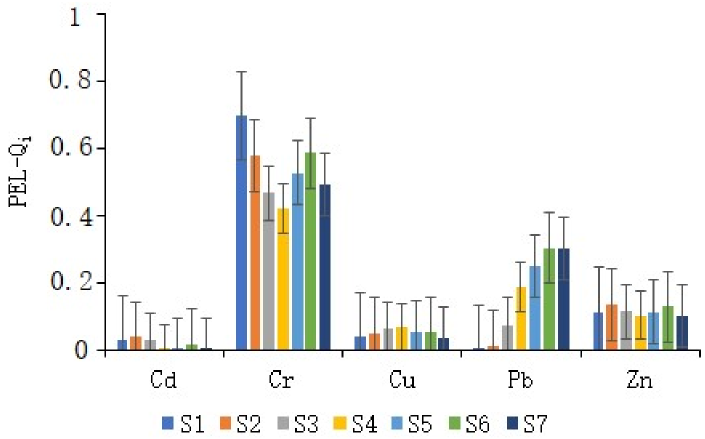

Figure 5. Statistical Characteristics of *PEL-Q$_i$* (Error Bars Represent Maximum Values)

Table 5. Statistical Characteristics of *SQG - Q*

		S1	S2	S3	S4	S5	S6	S7
SQG - Q	Range	0.16-0.19	0.13-0.21	0.11-0.19	0.13-0.18	0.14-0.22	0.19-0.25	0.17-0.20
	Mean	0.18	0.16	0.15	0.16	0.19	0.22	0.19

3.4 Statistical Analysis

Pearson's correlation analysis was applied to analyze the relationships between metals, and to determine the possible sources and dynamics of metals in sediments (Franco-Uria et al., 2009; Wang et al., 2012; Remeikaite-Nikiene et al., 2018, Yi et al., 2020). Correlation coefficients between heavy metals in sediment cores of study area are summurized in Table 3. Based on Pearson's correlation coefficients (*r*) values, Liu et al. (2013) have proposed the classification as follows: strong (> 0.75), moderate (0.75-0.50), and poor (0.50-0.30). Pearson matrix shows heavy metals association, such as: a strong positive correlation was evidenced between Cd and Zn (r = 0.82), and Co and Ni (r = 0.77). The strong correlations between pairs of heavy metals indicate similar contamination degree and common sources in sediment cores (Malvandi, 2017), most likely related to anthropogenic activities that may be the consequence of the past and present mining activities. Although, it should be noted that metals with significant correlations were not mainly derived from the same source, which would depend on the source and the interrelation between the elements (Pandey et al., 2015; Ma et al., 2016). In addition, moderate correlation was also between Al-Co (r = 0.64), Co-Pb (r = 0.55), Cu-Zn (r = 0.67). A positive correlation with Al and Pb (r = 0.32), Cd and Cu (r = 0.50), Cr and Ni (r = 0.49), Co and Pb (r = 0.55), and Ni and Zn (r = 0.48), while Cr did not show any correlation with other metals.

Table 3. Pearson Correlation Analysis Results of Heavy Metals in Sediment Cores of De Montigny Lake

Variable	Al	Cd	Cr	Co	Cu	Pb	Ni	Zn
Al	1							
Cd	***-0.51****	1						
Cr	-0.38	0.25	1					
Co	**0.64****	-0.31	0.18	1				
Cu	0.18	***0.50****	-0.35	0.16	1			
Pb	0.32	***-0.50****	-0.27	***0.55****	-0.08	1		
Ni	0.28	0.20	***0.49****	**0.77****	0.24	0.26	1	
Zn	-0.27	**0.82****	0.15	0.08	**0.67****	-0.08	***0.48****	1

Bold characters indicate the significant correlations, usually grater than 0.6 and bold italic shows the correlation less that 0.6 value.

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Principal Component Analysis (PCA) can effectively help to determine natural or/anthropogenic sources, of heavy metals (Wang et al., 2019). Three factors were generated that explained a total variance of 86.56% are shown in Table 4. PC1 component accounted 34.90% of total variance, characterized by high loading of metals, which includes Cd (0.95), and moderate loading of Zn (0.72). PC2 component explained 31.80% of the total variance and marked by high loadings of Ni (0.90), Co (0.82), and moderate loading of Cu (0.55). PC3 accounted 19.86% of total variance was characterized by high loading of Cr (0.91). According to Mohiuddin et al., 2012, Heavy metals with maximum loads on the Principal Component (PC) may corresponding and loading value in PC1 indicates anthropogenic source while PC2 and PC3 indicate natural origin. The higher load Cd and Zn indicated their anthropogenic origin and higher load values of Ni, Cr, Cu, and Co indicated their natural origin in sediment cores. The Cr and Ni metals were generally associated with crustal rocks in soil (Huang et al., 2020).

Table 4. Principal Component Analysis of Heavy Metals in Sediment Core of De Montigny Lake

Heavy metal	**Factor loading**		
	PC1	PC2	PC3
Al	***-0.69***	***0.43***	-0.31
Cd	**0.95**	0.22	-0.08
Cr	0.32	0.18	**0.91**
Co	***-0.49***	**0.82**	0.19
Cu	0.39	***0.55***	***-0.68***
Pb	***-0.63***	0.37	-0.07
Ni	0.03	**0.90**	0.37
Zn	**0.72**	***0.60***	-0.17
Eigen value	2.79	2.54	1.59
% of Variance	34.90	31.80	19.86
Cumulative %	34.90	66.70	86.56

Bold characters indicate the significant correlations, usually grater than 0.6 and bold italic shows the correlation less that 0.6 value

4. Discussion

The contribution of past and present mining activities in the pollution of De Montigny Lake is not limited, there are mining activities with Kiena and Goldex Mines, and the presence of mining wastes from Siscoe-Sullivan former mining in the Milky sub-basin. Siscoe (1929-1949) and Sullivan (1934-1967) mines located around the De Montigny Lake continued to add heavy metals in the lake. Although the two mines ceased activities since 1934 and 1967, respectively; over a long period of time, they discharged raw wastewater directly into De Montigny Lake. The high levels of Cr observed in seven sediment cores, should probably be associated with ultramafic (komatiite) and mafic (basalt) rocks in soil. Furthermore, the vertical distribution of Cr along the seven sediment cores showed that high concentration persists from bottom to upward surface layer, denotes hisrorical deposition. In any case, Cr is generally regarded as being of no negligible risk in terms of toxicity to human, animal and plant species. The significant Cd, Cr, Cu, Pb, and Zn enrichment of sampling sites S5, S6, and S7, as well as the moderate Co, Mn and Ni enrichment of sampling sites S1, S2, S3, S4, S5, S6 and S7, could be attributed to past and present mining activities.

5. Conclusions

This is the first on vertical distribution and contamination assessment in sediment cores of De Montigny Lake, Val-d-Or, Canada. The results showed that the mean concentrations of Cd, Cr, Co, Cu, Pb, Ni, and Zn in sediment cores of De Montigny Lake were below the World average shale values.

The Enrichment Factor (EF) stated minimal to significant enrichment for Cd, Cr, Cu and Pb, and geo-accumulation (Igeo) indicated sediments quality was uncontaminated for all heavy metals. Based on sediment quality guidelines, the sediments have moderate impacts with potential adverse biotic effects. According to Pearson's correlation matrix and Principal component analysis, heavy metals (Zn, Cd) have common anthropogenic origin and main contributors of heavy metals in the lake. Hence, control measures and management of contamination of Cr in nearby cities should be strengthened for protecting the De Montigny Lake environment and carcinogenic risk to children. The present study could be useful, serving as a baseline for evaluating the potential impacts of future development in the area.

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